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NEED FOR SMART MOBILITY AND CHALLENGES AND OPPORTUNITIES FOR TRANSITIONING TOWARD IT IN CAR-DEPENDENT COUNTRIES: INSIGHTS FROM LITERATURE

Summary. Car dependence is a trend brought about by the desire for comfortable transportation, in many countries around the world. After the invention and acceptance of automobiles, cities were designed with layouts that favored automobiles at the expense of other forms of transportation. However, the situation has changed with research and execution of plans for smart cities, with smart mobility transition taking centre stage. The purpose of this research is to highlight the need for transition to smart mobility, provide detailed description of various aspects of smart mobility and analyse the challenges and opportunities associated with the transition to smart mobility in car-dependent countries. A thorough and critical review of the literature has been done to achieve the aim of this study. Previous research efforts indicated that car-dependent cities have experienced several challenges in their transition to smart mobility, including inadequate infrastructure, low acceptance of new technological solutions, inadequate knowledge and framework for big data, financial constraints, data quality management, integration of data from different sources, privacy issues, and

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development of appropriate of government policies. There are several promising recommendations, which implementation is expected to help car-dependent countries overcome the above challenges and open opportunities for a successful transition. These recommendations include implementation of aggressive government policies, practicing greater inclusivity, and planning for the future of smart mobility by investing in Internet of Things (IoT) applications and reliable infrastructure. To facilitate the decision makers, challenges have been mapped with recommendations for transition to smart mobility, in light of the review findings.

Keywords: mobility challenges, mobility transition, smart mobility implementation, car-dependent countries

1. INTRODUCTION

Urbanization during the 20th century brought about a population shift from rural to urban centres [1]. More than half of the global population resides in urban centres [2]. The growth of population densities in these centres needed to be supported with good transportation links. An efficient transportation network was the driving force behind labour productivity and an attractive business climate. The desire for mobility brought about an undesirable trend, currently referred to as car-dependence. According to Litman [3] car-dependency happens when land use favours the car, more traveling per capita takes place through automobiles, and no or few transport alternatives exist [4].

There are several countries, which continue to struggle with car-dependence, especially those in the Middle East [5]. Their car-oriented nature was further compounded in the 1970s, with a major economic boom. Since then, the car dependence of this city has only grown [6]. However, after years of car-dependence, many countries (including Saudi Arabia) around the globe have come to a similar conclusion: a seismic shift in the trend of urban mobility is required to overcome some of the challenges of car-dependence. Therefore, urban cities worldwide are pushing for the transformation of existing urban centres to smart cities through the adoption of smart city concepts and technologies [7].

Currently, cities around the world are exploring and executing their smart city plans, which are supported through the accelerated pace of smart technologies [8]. Drawing from the research conducted by Caragliu et al. [9], there is a lack of consensus on the definition of smart cities. Despite no common definition, Hajduk [10] reported in his study that the smart city concept is found to increase the quality of inhabitants living in urban cities and helps to solve urban areas' issues such as land use, public services, infrastructure system, environmental pollutions, and mobility challenges by using innovation and technology.

One of the key components of a smart city is smart mobility. According to Surdonja et al. [11], a city cannot be sustainable without the adoption of smart mobility. Trombin et al. [12] define smart mobility as a combination of innovative transport solutions and development of current systems to fulfil passenger and freight transport demand. Innovative solutions incorporate the use of innovations in vehicle technology and information technology (IT) services to provide efficient transport solutions. On the other hand, the development of systems is focused on the improvement of existing systems for smooth operation of these modern technologies.

Transitioning to smart mobility is well-recognized as the first phase for the success of the transformation to smart urban cities. Smart mobility is multi-faceted and has recently piqued the interest of local municipalities and authorities and several other stakeholders who participate in city planning and development [13]. In this regard, Porru et al. [14] suggested that smart mobility can improve sustainability, minimize carbon solutions, improve quality of life, and reduce traffic and parking challenges. Smart mobility is a vision of smart cities whereby city occupants do not need to depend on automobiles, but rather on alternative means of transportation backed by technology and non-technology innovations. Therefore, any city seeking to transition to smart mobility anticipates a revolution that proposes to transform the transportation system. Moreover, recent developments in smart mobility are spearheaded by entrepreneurs in the transport industry, vehicles manufacturers, and it is expected that the number of vehicles will reach more than two billion by 2030 due to global urbanization [15]. The new approach of smart mobility seeks to restructure the conventional urban mobility system, which has become a problem due to the resultant rapid congestion and its focus on traffic and roads, rather than people [16]. As a result, more countries have begun plans to shift to smart mobility in urban settings. In this regard, employment of information communication technology (ICT) has been greatly extended to enhance access to transport services [17].

Several car-dependent countries have gone ahead to initiate a full transition to smart mobility. Notable examples of these countries include France and England. In France, many cities, such as Lyon, have adopted a smart mobility solution in the form of shared mobility [18]. Similarly, in England, London has continued to lead the way in smart mobility transition based on its well-integrated system of public transport. Despite these successes, the process of transitioning car-dependent cities to smart mobility has not been a walk-in-the-park. The process has been hindered by several challenges.

Therefore, the purpose of this research is to facilitate the transition to smart mobility by providing a review of state-of-the-art research about its concept, components, and progress made in achieving it and determining the challenges and opportunities of transitioning to smart mobility in car-dependent countries. It was done by conducting a thorough assessment of literature related to all the above components and the case studies related to the cities which have made significant progress in such transformation. Moreover, recommendations related to tackling the challenges proposed by fellow researchers, were also gathered and compiled in this research. Presently, there are no studies found which cover these aspects related to smart mobility. It is expected that such a review will facilitate the transition of car-dependent countries to smart mobility options. It would enable them to anticipate the challenges during the planning stages and adopt remedial strategies, thus saving costs and efforts.

The rest of the paper is organized as follows. Section 2 provides an overview of the approach adopted for collecting the literature and its review. The need for transition to smart mobility is established through the review of negative impacts of car-dependence in section 3. Then, section 4 elaborates more on the concept of smart mobility and its components and highlights its potential impacts. Section 5 presents some of the case studies for cities who have shown comparatively more progression towards smart mobility. Section 6 presents the findings of the literature and enumerates the challenges and recommendations for transition. Finally, section 7 highlights the main conclusions and recommendations of this study.

2. METHODOLOGY OF REVIEW

This research used a modified systematic literature review (SLR) to determine the challenges for smart mobility transition in car-dependent countries. Xiao and Watson's [19] guidelines on SLR, were modified to come up with an approach applicable to the research. The approach followed the three steps shown in Fig. 1. The figure also shows the primary tasks carried out in each step. An explanation of the methodology is provided as follows.

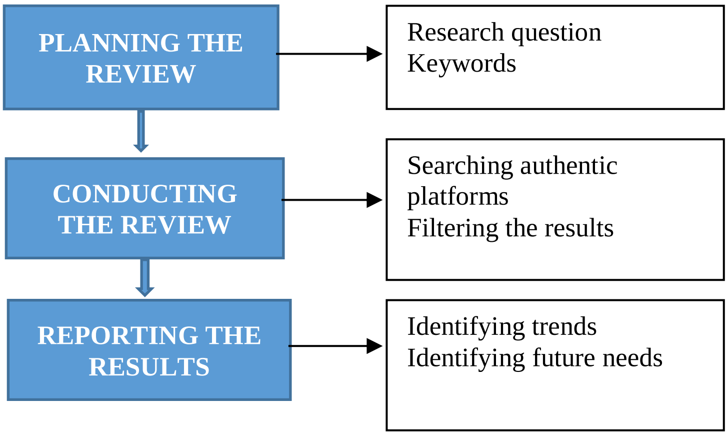

Fig. 1. A typical systematic literature review process

2.1. Planning the review

Planning the analysis involved formulating and validating the research question and the review protocol. In this case, the research questions were formulated from the purpose of the study. They included the following:

- What is smart mobility?
- What are the negative impacts of car-dependency?
- What are the components of smart mobility?
- What are the observed and potential impacts of smart mobility?
- What are the challenges for transition to smart mobility in car-dependent countries?
- How the challenges have been or could be tackled?

The review protocol was valid since it helped in answering the research question by identifying relevant research efforts and extracting and analysing qualitative data.

2.2. Conducting the review

The first step of this phase involved searching titles of literature to identify relevant articles. In this case, eight key phrases were used, exclusively and in-combination, for the Google Scholar literature database search. These phrases included smart mobility, smart mobility in car-dependent countries, challenges for smart mobility transition, mobility, cars, challenges, transition, and implementation. However, only the first twenty pages of the database search results were analysed to identify potential articles for this research. All duplicate articles were excluded later. The second step involved screening the identified articles for inclusion using their abstracts. Only articles with their primary objective related to smart mobility and/or car-dependency and challenges to smart mobility transition were included. The third step involved assessing the quality of the identified literature by scanning through full-text literature. Peer-reviewed journal articles and technical reports, sourced from reputable databases and publishers, were considered acceptable and included in the research. Most online technical and conference reports were excluded based on this criterion. However, some of them were still used in this research as their findings were confirmed/supported by other articles.

During the analysis, the articles were treated like interview transcripts. This meant that each article was critically reviewed in light of the research questions, and relevant information, as per the scope of this study, was extracted. Ideas, extracted from different studies, were sorted, and organized as shown in methodology review process in Fig. 2.

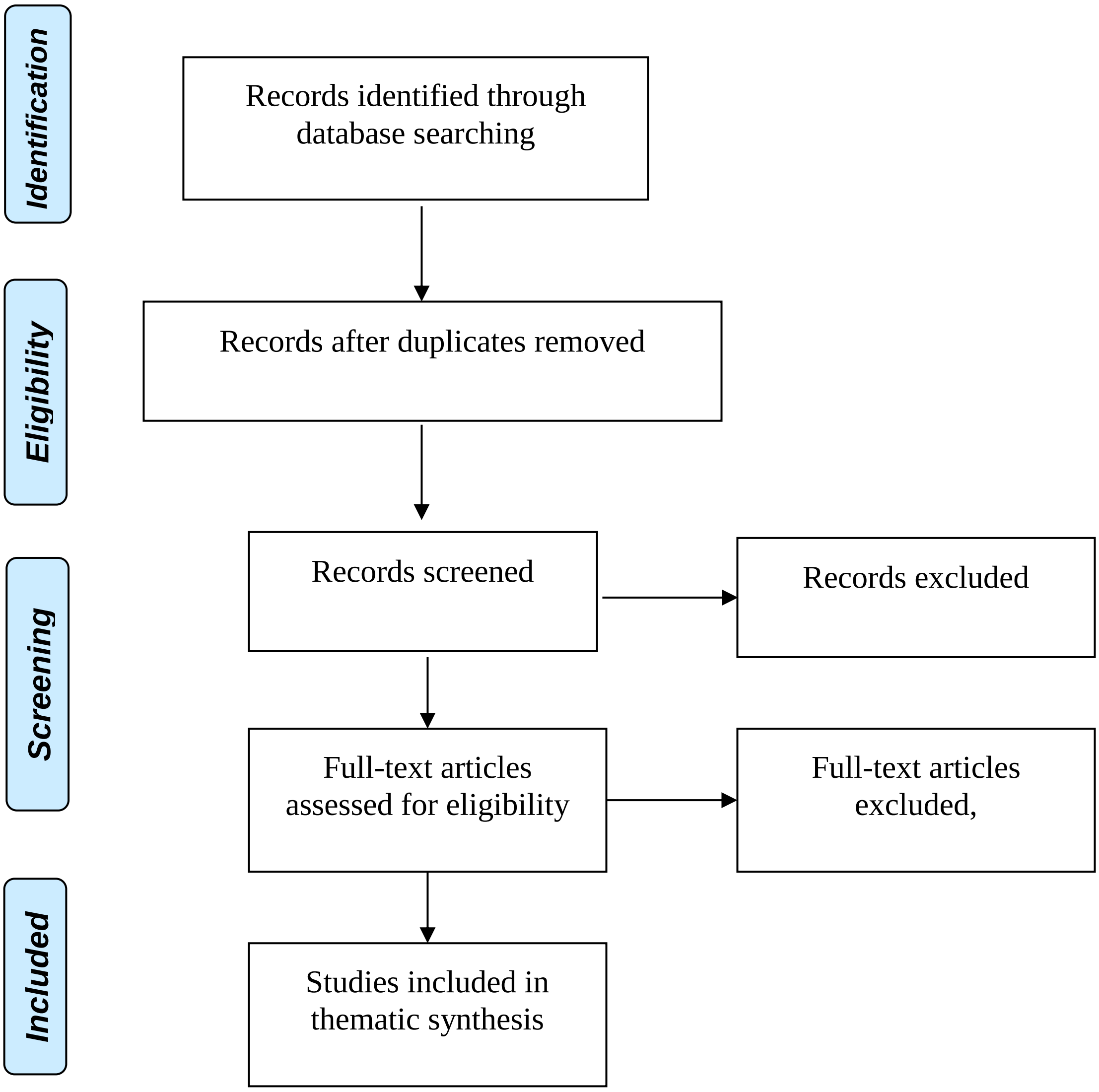

Fig. 2. Systematic review flow diagram

As shown in Fig. 2, the search methodology started with a general search using the keywords related to smart mobility. Since multiple sources were used for this search, duplicate records for these sources were combined. After that, the remaining documents were assessed for their eligibility and access. From this step, articles/studies from reputable sources with full-text access were used for review and synthesis development for this research.

2.3. Reporting the review

There were approximately 120 articles/studies, found from reliable sources, relevant to the transformation of cities to smart mobility. The distribution of these articles is shown in Fig. 3. Out of which, eighty-four (84) articles were found related to the scope of this research which covered either research related to smart mobility and its transformation, or challenges to this transformation and measures to overcome them. The excluded articles were those which dealt with specific technological or modelling aspects, thus considered irrelevant. The included literature was based on the technology, infrastructure, data management, social, financial, economic, political, and environmental factors related to transformation to smart mobility. These articles were reviewed to identify the requirements, and present future needs for the transition to smart mobility. Then, the results were formulated and reported in the context of car-dependent countries. It should be noted that the bibliography of the present study also contains, in addition to the above-mentioned 84 articles, articles which provided introduction to the basic terminologies and trends related to smart cities and mobility.

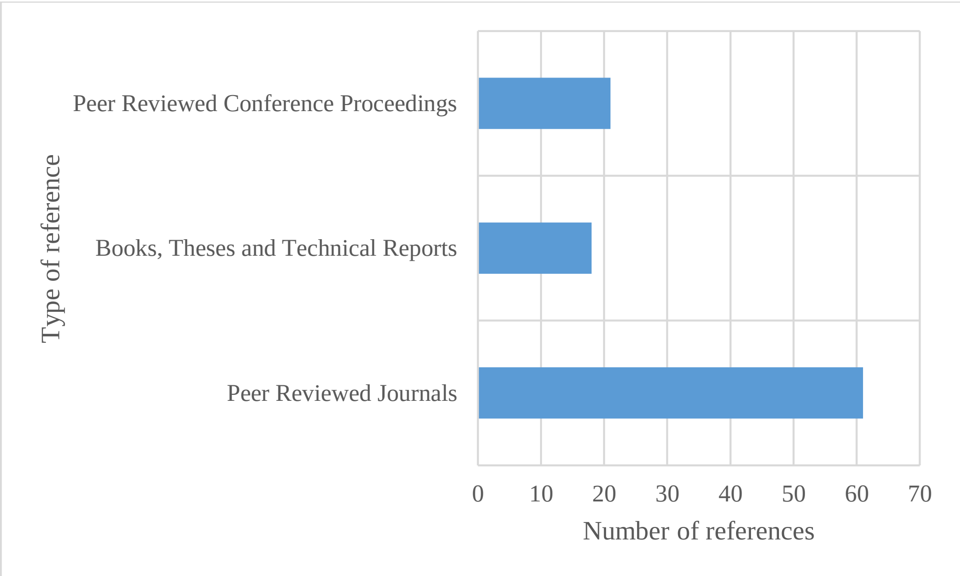

Fig. 3. Distribution of sources of literature

Fig. 4 represents the distribution of references, of the above-mentioned 84 articles, regarding the time of their publication. It can be noted that the majority of them were published between the period 2010 and 2020. In comparison to them, references published before 2000 were found to be very few. This increase in popularity is greatly associated with the accelerated pace of technological advancement in transportation and its associated fields. However, this distribution should not be taken as the true representative of the research published in this field of smart mobility. It is because references were filtered, on the basis of methodology shown in Fig. 2, before using it in this research.

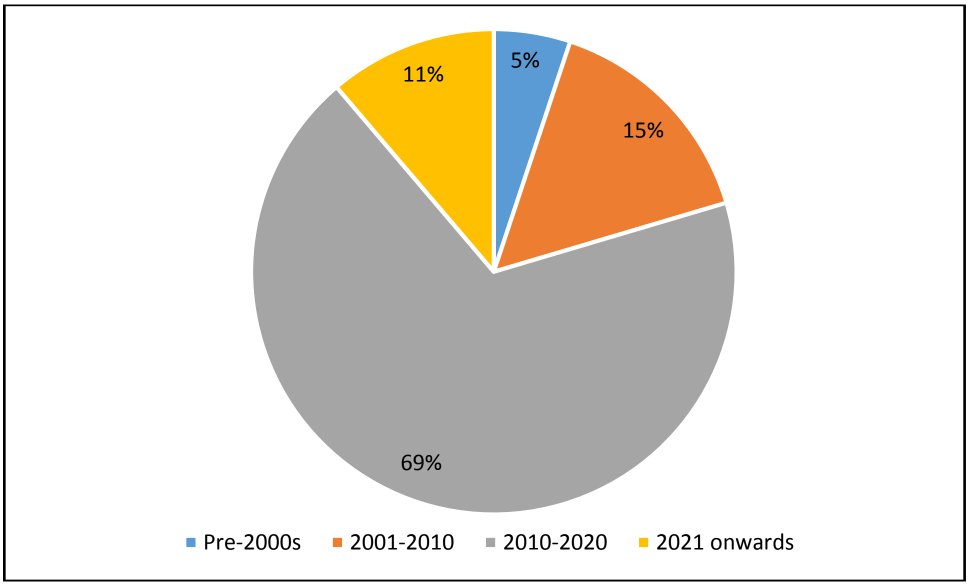

Fig. 4. Temporal distribution of references

The references were also analysed with regard to their keywords. Fig. 5 provides a representation of these keywords as a word cloud. These are the words which repetitively appeared in the references and the search results. In this figure, the size of the word is an indicator of its use in the given text. A free online tool (https://www.cortical.io/freetools/extract-keywords/) was used for the extraction of keywords from the references. It can be observed from Fig. 5 that the "transport", along with its derivative "transportation", and "smart" were the most common themes among the literature found in this area. It should also be noted that the mention of car-dependent countries and transition seldom appears in the literature, which justifies the need for the present study.

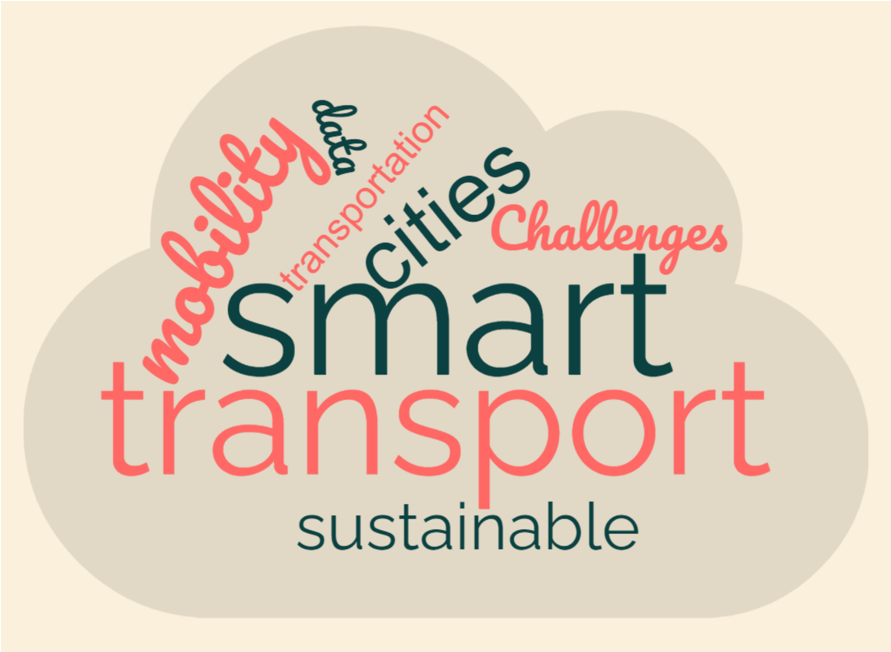

Fig. 5. Word cloud of keywords

3. CAR-DEPENDENCE

It seems pertinent to highlight some of the important issues linked with car-dependency and the ill-effects caused because of the car-dependence trends. These effects are the instigating factors behind the efforts for transformation to smart mobility.

As mentioned earlier, car-dependence is a result of the processes of urbanization and economic growth. While Mattioli et al. (20) states that car-dependency does not only depend upon individuals and land use areas, but also transport policies and the nature of trips play an important role in defining car dependencies. The results of such transport policies may result in the lack or insufficiency of public transit services for the ever-expanding suburban areas of metropolitan cities [21]. A car-dependent mobility system contributes to major transport problems such as congestion, emissions and shortage of urban spaces [22]. Research has also shown that car-dependency is not only linked with population density, or its relevant parameters, personal choices and characteristics also impact the extent of car use [23].

One of the important aspects of this trend is the effect on road safety. Car-dependency results in more vehicle miles travelled per capita, which increases the exposure to accidents [24]. Another side of this issue is the preference of car-travel in the policymaking and road design process, which, consequently, adds to the disadvantage of other mobility options, such as cycling and walking. These trends result in a lack of facilities for other mobility options and an increase in relevant safety hazards [25].

Car-dependency trends and their favoring policies are considered unjust, which produces social and political inequity [26]. These trends inherently support certain sections of the society, which are car users, at the expense of suppressing the others which cannot afford cars. One of the challenges faced during the change from car-dependence is the resistance from the groups which benefit from the prevalence of car-ownership and use. These groups may include automobile manufacturers and fuel suppliers, among others [27].

Another important aspect related to car dependence is its environmental effect. Abdelhamid et al. [28] has linked the car-dependence trends with the increase in traffic congestion, which is a measure cause of environmental emissions from the transportation sector. Consequently, the effects of automobile-dominant traffic congestion have been reported on the health of residents, especially in the urban areas [29]. The per-capita CO_2 emissions produced by cars are considered highest among the passenger transport modes operating on land [28]. Cox [30] has argued that some of the smart mobility options, such as ride-sharing and driverless vehicles, are an effort to redesign the car-dependent regime to a "greener alternative". On the other hand, other researchers have advocated the use of comprehensive strategies, such as Mobility-As-A-Service (MaaS), as a sustainable solution to reduce vehicle ownership and its resulting environmental impacts [31].

Another important issue related to car dependence or usage is the consumption of fuel. In the USA, it was reported that about 66% of the petroleum consumption was in the transport sector in 2008. Fuel consumption is directly linked and measured through CO_2 emissions, resulting in policies being devised at the national and international levels to curtail it [32, 33]. Despite the concerns over the depletion of fossil fuel and other natural resources, almost the entire transport sector is operated on fossil fuels worldwide [34], although there may be some exceptions in specific countries [35].

The above discussion, although not being extensive, provides enough evidence regarding multidimensional links and effects of the car-dependence paradigm and the necessity to shift from it. This, consequently, justifies the need for and importance of the current research which could help the planners and authorities to set up their path for shifting from car-dependence to more sustainable options related to smart mobility.

4. SMART MOBILITY

As mentioned earlier, there is no single agreed upon definition of smart mobility in the literature. Biyik et al. [36] considers smart mobility as a set of technological actions which considers social aspects of citizens during implementation. A smart mobility system may contain different sets of technologies based on local and regional stakeholders and their respective policies. Smart mobility may include connected and autonomous vehicles, public transport, mass transit, biking, walking, and shared mobility [37]. Surdonja et al. [11] indicated that many smart mobility solutions are based on Information Technology (IT).

Maldonado et al. [38] identified different components or drivers of smart mobility system including, but not limited to, public transport, car sharing, internet of things, internet communication and technology, electric mobility, smart payment system, and intelligent transportation system. The study also explains the role of mobility plans and transport policies in executing any smart mobility system. Fig. 6 shows the components of smart mobility which were gathered from Noy and Givoni [37] and Maldonado et al. [38]. The proceeding subsection provides a brief discussion about each of these components.

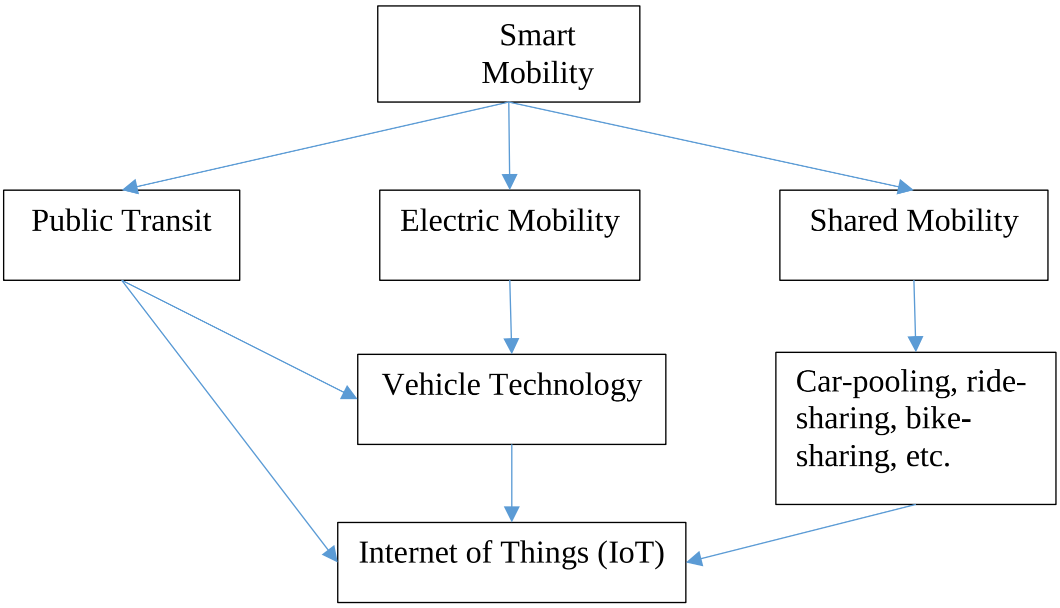

Fig. 6. Components of smart mobility

4.1. Components of Smart Mobility

4.1.1. Public Transport

The increase in population mandated the employment of public transportation systems. These services can be used on a sharing basis by the general public [39]. Since its inception, public transport has gone through many developments with the support from technology. These developments include use of GPS/GSM systems to reduce waiting time of travelers [40], use of electric buses, integration of the bus system with Internet of Things (IoT) [41] and use of vehicle-to-infrastructure (V2I) technologies for prioritization of public transport buses [42]. A review of the more recent literature shows that researchers have been investing more efforts in the utilization of big data and IoT for improvement in the operation and management of public transport systems [43].

4.1.2. Internet of Things (IoT)

As mentioned above, IoT has become the focal point of many researchers who are working in the area of mobility. IoT is a network of numerous intelligent communicating devices which are spread around us. This is a system of these heterogeneous devices which can be connected to each other [44]. The greatest advantage of IoT systems is the exemption of a human interface for transfer of data and taking of decisions [45]. In the field of transportation and mobility management, IoT systems could be established with the connection of Radio Frequency Identification (RFID) tags installed on the vehicles, mobile devices, sensors and actuators and traffic control devices which are installed along the roads [46]. The potential use of such systems has greatly boosted with the increased capacity of communication systems, such as the advent of 6G networks. These advancements have made it possible to establish fast and secure connections beyond the boundaries of different media (air, water, ground) [47]. However, there are issues identified with the wide-spread use of IoT systems, which are identified as possible challenges hindering the realization of the full potential of IoT systems. Some of these challenges include collection and management of data from various sources, and privacy issues related to the use of data over a platform [48].

4.1.3. Electric Mobility

The electric mobility concept was initiated mainly due to the environmental impacts of the transportation sector [49]. Moreover, they are also seen as a potential solution to reduce fuel consumption [50]. This is one of the reasons that the preliminary focus of the automobile industry was on the electrification of cars, as these cars constitute the majority of traffic flow globally [51]. Dijk et al. [52] have identified that the rise in fuel prices and implementation of carbon emission constraints have pushed the industry towards investing more in the field of electric mobility. They have also mentioned that the development of this technology depends upon the in-place infrastructure, and changes in electricity and mobility sectors.

Leurent and Windisch [53] identified the establishment of recharge infrastructure, its connection with the electricity net and required technological progress in the vehicle industry, as the challenges for the implementation of electric mobility. Later research has reinforced the existence of these barriers and also showed that decision-making at different levels also influences the penetration of electric mobility in the current market [54]. With regard to the promotion of electric mobility, cost incentives and availability of charging infrastructure have been identified as efficient policy measures to attract buyers [55]. This has been further corroborated by Rietmann and Lieven [56] who found that countries with high purchasing power have higher market share for electric mobility.

4.1.4. Shared Mobility

Shared mobility, similar to public transport, is not strictly linked with smart mobility. But it has been given its due importance within the smart mobility options and solutions. It refers to all the alternatives of/for trips, encompassing various mobility resources, to disconnect usage of mobility from ownership [57]. Shared mobility comes under the paradigm of shared economy, wherein, assets are shared among different entities, increasing their utilization rates [58]. The current trends in blockchain technology and IoT are taking the car-sharing approach forward with time [59]. This is expected to increase with the propagation of Autonomous Vehicles (AVs) [60].

One of the most common and earliest forms of shared mobility is car-sharing, which supports the use of car services without being bothered by parking issues. Different car-sharing models have been implemented since its inception, including fixed trip-based, floating use-based and peer-to-peer models [61]. Moreover, other services, such as; bike sharing, microtransit, ride hailing have also evolved [62]. Efforts have been made to integrate all possible options of ride-sharing, along with public transport, to discourage car-ownership while providing the flexibility of mode choice to the travelers. Such integration has resulted in the development of Mobility-As-A-Service packages and models.

4.2. Impacts of Smart Mobilities

Yigitcanlar and Kamruzzaman [63] explained how the internet and smart technologies affected the commuting patterns in smart cities, thus emphasizing the importance of public choices and opinions within smart mobility policies.

Numerous studies have compiled a list of the possible advantages of smart mobility for city residents and society at large. The first advantage is the reduction of traffic congestion. Midgley [64] has provided evidence from 16 countries, mainly in the European region, that the use of smart sharing technology has reduced traffic congestion in previously car-dependent countries. Secondly, smart mobility benefits residents and society by reducing air and noise pollution [65]. Thirdly, smart mobility increases the safety of transit-riders [66]. Smart mobility uses advanced technology to coordinate traffic in a manner that ensures the safety of road users. Lastly, smart mobility reduces transfer costs between different modes of transportation [67]. The possibility of these benefits of smart mobility has made it a worthy investment in numerous countries around the world [68].

Despite the advent of smart mobility and its world-wide acceptance by urban planners, questions have been raised concerning its sustainability. Noy and Givoni [37] studied the sustainability of smart mobility. The study was extensive, since it involved reviewing the views and beliefs of technological entrepreneurs in the transport sector. The results showed that according to technological entrepreneurs, technological developments, such as autonomous and connected automobiles, are key to a sustainable transportation system. Some researchers, such as Söderström [69], have contested this view by advocating diverting more efforts towards social and political changes rather than technological driven solutions. Some other researchers have argued that autonomous vehicles would add to the vehicle miles traveled per household [70]. Previous research has also made a stand on the significance of big data in the development of smart cities and, to an extent, smart mobility. Lim et al. [7] studied the reference models, challenges, and considerations in relation to the use of big data in smart cities. Some of these challenges include the integration of data from different sources and data privacy issues.

Traditionally, smart mobility solutions have been directed towards urban areas, which have higher impacts of traffic congestion. However, latest research has also identified rural areas as potential areas of focus in the adoption of smart mobility. Porru et al. [14] explored the opportunities and challenges for smart mobility and public transport in rural and urban centres. Currently, regional authorities have had to consider and procedurally implement innovative strategies in their transportation systems due to the demographic changes in low population density areas. According to Porru et al. [14], these regional transport systems have responded to mobility challenges in rural areas by using the IoT to develop a new concept referred to as smart land.

5. CASE STUDIES OF SMART MOBILITY TRANSITION

Different countries have had different experiences in the quest for full smart mobility implementation. These experiences have shaped their progress and trends in smart mobility. Researchers have proven this by studying the differences and challenges of the smart mobility transition process in different cities in various countries around the globe. Debnath et al. [71] studied and ranked 26 cities, based on their progress in smart mobility transition. The study came forth with benchmarking results depicting the smart mobility transition performance of these cities during the 21st century, until the time of research. Tab. 1 illustrates the results of this benchmarking. According to this research, 4, out of the top 10 cities that made major progress in transition to smart mobility, are from the USA. This could be attributed to the contribution of the USA to the technological solutions, which would have boosted the implementation of smart mobility solutions [72]. Apart from Singapore, no other Asian cities were found in that list. It is expected that it would not be the case if the study was done more recently, as other cities, especially in Korea [73] and China [74], have also made significant progress in this aspect.

Tab. 1

Ranking Smart Mobility Transition Process [71]

Country	City	Rank
UK	London	1
USA	Seattle	2
Australia	Sydney	3
USA	New York	4
Australia	Melbourne	5
Singapore	Singapore	6
France	Paris	7
USA	Washington	8
Canada	Vancouver	9
USA	Chicago	10

It should be noted at this stage that there has been no study or government report which claims 100% transition to smart mobility for any city or country. Hence, the list and case studies presented in this section highlight the cities which have made comparatively more progress than the others.

London, U.K., is the most progressive city when it comes to smart mobility transition. It has implemented a myriad of smart technology in its transport system, Debnath et al. [71]. The earliest evidence of smart mobility has been reported in the form of development of public transportation and traffic systems even in the previous century [75]. Over the years, public transportation has expanded to serve the largest portion of London's population [76]. The technology has only gotten better with the latest smart innovation coming in 2018 under the "Green man authority" which designs traffic lights in London to prioritize pedestrians over cars [77]. This smart mobility solution aims to increase walking in the city [78].

Despite the strides made in the 20th century, the bulk of London's smart mobility solutions have been introduced in the 21st century [79]. The introduction of car-sharing services in 2016 marked a new milestone in the smart mobility transition [80]. In 2017, authorities in London enforced several policies that sought to fully transition the city to smart mobility [81]. The notable smart solutions, that year, were the stricter new emission test regulation, green buses, and the rapid chargers [82]. The new emission test policy implied that all new petrol and diesel vehicles had to pass stricter tests before being allowed on London roads [83]. The green bus initiative was introduced in London following the Air Quality Plan of 2017. The initiative saw 153 cleaner buses introduced on London roads in 2018. In the same year, London also experienced several milestones in smart mobility transition, especially with the Deep Tube Program and the decision by the London Black Cabs to go green [81]. Other revolutionary technologies, introduced in the 21st century in London, include the bus priority system using Automatic Vehicle Location Systems (AVLS) [84].

Moscholidou and Pangbourne [85] explored three essential and important features for the transition towards smart mobility in the case of London and Seattle. These three features included smart mobility regulations by their city authorities, responsibilities of the solution providers, and long-term city strategies. The initiatives in Smart London ensured that the public trust was achieved by providing data rights, accountability, and transparency of the open data required for the smart mobility architecture [86]. Similarly, Liao [87] mentioned that the smart mobility solutions, such as the congestion area zones, to discourage cars entering central London, may frustrate the leading automobile business communities.

The other city with a rich history of smart mobility transition is New York. New York City, USA, was ranked as the fourth most progressive city by Debnath [71]. Similar to London, the initial employment of the smart mobility concepts was seen in the development of public transportation, which has improved over the years, culminating with the introduction of 535 state-of-the-art, next-generation subway cars in 2018. A smart solution was set up to improve the city's metro. The second notable milestone was the introduction of the first permanent traffic signals in 1920 [88]. Just like London, New York also experienced numerous transportation improvements that helped transition it towards smart mobility in the 20th century. However, most of the notable smart mobility solutions have been adopted in the 21st century.

A notable milestone was achieved in 2016 with the implementation of car sharing services [89]. The launch of Uber's product, Uberpool, has since been a great success in New York [90]. The second notable milestone was the introduction of autonomous public transportation in 2019. The use of these vehicles designed by Optimus Ride, a self-driving car company, has since been increasing in New York. Just like London, New York is still on course to achieve full smart mobility transition [91]. The introduction of the zero emission vehicles (ZEVs) in 2021 is a testimony of the efforts implemented in the city [92]. It has also introduced several high-end smart mobility systems in the past two decades, such as automated parking systems, variable speed limit technology, adaptive signal-control system, real-time system for broadcasting the availability of parking spaces, and Electronic Toll Collection (ETC) system for transit toll stations [71].

During these transitions, New York, like many other cities, faced different challenges. A study conducted by Vechione et al. [93] showed that most of the senior citizens faced mobility issues, and it was very difficult for them to alter their choices by switching from driving cars to using public transportation, sharing vehicles, or carpooling. Smart city solutions in New York could be influenced by differences and separation of societal classes, along with decentralization. The potential challenges for New York smart city solutions may also include hierarchy of the system, migration, population, and environmental issues, according to Kubina et al. [94].

Apart from the U.K. and the U.S., cities in Europe, Asia, Asia-Pacific, and the Middle East have also experienced rapid progress in smart mobility transition. Notable examples in this regard are shown in Tab. 2. In Asia-Pacific, cities such as Sydney and Melbourne take center stage. These cities are within the top five most smart mobility progressive cities in the world. For example, Sydney boasts of diverse smart mobility trends such as the Sydney Coordinated Adaptive Traffic System (SCATS) that coordinates traffic signals, ramp metering on motorways, variable speed limit control systems, ETC systems, and automatic parking systems [95]. Sydney also has the bus rapid system, bus priority technology such as bus lane cameras, and a computer-aided dispatching system or emergency transit. In Europe, Italy has the most progressive smart mobility transition. Its cities have elaborate transport sharing systems [96]. Mid-sized cities in Europe have emulated major cities such as Rome, Paris, and London [66]. In the Middle East, cities such as Dubai and Riyadh are at the forefront of the smart mobility transition [97]. The Riyadh Metro project in Riyadh has improved its status of smart mobility transition.

Tab. 2

Cities which made significant progress in transformation to smart mobility in Asia Pacific, Europe and Middle East

Region	City
Asia Pacific	Melbourne
	Sydney
Europe	Paris
	Rome
Middle East	Dubai
	Riyadh

6. CHALLENGES AND OPPORTUNITIES FOR TRANSITION TO SMART MOBILITY

Previous research indicates that car-dependent cities have experienced several challenges in their transition to smart mobility. Based on the literature review, the following are some of the key challenges encountered by these cities and a set of recommendations to overcome smart mobility transition challenges. Some of these challenges and recommendations have already been stated in the previous subsections and reiterated in this section for completeness. Other challenges and recommendations have been introduced with discussion and relevant references.

6.1. Challenges to Smart Mobility Transition

The challenges to smart mobility, listed below, have been identified as a result of the review of those studies from the literature which have presented a critical viewpoint about the transition process as a whole or, about specific aspects of smart mobility.

6.1.1. Inadequate Infrastructure

Inadequate infrastructure threatens smart mobility transition in car-dependent countries. Poor infrastructure in the form of rail and road network, telecommunication, and power distribution tends to slow the development of smart mobility solutions [98]. Several car-dependent countries, in the Middle East, Asia, and Africa, are heading towards an increase in urban population relative to rural population [99]. However, inadequate infrastructure has hindered progress towards full smart mobility transition. Therefore, the rapidly growing urban centres in these countries need to improve their infrastructure for expanding their implementation of smart mobility. In this context, Feigon and Murphy [62] have also pointed out the added disadvantage to the public transport system, which required large investments and being overtaken by other technological solutions which are rapidly gaining the market share.

6.1.2. Low Acceptance of New Technological Solutions

Often, the adoption of new technological solutions has encountered resistance from people who are attached to traditional or contemporary solutions. The concept of car-dependence has been ingrained in the lifestyle of the residents of many cities for more than half a century. People have been accustomed to a certain way of living in relation to their mobility [100]. The advent of smart mobility aims to introduce several new technological solutions that will alter the lifestyle of people in car-dependent cities. Most of these cities are experiencing challenges in transitioning to smart mobility because their residents are finding it difficult to accept new technological solutions for mobility [11]. Therefore, car-dependent cities will have to examine the kind of behavioural change required to implement smart mobility solutions successfully.

6.1.3. Inadequate Framework for Big Data Use for Smart Mobility

Big data can be described as the set of large and complex data that is collected from digital evidence of human activities [101]. Urban centres around the globe collect voluminous amounts of data that represent digital traces of urban living. The inter-linking of this data is part of the IoT platform, which is considered crucial for different components of smart mobility, as mentioned in section 4.1. Recent studies have proven that the utilization of urban big data is crucial in the smart mobility transition [102]. However, most car-dependent countries lack the framework to utilize big data, making it a challenge for their transition to smart mobility. Inadequate frameworks to take advantage of urban big data prevent the cities, within these countries, from creating useful content for key stakeholders such as companies, local governments, visitors, and citizens [103].

6.1.4. Financial Constraints

Financing is another major challenge to the smart mobility transition [87]. Despite the undoubted benefits of smart mobility, questions are still being raised concerning its financial sustainability. Many countries are yet to figure out the cost implications of smart mobility in terms of capital investment and cost recovery mechanisms and the operation cost. In addition, governments are exploring the financing options with the private sector to minimize the capital and operational cost [104]. Therefore, the financial uncertainties of the smart mobility transition challenge its implementation.

6.1.5. Data Quality Management

This challenge is also related to the use of data in the transition to smart mobility. The initial condition for identifying trustworthy smart mobility information is the quality of urban data [105]. Car-dependent cities collect large quantities of vehicle driving data. In some cases, cities have had to deal with incorrect data generated by different sources [106]. Apart from the inaccurate data, most vehicles in such countries use data collection devices from different manufacturers [107]. As a result, these vehicles introduce large variances in the collected data. Therefore, most car-dependent countries find it challenging to transition the transportation systems in their cities to smart mobility systems due to the inferior quality of generated data. Such cases highlight the vitality of the quality of transportation-related data in attaining a successful transition to smart mobility.

6.1.6. The Integration of Data from Different Sources

The integration of data from different sources is a major challenge to the transition to smart mobility in car-dependent countries. Apart from the large number of automobiles in such countries, modern cities collect different types of data from various other sources [108]. The key to a successful transition to smart mobility is to connect data from different sources. However, in this case, integrating the data is challenging since different sources use different data structures, making it challenging to attain a successful transition [109]. Therefore, car-dependent countries fail to fully transition to smart mobility due to their struggles in integrating data archived in the databases of different agencies.

6.1.7. Privacy and Integrity Issues

The recent privacy and integrity issues, raised for the use of data by public and private agencies, pose a key challenge in the smart mobility transition for car-dependent countries. Data collection technologies in both urban and rural centres are known to target residents, qualitatively and quantitatively [110], which raises concerns in society about their privacy [111]. While the decision makers and stakeholders acknowledge the importance of data collection and analysis techniques for smart mobility. However, they retain the stand that a prerequisite of their application should be a guarantee of their privacy.

6.1.8. Regulatory Barriers

City, state, and national governments' influence smart mobility transition through a combination of carrots and sticks. For example, the U.S. has several cities that are still predominantly car dependent [112]. The federal government and state governments regulating these cities have historically focused on promoting smart mobility by using incentives, such as tax credits and rebates [113]. These incentives are meant to make smart mobility cheaper for early adopters. Despite the existence of such policies, the country still lags in the smart mobility transition [114]. The lack of stricter government policies has constrained the speed of smart mobility transition in most U.S. cities. The aggressive government measures implemented in other car-dependent cities, such as Madrid, Paris, and London have accelerated the adoption of smart mobility, as discussed previously.

6.1.9. Users' Complaints

The most significant challenge to the transition to smart mobility are the people residing in the car-dependent countries. People are known to complain whenever authorities implement smart mobility solutions. Solutions such as the reduction of speed limits, and the transformation of streets into pedestrian areas, have been met by frequent user complaints [115]. People tend to resist smart mobility transitions, especially when the solutions require significant changes to their travel behaviour and infrastructure [116].

6.1.10. Unequal Accessibility

Unequal accessibility to smart mobility resources and solutions is a major challenge to the smart mobility transition. Smart mobility transition needs to satisfy user demand by considering accessibility during urban planning and the setting of innovations [117]. For instance, the failure of most mobility solutions to consider the needs of the disabled and the elders, presents an implementation problem. A large proportion of the people lack the ability to get access to or use smart devices and solutions, which is considered as a barrier to the implementation of smart mobility options [118].

6.2. Recommendations and opportunities of smart mobility transition

There are several recommendations which implementation that would help car-dependent countries overcome smart mobility transition challenges. The main source of these recommendations is the review of case studies and research undertaken in the past, some of which are mentioned below. While other recommendations have been gathered from their success at small-scale or in other fields, which have been provided with references for readers' convenience.

– Implement aggressive government policies to enforce the adoption of smart mobility solutions. As mentioned in the section above, countries, such as the U.S., have historically implemented average measures. Their measures can be termed as average because they only focus on encouraging automobile manufacturers to adopt the use of less carbon-based fuel and the resultant emissions resulting in the advent of electric mobility [119]. In this case, stricter government policies need to be imposed to ease the transition to smart mobility. These policies will direct agencies and cities in the country to follow in the footsteps of relatively successful cities such as London and Paris that have instituted more aggressive approaches, which has been attributed to a "stronger welfare model" in these countries [17]. The purpose should be to accelerate the transition to smart mobility.

- Countries should practice greater inclusivity before, during, and after the implementation of smart mobility solutions. Inclusivity in decision-making could take the form of public debates, education, surveys, and presentations. Practicing inclusivity will help solve the challenge of low acceptance of new technological solutions [120]. The public would be more willing to participate in smart mobility transition if they were made aware of future mobility solutions, their costs, and their benefits.
- Countries should plan for the future of smart mobility by investing in IoT applications and reliable infrastructure. According to Davidsson et al. [121], the evolution of mobility that is supported by IoT applications will open new opportunities in many aspects of smart mobility, such as public transportation. A major opportunity, yet to be tapped, is the current high number of transport users in rural areas [14]. Leveraging IoT technologies, in this case, will help provide relevant data that will facilitate the improvement of transport usage monitoring and the understanding of usage patterns in rural areas. Generally, the technologies will help authorities in car-dependent countries to adjust and balance transport services [122].
- Government authorities should improve the use of smart mobility solutions in urban centres by introducing fees and levies that discourage the car-dependence tendency. Riyadh is a modern city in the Middle East that has invested in smart mobility transition by introducing the Metro ridership. A study done for Riyadh has suggested that the authorities should tax parking in the central business district or tax fuel [98]. According to Youssef et al. [98], increasing the taxes, applicable to fuel and parking by 10%, will increase the use of the smart mobility solution by 5.3%. It follows that such measures may also help other car-dependent countries to improve smart mobility transition by increasing the cost of alternative means of transportation.

Tab. 3 presents a matrix to show the relationship between challenges to smart mobility and how they are addressed by the recommendations. The matrix is prepared as per the discussion presented above and it is one of the important contributions of this research.

Tab 3

Matrix of challenges and recommendations

Challenges	Recommendations (Opportunities)			
	Aggressive Government Policies	Greater Inclusivity	Investment in IoT	Fees and Levies to Reduce Car Use
Inadequate infrastructure	√		√	√
Low Acceptance of Technological Solutions		√		
Inadequate Framework for Big Data Use for Smart Mobility	√		√	

Financial Constrains	√			√
Data Quality Management			√	
Integration of Data from Data Sources			√	
Privacy and Integrity Issues		√		
Regulatory Barriers	√			√
Users' Complaints		√		
Unequal Accessibility		√		√

7. CONCLUSIONS AND FUTURE WORK

This research recognizes smart mobility as a key component in the adoption of the concept of smart cities. It employs a systematic review process to identify the need for shifting from car-dependency, different components and aspects of smart mobility and the several challenges that car-dependent countries experience in their course to transition to smart mobility.

Previous research has clearly highlighted that car dependency has resulted in issues related to road safety, social inequity, environmental emissions, and depletion of fossil fuels. Smart mobility solutions are targeted to mitigate these issues through the use of technological solutions for public transport, shared mobility, IoT and alternative fuel (electric vehicles).

This research has identified the following as the major challenges faced during the transition to smart mobility solutions; financial constraints, lack of infrastructure, issues with data integration and quality, ensuring the privacy of users, regulatory barriers and public resistance. These challenges have led to the prevalence of traditional transportation modes by slowing down the adoption of smart mobility solutions. These challenges can be met with investment in the IoT sector, public inclusivity, fees and levees for private car use and other aggressive policies.

One of the major contributions of this research was to develop a matrix linking the major challenges faced in the transformation of cities to smart mobility solutions with a set of recommendations. In this context, some of the new ideas could be in the development stage and a thorough review of the conference papers and latest patents may provide more insights into it. The current research did not cover these aspects, which could be considered as one of its limitations.

Author contributions

The authors confirm contribution to the paper as follows: study conception and design: U. Gazder, O Abudayyeh; data collection: T. Almaghlouth; analysis and interpretation of results: T. Almaghlouth, U. Gazder; draft manuscript preparation: T. Almaghlouth, U. Gazder, O. Abudayyeh. All authors reviewed the results and approved the final version of the manuscript.

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