Smart Transportation Systems in Smart Cities: Practices, Challenges, and Opportunities for Saudi Cities

A. H. M. Mehbub Anwar and Abu Toasin Oakil

Abstract Smart transportation is an approach that incorporates modern technologies into transportation systems to improve the efficiency of urban mobility. Cities worldwide call digital technologies to harness their development to address potential challenges and concerns, which provoke technology-driven practices in urban context. Big data and technologies now offer tools, techniques, and information that can improve how cities function. Consequently, urban process and practices are becoming highly responsive to a form of technology-driven urbanism, that is the key mode of production for smart urban development. This furnishes the prospect of building models of smart sustainable cities performing in real time from routinely available data. This in turn allows to monitor, understand, analyze, and plan such cities to improve their urban efficiency and promotes new urban intelligence functions as an advanced form of decision support. Although technology-driven approach to transport analysis and management is emerging as smart city principle, the application is limited in the Kingdom of Saudi Arabia (KSA). This chapter investigates the potentials and the role of technology-driven solutions in improving and advancing urban transport management in the context of smart cities. It also explores the relevant practices as well as potentials in smart urban development context for Saudi cities. Our approach of technology-driven urban management will envision cities as a complex social and technological ecosystem and build on lessons learned from the research at city level and conceptualizes actors and institutions in a technology-driven urban management for Saudi cities toward achieving liveable smart city.

Keywords Smart cities · Smart transport · GCC · Riyadh city · Urban mobility

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1 Introduction

The United Nations (UN) predicts that 68% of the global population will live in cities by 2050 (UN, 2018), adding approximately 2.9 billion vehicles to the road (Djahel et al., 2018). This increasing demand will challenge the long-term sustainable goals of the present transportation system. In addition, people's choice regarding travel has been changing. Policies regarding sustainable transport and changing people's behavior make it harder to formulate solutions that protect individual well-being and societal interests. Traditional ways of depending only on automobiles or on public transport have come to an end (Sharmeen et al., 2020). The new generation of travel behavior suggests a more flexible way of traveling. Such a flexible lifestyle, together with a shared economy and the development of information technology, has encouraged the reconfiguration of transport systems (Sharmeen & Meurs, 2019). The system should serve the purpose without limiting travelers' intentions by means of transport. This requires having all possibilities open. For example, people may choose small cars when traveling to a place where parking can be difficult. However, people may prefer bigger cars when traveling to shopping centers or furniture shops. In terms of car ownership, it is difficult and costly to own cars for every purpose. Therefore, car-sharing options have become promising. People can choose whatever car they need at the time of travel. People may also choose to travel by public transport for many reasons, such as congestion charges and parking fees. Additionally, they may want to use an active transport mode such as walking or cycling. People may also find it beneficial to use multiple modes for one purpose. For example, people may take a car to the residential train station to catch a train and then take a cycle at the destination in a busy center to avoid congestion. Therefore, mobility should be considered as a single service, which may take different forms. Whereas this flexibility creates great satisfaction with travel at the individual level and benefits society by creating options for sustainability, such flexibility brings a high level of complexity in the transport system incorporating multiple stakeholders, clients, and actors in play, and therefore, an integrated transport system becomes difficult (Meurs et al., 2020). The more complex it gets, more sophisticated the system we need to manage our transport system. An intelligent/smart transport system (I/STS) is therefore coined. Although it is not necessarily a very new concept, the momentum that it achieved is recent (Debnath et al., 2014).

In general, the goal of a smart transport system is to solve direct and indirect transport-related problems in the most efficient way to maximize the well-being of individuals and society. Whereas the meaning of smart transport can be broad, ITSs add specific interest to the technology dependence of the system for the same goal. It creates a system that is more adaptive to changing circumstances. The information and communication technologies that connect diverse parts of the transport system seamlessly allow managing and solving issues in transport in a (near) real-time manner. It refers to an automatic, demand-responsive, and real-time system. According to the US Department of Transportation,

> Intelligent Transportation Systems (ITS) apply a variety of technologies to monitor, evaluate, and manage transportation systems to enhance efficiency and safety.

An ITS maximizes the use of existing infrastructure through a range of technological means, such as traffic signals, travel planners, smart ticketing, and cooperative systems (Bıyık et al., 2021; Bazzan & Klügl, 2013). ITSs often focus on smart technologies established in transport infrastructures and vehicles but are not limited to them. In general, smart transport refers to any technology used for efficient transport management. As per Shaheen and Finson (2013),

> Intelligent transportation system (ITS) is composed of a wide range of technologies—including electronics, information processing, wireless communications, and controls—aimed at improving safety, efficiency, and convenience of the overall surface transportation network.

In an introductory guide for ITSs, the Japan Society of Civil Engineers (JSCE, 2016) referred to ITSs as a new transportation system to resolve a variety of road traffic issues (such as traffic accidents and congestion) by linking people, roads, and vehicles in an information and communications network by cutting-edge technologies (Fig. 1).

With the increase in the Internet of Things (IoT), many devices are now connected through the internet, making information exchange among these devices fast and flexible. Whereas ITS started to develop infrastructure and vehicles with connected devices such as sensors and cameras, IoT has made it even easier through utilization of mobile devices such as mobile phones and navigation systems. Information coming from mobile devices is a convenient and inexpensive alternative to physically installed sensors within transport infrastructure (Alomari et al., 2021). Data and information are key to the efficient functioning of the transport system. Whereas data can be collected from different sources, transport sometimes requires real-time data to manage it, for instance, congestion control and traffic rerouting, public transport re/scheduling, accident response, etc. ITS harnesses the opportunities from the application of big data generated from different smart devices, either established in the infrastructure or carried by people such as mobile phones, navigation systems, or tablets. Not only data availability but also on-time availability is important. In addition, the ubiquitous nature of data provides more opportunities than ever before. Smart devices such as mobile phones have reached

Fig. 1 Components of ITS. (Source: JSCE (2016))

many places in the world, reducing spatial disparity in functioning and management. Developed countries as well as developing countries are using smart devices to solve local problems and create efficiency. A key to problem-solving is to understand the problem, and information is a prerequisite in this regard. Although data ubiquity is the essence of modern-day smart devices, the application of data is not universal.

The remainder of this chapter is organized as follows: Sect. 2 provides a review of smart transport system (STS) applications around the world with a few examples. Section 3 focuses on STS practices in Saudi cities. Section 4 discusses smart cities from the perspective of Riyadh city. The final remarks, including the opportunities and challenges of STS, are put at the end of the paper.

2 Smart Transport System (STS): Applications

The goal of STS is many-fold—reducing carbon emissions and traffic congestion and increasing reliability, efficiency, and safety. To achieve these goals, transport systems must implement sustainable strategies in an efficient way, for which information and technology play a vital role. According to Nikitas et al. (2020), society needs to shift to a more sustainable techno-social paradigm to avoid the adverse repercussions of a resource-intensive and unthoughtfully opportunistic liveability philosophy. At the core of intelligent transport systems remains the efficiency, management, safety, and resilience of the transport system. The benefits of such efficient management could be real-time information, more efficient administration, the possibility for citizens to access the information system online via smartphones, and on-request traffic light control (Tomaszewska & Florea, 2018). According to Giannopoulos (2004), ITS achieves efficiency by improving the transport system in three main areas: (1) operation and management of transport system and networks, (2) information and guidance to the users of the system, and (3) operation and management of freight transport systems. It can be simplified into the following concepts for what makes up smart transportation: management, efficiency, and safety. In other words, smart transportation uses new and emerging technologies to make moving around a city more convenient, more cost-effective (for both the city and the individual), and safer. Thus, STS focuses on three dimensions (Yan et al., 2020): (i) smart cells, (ii) ICT (Information and Communication Technology), and (iii) development mechanisms. Smart cells should include smart cars, unmanned aerial vehicles (UAVs), smart infrastructure and devices, and smart base stations supported by ICT and enabled by various developmental mechanisms (Yan et al., 2020). In general, we can see the system as two interconnected segments—one is responsible for the operation and management of the system through smart technologies, and the other is the user of the system. STS creates a seamless connection between these two segments. STS does these in many ways.

2.1 Real-Time Traffic Updates and Management

There are two important components of STS: Vehicle to Vehicle (V2 V) and Vehicle to Infrastructure (V2I) solutions. V2 V solutions mainly increase travel safety by enabling advanced emergency braking systems. Similarly, V2I relies on different sensors installed at the road network to detect different traffic variables, such as speed, density, and waiting time (Mangiaracina et al., 2017). For instance, through V2 V applications, drivers will be alerted to imminent crashes, such as merging trucks, cars in the driver's blind spot, or when a vehicle ahead stops suddenly. This application includes forward collision warning, emergency electronic brake light, blind spot/lane change warning, not pass warning, intersection movement assist, and left or right turn assist. On the other hand, through V2I applications, for example, drivers will be alerted when they are entering a school zone, if workers are on the roadside, and if an upcoming traffic light is about to change. This application includes curve speed warning, red light violation warning, stop sign gap assist, smart roadside, and transit pedestrian warning.

Smith et al. (2013) analyzed the case of SURTRAC (Scalable Urban Traffic Control), a pilot implementation of an adaptive traffic signal control system installed for a nine-intersection road network in Pittsburgh, Pennsylvania (USA). The pilot test results demonstrated the effectiveness and potential of decentralized, adaptive traffic signal control in urban road networks. The SURTRAC system improved traffic flow efficiency by 25–40% and reduced emissions by over 20%.

2.2 Demand-Responsive Public Transport/ On-Demand Transport

There are over 40 cities around the world that are trialing on-demand public transport pilots and operational services. There is no universally accepted definition of on-demand public transport (sometimes referred to as demand-responsive transport or DRT). On-demand public transport (ODT) is a form of publicly subsidized transport that takes multiple passengers within a defined area from one place to another on a next-available or prebook basis. The ODT does not operate on fixed routes and fixed schedules. For the case in Australia, this ODT service becomes very popular initially in New South Wales (NSW) and later spreads over other parts of the country. This service picks passengers up from their home and takes them to their desired destination. For booking, the specified mobile apps must be installed; otherwise, computers can be used before the journey. Its flexible and nonregular route service encourages the use of public transport by providing mobility options for all in areas where daily demand is variable. On-demand services can connect passengers with other public transport hubs or direct to their destinations to enhance the mobility of the entire community.

2.3 Smart Ticketing

Smart ticketing is a ticketing system where a travel ticket is electronically stored on a smart card or a smartphone, eliminating the need for traditional paper tickets and enabling users to simply tap their smart card or device on a gate or validator to access travel. This system allows the user to skip the ticket counter at the station. Users can buy tickets for a specific period in advance or load credit onto their account. For example, in London, back in the 1990s, the Transport for London (TFL) began introducing the Oyster travel card, a contactless card to speed up access for people traveling on the London Underground. Over 60 million Oyster cards were recorded until 2013, with 85% of all rail and bus travel paid for using this system.[1] Contemporarily, various types of smart tickets, such as mobile tickets and smart cards, are seen, and they use significantly different technologies. Some widely used contactless smart cards include Melbourne's myki, Sydney's Opal Card, South Korea's T-money, Hong Kong's Octopus card, Stockholm's Access card, Japan's Suica and Pasmo cards, Singapore's NETS FlashPay and EZ-Link cards, Manila's Beep cards, Paris's Calypso/Navigo, the Dutch OV-Chipkaart, Greater Toronto's (as well as Hamilton and Ottawa) Presto card and Lisbon's LisboaViva card, including many in the USA, such as Go-To card in Minneapolis–Saint Paul, SEPTA Key in Philadelphia, CharmCard in Maryland, etc.

2.4 Ridesharing

Ridesharing refers to a mode of transportation in which individual travelers share a vehicle for a trip and travel costs such as gas, toll, and parking fees with others that have similar itineraries and time schedules. Thus, ridesharing appears to be an advantageous approach to society and the environment that includes saving travel costs, reducing travel time, mitigating traffic congestion, conserving fuel, and reducing air pollution (Ferguson, 1997; Kelly, 2007; Morency, 2007; Chan & Shaheen, 2012). Mitropoulos et al. identified approximately 29 rideshare platforms in their paper and noted that most of the ridesharing platforms were found to operate in the EU (48%), with 27% of them operating in Italy (Mitropoulos et al., 2021). In addition, ridesharing platforms operate in the USA, Asia, and Latin America remarkably. The majority of ridesharing platforms (93%) started their operation in 2005 or after, while 62% were found to start operations in or after 2010, which might be explained by the rapid development of mobile applications and the spread of smartphones. Smartphone annual sales doubled between 2007 and 2010 (i.e., 122.32 vs. 296.65 million units) and increased by a factor of 4.2 between 2010 and 2014 (i.e., 296.65 vs. 969.72 million units), reaching 1540.66 million sold units in

[1] Pablo Vinuesa. 2021. Smart ticketing: the revolution for the tickets of the future or just an anti-covid measure? URL: https://tomorrow.city/a/smart-ticketing accessed on May 26, 2022.

2019 (Mitropoulos et al., 2021), meaning that the increasing rate of smartphone users has made ridesharing convenient for travelers.

2.5 Smart Parking System

Sustainable strategies target many aspects of transport systems to encourage less carbon-intensive travel as well as to increase efficiency, comfort, and safety. For instance, transport authorities consider car parking charges in busy areas to avoid congestion, encourage public transport, discourage car use, and save space for productive or recreational uses (Anwar & Oakil, 2021; Calthrop et al., 2000; Buehler et al., 2017). However, the outcome might not be positive if we cannot implement such car parking policies efficiently. Reducing the availability of car parking in a busy urban center may discourage car use, but it may also create difficult situations for people who need to use cars. Finding a parking space is time-consuming and requires unnecessary driving around the city burning fuels (Awaisi et al., 2019; Durga Devi et al., 2017). This may also aggravate traffic congestion in the inner city. For instance, cars searching for parking spaces generate up to 40% of the total traffic on the street (Kazi et al., 2018).

A smart parking system can acquire information regarding the availability of parking spaces and help reserve a space needed. It can also reduce the stress of maintaining the time on the parking meter because the billing system can be adjusted for use. It utilizes smart sensor technologies that can be installed on the street to collect real-time data and update a web-based portal to monitor the parking spaces and feedback the drivers using a mobile app that can enable the user to reserve the space and make online payments as well as navigate to the nearest vacant space (Durga Devi et al., 2017; Mainetti et al., 2015). Furthermore, smart parking systems can reduce parking pressure in busy areas by sharing parking spaces (Atif et al., 2016).

Many parking apps have been developed, such as Parkmobile, BestParking, Parker, SpotHero, ParkMe, Parking Mate, Parking Panda, ParkWhiz, and VoicePark. These apps help you to

- Locate available parking spots in garages and lots as well as local street parking
- Quickly compare the price, distance, hours availability
- Navigate to the nearest open/vacant spot
- Run a timer, so there is no need to worry about parking tickets
- Reserve a spot
- App may own dedicated unsold spots from parking facilities in an area.
- Provide a discounted rate.
- Record the history of your parking (location, time, price)
- Notify about parking expiration based on parking regulations such as limited hour zone

- Collaborate with attraction points such as stadiums, family attractions, and other events to ensure attraction.

2.6 Public Transport Management

Whereas smart parking management leads to better outcomes, the acceptance of parking policy can vary and may lead to inequitable implications for society (Hamer et al., 2012). We need to create opportunities for travelers. If cars have been discouraged from encouraging public transport use, then public transport should be attractive, acceptable, and satisfactory to users. Often, public transport frequencies affect user experience. Waiting for a train or bus, not finding a better route, and the absence of appropriate transfer/connection information may discourage public transport use. A smart public transport system intends to make not only the system efficient and flexible but also easily accessible for users. For instance, smart ticketing and real-time journey planning are two important features of smart public transport. Smart ticketing allows travelers to use one card for any combination of travel, including hiring a taxi or bicycle or renting a car. In addition, multiple service plans are provided, such as pay-as-you-go, monthly billing afterward, seasonal tickets, or just using your own bank card. Similarly, real-time journey planners are no longer for one travel mode; they combine bus, tram, train, metro, and other available public transport. Weng et al. (2016) estimated the real-time bus travel speed and the location of the bus. Combining the real-time bus positioning system data with the bus geographical information system map, the study accurately matched the bus location onto the map so that it could determine the bus position of the given route and estimate the bus arrival time, which might increase the wait time performance for the passengers.

2.7 Mobility as a Service (MaaS)

The increasing number of transport services offered in cities and advancements in technology and ICT have introduced an innovative concept called mobility as a service (MaaS), which makes it easier for citizens to access and utilize several complementary mobility services. MaaS combines different available transport modes to offer a customized mobility package and includes other attractive complementary services in comparison to privately owned vehicles, such as trip planning, reservation, and payments, through a single interface (Hietanen, 2014). Such mobility bundles promote a shift from private transport to smart access-based transport. MaaS-like services have been trailed and are planned to be implemented in upcoming years, including in Europe, North America, Asia, and Oceania. Smith and Hensher (2020) pointed out numerous benefits that we can obtain from this service, such as a smaller carbon footprint from personal mobility and reduced congestion, which in turn could lead to higher productivity, improved air quality, fewer traffic accidents, and reduced social exclusion.

3 Smart Transport System Practices in the Kingdom of Saudi Arabia (KSA)

3.1 Past to Present

The Ministry of Interior signed a contract with Doxiadis Associates (Consultants on Development and Ekistics of Athens, Greece) for the formulation of a master plan to guide the development of Riyadh city up to the year 2000, and Doxiadis submitted a Master plan in 1971. In terms of mobility, the master plan was designed in a way that promoted automobiles as the only mode of transport (Al-Hathloul, 2017). Later, this plan became obsolete due to predicting the size of urban growth inadequately; therefore, it revealed the necessity of further adjustments to the master plan to accommodate the subsequent city's rapid growth. However, the ADA (Arriyadh Development Authority) established a Comprehensive Riyadh Strategic Plan called the MEDSTAR (Metropolitan Development Strategy Arriyadh) project in 2003 to plan, manage and control city growth by setting up urban growth boundaries. Under the MEDSTAR project, the Riyadh Public Transport Network (RPTN) has been proposed to achieve reliable, efficient, and affordable public transport for residents. The network is composed of metro lines with Bus Rapid Transit (BRT), community bus lines, feeder buses, and park and ride facilities. The project is underway and expected to be in operation soon. As a result of implementing the RPTN, the Royal Commission for Riyadh City (RCRC) is currently undertaking a preliminary study of transit-oriented development (TOD) within Riyadh city, which symbolizes the TOD strategy for future Riyadh, intensifies mixed-use activities and increases the density around metro stations. Cervero and Murakami (2008) argued that TOD embodies physical features of high density and mixed land uses accommodating enough population living within the acceptable distance that encourages walking, cycling, and public transport that can also contribute to improving social cohesion.

3.2 Traffic Condition and Accessibility Analysis

Accessibility is the most important measure in transport systems. Evaluating and assessing how a transport system might and will perform depends on how the system makes different activities or destinations accessible. However, the measurement of accessibility is difficult. A high level of accessibility does not come with only a high level of mobility (El-Geneidy & Levinson, 2006). We can achieve high mobility without achieving a high level of accessibility. Mobility comes with high speed, and accessibility comes with a combination of time, speed, and destination. Therefore, density, population, network and connectivity, travel cost, time, and speed, among others, are combined in accessibility measures. A rigorous collection of data is required to accurately assess accessibility.

KSA's planning principle is often toward mobility. Accessibility is often ignored in the planning process. Therefore, Saudi cities represent urban sprawl. Whereas you can achieve high speed on the road using automobiles with wide roads, you cannot reach a destination in a short time. Moreover, sprawl, meaning a low density of people leading to the overall accessibility of a city, is reduced. Since the city has been built without considering accessibility, a detailed description of built environment characteristics, walk time to destinations, and concentration of services are often not known. A physical as well as social survey is necessary to collect such data. This is often time-consuming and costly and cannot cope with the rapidly changing environment of Riyadh. Ubiquitous data generated from different smart devices can sometimes be used to proxy such large-scale data collection.

Al-Hosain and Alhussaini (2021) evaluated the potential accessibility to Riyadh's planned public transport system using geospatial analysis. The study showed that approximately 34% of Riyadh's population could be served if 5-minute driving to the metro station is assumed, while this percentage would increase to 74% if 10-minute driving is considered. Smaller percentages of the population were found within an acceptable walking distance to the stations. Specifically, 5% and 14% of the population could walk to a metro station within 5 and 10 minutes, respectively.

3.3 Freight Management and Analysis

The KAPSARC (King Abdullah Petroleum and Studies and Research Center) estimated freight transport activities in China, India, and Saudi Arabia using Nighttime Lights Satellite Data sourced by the National Ocean and Atmospheric Administration. This paper focuses on using night satellite radiometry to estimate total freight transportation activity in any city, region, or country based on the intensity of nighttime lights and their relationship with economic and human activity on the ground (Lopez-Ruiz et al., 2019).

3.4 Walk Behavior Analysis

Walking is a mode of contributing positive impact to health and social benefits. Almahmood et al. (2017) studied this component in the Riyadh context using a method that is a combination of movement tracking data using GPS technology and map-based workshops where participants can reflect on their walking behavior and spatial preferences. The results map the city by exploring gender-specific walkscapes. According to Riyadh respondents, women enjoy shopping malls as a function of urban shelters, indicating spaces for walking, while young men mainly walk in urban streets. Thus, streets are perceived as men's walkscapes, where women's presence is limited. The key message of this study is that walkscapes are determined not only by the quality of the space nut but also by sociocultural settings.

3.5 Traffic Safety and Event Analysis

Roadside events are sometimes crucial to detect either a mechanical breakdown or an accident. A mechanical breakdown can cause traffic congestion and delays, leading to economic and time losses if not solved in a timely manner. Accidents can be life-threatening, and immediate detection of the event can save lives directly. Notification can reduce traffic congestion and delays due to any accident since on-time measures can be taken to divert traffic to another situation. However, diversion is also needed to provide support to the accident itself and may also reduce chances of other accidents. Deaths in road transport account for 1.25 million deaths globally (Aqib et al., 2019). The car accident rate in the KSA is very high, making the KSA one of the world's highest rates of death and casualties (Al-Mosaind, 2018). Information boards are not well designed. Updates are not coming on the road. People rely on social media, which has increasingly become a convenient and inexpensive alternative for physical sensors, such as in the transport sector in smart societies (Alomari et al., 2021).

4 Riyadh from the Perspective of Smart Cities

Due to urbanization challenges, the concept of "smart cities" has become a popular tale in the modern urban planning era. The extant research indicates that the latest technological advancements are fully capable of offering solutions for those challenges (Kumar et al., 2020). These challenges are not different in Saudi Arabian cities, particularly in Riyadh. Saudi Vision 2030 (SV2030) is committed to revitalizing economic cities, establishing special zones, and deregulating the energy market to make it more competitive. The Ministry of Municipal and Rural Affairs (MOMRA) launched the "application of smart cities" initiative as one of the municipal transformation projects emanating from the National Transformation Program 2020 (NTP2020) and SV2030 to enhance urban development in the Kingdom through smart city initiatives. The Ministry conducted a field study in 2017 to determine the readiness and feasibility of Saudi cities to be transformed into smart cities. This study covered 17 major cities that make up nearly 72% of the Kingdom's population and indicated that there could be disparity in the Kingdom's cities' preparedness to shift to smart cities, with Makkah coming first, followed by Riyadh, Jeddah, Madinah, and Asha.[2] Moreover, in the First Saudi Conference for Smart Cities at Riyadh, the Minister of MOMRA unveiled plans to establish 10 smart cities in the Kingdom, and Riyadh is one of them.

4.1 A Concept of Smart City

Substantial infrastructural development can direct positive outcomes for citizens as well as adverse effects and challenges on the smooth functioning of the city. Some of the challenges of current cities are as follows (not limited to):

1. Urban sprawl (Artmann et al., 2019; Kovács et al., 2019; Mahmoud & Divigalpitiya, 2019)
2. Urban pollution (Luo et al., 2019; Munksgaard et al., 2019; Munoz-Pandiella et al., 2018)
3. Inadequate citizen participation in planning and management process (Glaas et al., 2020; Slaev et al., 2019; Sou, 2019)
4. Technological infrastructure (Appio et al., 2019; Pham & Phan, 2018; Juwet & Ryckewaert, 2018)
5. Waste management (Zabara & Ahmad, 2020; Das et al., 2019; Zhang et al., 2019)
6. Poverty: inequality of wealth distribution (Bradshaw et al., 2019; Siwar et al., 2016; Muktiali, 2018)
7. Urban mobility (de Oliveira et al., 2019; Kijewska et al., 2019; Goetz & Alexander, 2019)
8. Aging population (Cheng et al., 2019; Heffner et al., 2019; Jayantha et al., 2018)

Due to identified challenges and complex issues, there is a growing need for innovative and dynamic solutions to address these issues in urban life. In the last couple of decades, the smart city concept, which enables better housing, transport, energy, and other infrastructure needs and is treated as a key strategy to combat poverty and inequality, unemployment, and energy management, has gained considerable attention in the urban development domain. The diverse scope, concept, and empirical approaches incorporated in the smart city debate have contributed to the lack of an absolute definition of smart cities. However, Lee et al. (2014) suggest that effective and sustainable smart cities emerge as a result of dynamic processes in which the players of the public and private sectors coordinate their activities and resources on an open innovation platform. Ahvenniemi et al. (2017) conceptualized smart cities as an "urban development model" geared to the utilization of human, collective, and technological capital within urban agglomerations. In a common sense, the concept of smart cities is embedded within the advances of ICT and their effective use and application in the context of cities and urban spaces (Visvizi & Lytras, 2019). Thus,

[2] Arab News, 2017. Smart City Initiative Launched. http://www.arabnews.com/node/1087402/saudi-arabia accessed on May 26, 2022.

the smart city is an aggregate concept of connectedness of the various aspects of a city that plays a role in its function. Doheim et al. (2019) emphasize the main concept of a smart city, which focuses on the interconnection of all aspects of the city, such as social, urban, economic, and environmental institutions. and reflects a holistic approach to handle urban problems by taking advantage of the new technologies of ICT. This means that a balance of technological, economic, environmental, and social factors involved in an urban system is a prerequisite to defining a smart city. Technology, people, and institutions are the key strategic principles of smart cities, such as the integration of infrastructures and technology-mediated services, social learning for strengthening human infrastructure, and governance for institutional improvement and citizen engagement (Nam & Pardo, 2011). Other research has identified two domains (Doheim et al., 2019) to define smart cities: *hard domains* such as buildings, energy grids, natural resources, water management, waste management, and mobility (Neirotti et al., 2014), where ICT can play a vital role in the functions of the systems, and *soft domains* such as education, culture, policy innovations, social inclusion, and government, where the applications of ICT are not usually decisive (Albino et al., 2015). Accordingly, it is difficult to obtain an absolute definition of smart cities. However, Giffinger et al. (2007) defined a smart city by assessing six basic dimensions: (i) smart governance, (ii) smart economy, (iii) smart mobility, (iv) smart environment, (v) smart people, and (vi) smart living (Fig. 2) as pillars of the smart city that make it the most practical classification of the smart city concept.

Smart governance can be expressed by the intelligent use of ICT to improve decision-making through better collaboration among different stakeholders, including government and citizens (Pereira et al., 2018). Smart governance also has an important role in smart city initiatives, which require multilayered interactions between governments, citizens, and stakeholders. *The smart economy* is understood as an economy based on innovation, entrepreneurship, high productivity, flexibility in the labor market, international and interregional embeddedness, and the ability to transform (Giffinger et al., 2007). *Smart mobility* is largely permeated by ICT, used

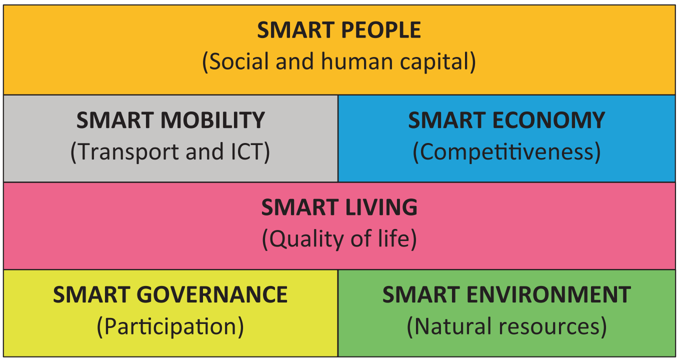

Fig. 2 Six main pillars (dimensions) of smart cities. (Adopted from Giffinger et al. (2007))

in both backward and forward applications, to support the optimization of traffic fluxes but also to collect citizens' opinions about liveability in cities or the quality of local public transport services (Benevolo et al., 2016). *The smart environment* is measured by maintaining the attractiveness of the natural environment, pollution levels, environmental protection activities, and resource management (Winkowska et al., 2019). *The smart people* concept focuses on the sensible participation of citizens in urban life and their ability to adjust to new solutions through adequate qualification, and motivation for lifelong learning is a critical requirement for a smart city (Doheim et al., 2019). *Smart living* is understood as an attempt to achieve a high quality of life by enhancing health conditions and individual safety; combining different values, cultures, and styles harmoniously; building opportunities for social cohesion using public space; and having sustainable and environmentally friendly buildings (Giffinger et al., 2007).

Based on the above discussion, Doheim et al. (2019) categorized the smart city concept into three classes:

1. *The digital city* (technology-based city) refers to a city where ICT connects and facilitates services interactively. The dimensions of *smart governance, smart economy,* and *smart mobility* may fall in this class.
2. The *intelligent city* (knowledge-based city) refers to a city where people are well educated, knowledgeable, and curious to learn lifelong. The smart city dimension, called *smart people,* may fall in this class.
3. The *environmental city* (community-based city) refers to a city where establishments promote the opportunity to build social cohesion/capital among citizens for a better quality of life and well-being. It is a community-driven city that ensures citizens' participation in decision-making processes at each level. The practices of *smart living* and *smart environment* dimensions may fall in this class.

4.2 Smart City Practices in Riyadh City

Riyadh city is the capital and financial hub of the Kingdom. It is economically vibrant and has approved many initiatives relating to smart cities, which are elucidated below.

KSA has recently announced and adopted a sustainable strategy of urban planning that inflames its shift from a traditional focal point to the development of a knowledge-based society. From this perspective, King Saud University (KSU) has initiated two remarkable projects to set up Riyadh as a smart city node, which are associated with the *smart people* dimension of the smart city concept. The projects are the Riyadh Techno Valley (RTV) and the Riyadh Knowledge Corridor (RKC). RTV is developed as the establishment of an ecosystem to attract research and business for a competitive and highly proficient knowledge-based economy (Aldusari, 2015). RTV aims to deliver a leading and outstanding smart environmental campus to enhance research and development for efficient operation, maintenance, and service delivery. The RKC is designed to promote an interlinked group of innovation outlets and pioneering knowledge that is planned to develop a knowledge-based society. In this context, Riyadh implements a range of education and economic entities to achieve such societies, proposed by KSU, known as RKC, which is one of the greatest initiatives to develop and enhance knowledge, intellectual, economic, research, and educational entities (Aldusari, 2015). Moreover, another objective of the RKC project is to improve and enhance the communication and interaction among all these entities in a smart manner. The RTV and RKC projects can also represent the *smart economy* dimension of the smart city concept, as both are designed to be the gateway of the knowledge-based economy. KSU has built a partnership with RTV to facilitate the Saudi economy to a knowledge-based economy.[3] The term "knowledge-based economy" can be understood as production and services based on knowledge-intensive activities that contribute to an accelerated pace of technological and scientific advancement. Moreover, it includes a greater reliance on intellectual capabilities than on physical inputs or natural resources, combined with efforts to integrate improvements in every stage of the production process, from the research and development lab to the industry to the interface with customers (Powell & Snellman, 2004). There are several projects relating to the *smart economy* of the smart city concept, such as the King Abdullah Financial District, the City of Communication, and Information Technology, the first and second industrial cities, and other centers that are all emerging, helping to provide growth and development opportunities in the city (Doheim et al., 2019). Riyadh is set to be the Arab world's first digital capital and leads the region in the promotion of ICT as a catalyst for increased economy.[4]

Regarding *smart governance* of smart city vision, it relies on the good governance of having open (i.e., transparent), accountable, collaborative (i.e., involving all stakeholders) and participatory (i.e., citizens' participation) principles, and on Electronic Government (e-Government) (Lopes, 2017). In Riyadh, establishments facilitate the ease of the administrative process and increase transparency. For example, Al Helal and Mokhtar (2018) proposed the "Riyadh Wiki Information and Complaining System" for citizen engagement in Riyadh. It is an initiative to make Riyadh smarter and presents a hybrid model of citizens' engagement where they can involve themselves in making their city smart by publishing issues relating to Riyadh and data regarding different sectors such as health and education. Additionally, citizens are allowed to add new features, functionalities, and even new sectors to the system to contribute to and support the government in making the city smart. This tool is embedded with two approaches: "codesign," which allows citizens to be involved in the planning and decision-making process to build new services, and "cloud sourcing," which allows citizens to act as sources of data to

[3] KSU News, 2018. Riyadh Techno Valley, King Saud University's Gateway for the Knowledge Economy. King Saud University. https://news.ksu.edu.sa/en/node/101739

[4] Business Wire, 2019. Riyadh Set to Become the Arab World's First Digital Capital in 2020 https://www.businesswire.com/news/home/20191219005518/en/Riyadh-Set-Arab-World%E2%80%99s-Digital-Capital-2020

cooperate with the government and eventually improve their city. This type of interaction between citizens and the government can enhance the transparency and trust between them, which improves administrative governance by listening to the concerns of citizens; thus, the level of satisfaction is increased among city dwellers. This approach can strengthen the *smart people* concept of smart city vision because of its wide range of peoples' participation in urban life as well as ability to cope with new services.

In Riyadh, a huge investment project has been initiated to facilitate *smart mobility* in developing urban public transport systems and efficient traffic management. For instance, the MEDSTAR project was initiated in 2003 to manage the city smartly. Under the MEDSTAR project, ongoing metro service development is the discussed component. The metro will run automatically (without a driver) and be operated and monitored by a central control room. The required electric power will be optimized by providing electricity from independent sources. Metro cars and stations will be under continuous advanced surveillance systems.[5] This new system of public transport provides effective solutions for citizens to move across Riyadh efficiently and easily through comfortable train cars equipped with the latest technological advancements. Moreover, the video stream cameras are placed along the Riyadh Road network that has been integrated into a video-monitoring system to oversee major traffic "corridors" of the city (Doheim et al., 2019). The public transport system that Riyadh has introduced enables the enhancement of the quality of life of people, and it can also be labeled *smart living* due to its opportunity for efficient, safe, and comfortable mobility, which also brings about the opening of active transport to connect with open/public spaces and public transit stops.

In terms of the *smart environment* dimension, Riyadh city has initiated a few air-quality monitoring networks to control air pollution, which is composed of dust and other toxic chemicals. The initial monitoring network was found to be insufficient; therefore, the Natural Resources and Environmental Research Institute (NRERI) at King Abdulaziz City for Science & Technology (KACST) took the initiative to construct such a network in Riyadh (Alharbi et al., 2014). The first monitoring station was constructed in 1999 at the KACST campus, and then another four stations were established across the city by 2002. Another example is the HYDRUS smart water meters and Hydrometer Automatic Meter Reading (AMR) system that has been introduced in some parts of the Riyadh region. Smart water systems use ultrasound measuring techniques to measure the amount of water and computers to collect, analyze, and control data for efficient water use.[6] Diehl Metering and Abunayyan Trading have worked together to achieve smart solutions in the metering segment in Saudi Arabia since 2008. In the last 10 years, in partnership with Abunayyan Trading, Diehl Metering has provided an innovative solution to cope with the environmental and technical challenges in the water system. Recently, almost 20 fixed

[5] RCRC 2020, King Abdulaziz Project for Riyadh Public Transport https://www.rcrc.gov.sa/ accessed on 27th Feb. 2020.

[6] Abunayyan Trading, 2016. Technical Workshop on HYDRUS Smart Water Meters & AMR Systems for GDOW-Riyadh. Abunayyan Trading.

networks have been installed, and one million HYDRUS are connected around Saudi Arabia.[7]

5 Conclusions: Opportunities and Challenges

Saudi Arabia's Public Investment Fund (PIF) and STC Group (STC) have announced the signing of a joint venture (JV) agreement to establish a new company specializing in the Internet of Things (IoT). It will contribute toward boosting IoT adoption by being a technology-agnostic service provider with offerings in the smart industrial manufacturing sector, smart logistics transportation sector, and smart cities. Additionally, the company will also help to create an ecosystem by providing consulting, implementation, and training support as well as facilitating funding models to support businesses in their adoption of IoT. According to local market studies, there is vast growth in the size of the Kingdom's IoT market to potentially reach SAR10.8 bn by 2025, with an annual growth rate of 12.8%.[8]

Recently, the Saudi Ministry of Transport and Huawei, a provider of ICT infrastructure and smart devices, have signed a memorandum of understanding (MoU)[9] to enhance future transport and technology adoption in the transport and logistics sector by exploring the prospects of utilizing advanced technologies such as 5G, artificial intelligence (AI) and big data. According to the MoU, the Kingdom is set to receive urban solutions in the fields of automation, big data, and digitization. In addition, it will also contribute to the provision of solutions for shared mobility, sustainability, and the use of disruptive technology in the development of the logistics sector and smart transport systems in the Kingdom. The MoU ensures the utilization of the latest technology in the Saudi transport sector to enhance its performance in transporting freight and people, which is part of the Vision 2030 objectives. The adoption of advanced technologies such as AI and IoT improves the logistical performance of the Kingdom's transport systems, hence directly boosting Saudi Arabia's rank on the Logistics and Trading Across Borders performance indexes, further establishing the Kingdom as a global logistics hub connecting three continents: Europe, Africa, and Asia. The agreement also contributes to enhancing the quality of life across the country through the adoption of advanced smart

[7] Diehl Metering, 2018. One million HYDRUS ultrasonic water meters installed in Saudi Arabia. https://www.diehl.com/metering/en/news-events/news/1-million-hydrus-ultrasonic-water-meters-installed-in-saudi-arabia/ accessed on 27th Feb. 2020.

[8] Zainab Mansoor, 2022. Saudi's PIF and STC Group sign agreement to establish a new IoT company. URL: https://www.msn.com/en-ae/money/news/saudi-s-pif-stc-group-sign-agreement-to-establish-new-iot-company/ar-AAVPfYt?ocid=entnewsntp&cvid=d5ba2bb4872b45d288dbc3854e0e5bf4 accessed on May 26, 2022.

[9] Manda Banda, 2021. SMT and Huawei sign MoU to enhance mobility adoption in the transport sector. URL: https://www.intelligentcio.com/me/2021/05/05/smt-and-huawei-sign-mou-to-enhance-mobility-adoption-in-transport-sector/ accessed on May 26, 2022.

transport systems as well as improving the services provided to citizens, residents, and visitors across all transport facilities, including airports and railway stations. It focuses on finding ways to implement the latest automation and IoT practices in operations in addition to increasing multimodal integration to enhance transportation inside and across cities and reduce travel time. The Ministry of Transport targets boosting the adoption and utilization of technology in the field of transportation and logistics through collaboration with leading ICT organizations to enhance the services it provides and realize the goals of SV2030. NEOM, a brand-new high-tech city in progress, is a good example in this regard. The fundamental purpose of this city is to create a sustainable smart city that incorporates cutting-edge technologies and heals the environment from the damaging emissions it has experienced in recent years. NEOM aspires to remain committed to sustainability and putting in place mobility systems that are fueled entirely by renewable energy. Zero-emission vehicles will be deployed across all urban and regional mobility modes. In addition, NEOM plans to introduce shared mobility services, driverless shuttles, electric boats, delivery drones, and solar-powered mobility hubs. To align with this, the Kingdom has collaborated with the German aircraft manufacturer Volocopter, who will propel the city of NEOM to new heights of technical growth. Air taxis will be fully integrated into the city with the aim of carrying passengers and transporting logistics.

Furthermore, Saudi Arabia's Royal Commission for AlUla (RCU) launched an autonomous pod vehicle service in AlUla early in 2022,[10] which will experience residents in the future of sustainable, zero-emission mobility on their doorstep. It is planned to extend further to new locations, including Dadan, Hegra, and Al Jadidah, later in 2022. This service is part of the RCU's comprehensive Journey Through Time (JTT) master plan to develop a range of fully integrated, accessible, and environmentally friendly public transport options. The launch of this pilot scheme for the autonomous pod public transport service is the first step toward RCU's goal of providing the AlUla community with access to the very latest clean, safe, and energy-efficient mobility solutions. As outlined in the JTT master plan, sustainability is the driving force behind the ambitions for the future of AlUla and the goal to establish the wider northwest Arabian region as a hub for innovation, business, and tourism. The pilot project of this service monitors energy consumption, connectivity, and practicality carefully before rolling out the autonomous service across specially chosen sites in Al Ula. The position, progress, and performance of the pod are monitored by smart transport systems in the RCU called the Smart County Control Platform, while cameras can be added to enhance passenger safety and capacity planning.

Finally, the pattern of mobility, the way of city planning and transporting people and goods will experience drastic changes in the coming years. Smart transportation systems are aligned with the concept of smart cities and sustainable development

[10] Intelligent Transport, 2022. Saudi Arabia's RCU launches autonomous pod vehicle service in AlUla. URL: https://www.intelligenttransport.com/transport-news/132935/saudi-arabia-rcu-autonomous-pod-alula/ accessed on May 26, 2022.

goals (SDGs), as defined by the United Nations, considering the 17 SDGs for 2030. The increasing population will add vehicles to roads; therefore, authorities need to act to reduce traffic congestion and plan new route optimizations with a reduced ecological footprint, which are essential factors of smart transportation systems. Emerging technologies such as AI, IoT, blockchain, and big data technology will serve as the main entry points and fundamental pillars to promote new innovative solutions that will change the current paradigm of cities and their citizens. The growth in cities would translate into the need for new route optimization algorithms for vehicles and people, traffic management to reduce congestion, and more significant optimization in processes. With the integration of smart technologies and mobility, we will see several changes in the coming years, such as mobility-as-a-service (MaaS) traffic flow optimization, which will transition existing cities into smart cities. This is how smart transportation will be a part of a smart city ecosystem.

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