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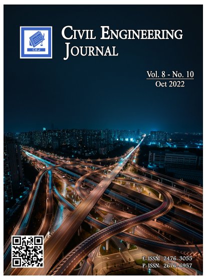

The Implementation of Smart Mobility for Smart Cities: A Case Study in Qatar

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Abstract

This paper contributes to building a systematic view of the mobility characteristics of smart cities by reviewing the lessons learned from the best practices implemented around the world. The main features of smart cities, such as smart homes, smart infrastructure, smart operations, smart services, smart utilities, smart energy, smart governance, smart lifestyle, smart business, and smart mobility in North America, Asia, and Europe are briefly reviewed. The study predominantly focuses on smart mobility features and their implications in newly built smart cities. As a case study, the modern city of Lusail located in the north of Doha, Qatar is considered. The provision of car park management and guidance, real-time traffic signal control, traffic information system, active-modes arrangement in promenade and busy urban avenues, LRT, buses, taxis, and water taxis information system, and multimodal journey planning facilities in the Lusail smart city is discussed in this study. Consequently, the implications of smart mobility features on adopting Intelligent Transportation Systems (ITS) will be studied. The study demonstrates that the implementation of Information and Communication Technologies (ICT) when supported by Intelligent Transportation Systems (ITS), could result in making the most efficient use of existing transportation infrastructure and consequently improve the safety and security, mobility, and the environment in urban areas. The findings of this study could be considered an initial step in the implementation of Mobility-as-a-Service (MaaS) in cities with advanced public transportation such as Doha, the capital of Qatar.

Keywords: Smart City; Smart Mobility; Mobility-As-A-Service (MaaS); Real-Time Transportation Data; Intelligent Transportation Systems (ITS); Lusail City.

1. Introduction

New trends towards improving sustainability and quality of life in urban areas by applying advanced technologies in cities have led to urban transformation and emerging smart cities. Smart cities are usually developed urban areas in which a system of interrelated information, communication, mechanical, and digital machinery technologies is implemented to minimize human involvement with the city services and improve the quality of services for citizens. Several studies have proposed different types of systems for smart cities [1-6]. In fact, the concept of a smart city was initially introduced in the 1990s and thereafter has evolved, particularly since 2010, given the advancement of technology such as the Internet of Things (IoT) [7]. UNE (Spanish Association for Standardization) [8] outlines the topics such as life quality, technology, economy, sustainability, ICT, and healthcare that are commonly used in the smart city context.

In recent years, rising consumer expectations, the increasing habit of sharing consumption, the explosion of multiple transportation options, emerging ICT technologies, and the rise of big data analytics have all called for an innovative, shared, and cost-effective system for urbanized areas in different domains such as infrastructure, mobility, operation, energy, services, and utilities.

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Although the importance of technology, administration, and society in the creation of efficient governance, smart mobility, and the environment has been underlined, the role of ICT-enabled mobility in developing smart cities deserves further attention. Hence, this study aims to shed light on the development of the smart city concept from the point of view of smart mobility in planned cities. In this technical paper, at the beginning, an overview of smart city features is briefly described. Smart city services and systems from different aspects, such as transportation, energy, business, infrastructure, and maintenance, are explained. This is associated with a literature review in the contexts of definition, enterprise, data availability, and sustainability for smart cities. Nonetheless, the focus of this paper is on smart mobility, its definition, and its implications for ITS requirements.

Moreover, in this paper, a case study will be investigated from the smart mobility point of view. The newly developed city of Lusail in the north of Doha, in the State of Qatar, is a planned city that is currently being developed and is located approximately 23 km to the north of the capital Doha center. Extensive features of Lusail smart mobility are presented in this paper. Carpark management, dynamic traffic signal control, the integration of active transportation modes into the city transport masterplan, a real-time comprehensive public transit information system, and multimodal transport planning will be described consequently.

This study can contribute to the state of practice and Mobility-as-a-Service (MaaS) applications to create extensive accessibility for all types of residents and visitors in planned cities via smart mobility systems. With the latest developments in transportation technologies and services, the concept of Mobility-as-a-Service spawned its way in the last decade, where consumers can purchase access to different modes and services owned and operated by several mobility services provided through a single integrated digital platform.

2. Overview of Features in Smart Cities

Although it is difficult to end up with a concise definition of a smart city, some researchers hint at the features of a smart city, which can lead to a better understanding and perception of the smart city concept. Deakin [9] defines the smart city as one that employs ICT to fulfill market demand, i.e., the citizens Furthermore, they indicate the necessity of community engagement in the process of developing a smart city. Khatoun & Zeadally [10] define a smart city as "an ultra-modern urban area that addresses the needs of businesses, institutions, and especially citizens". In this context, they make a distinction between a smart city and smart urbanism. They indicate the latter should be considered as an aspect of a smart city, including information-communication technologies.

Fundamentally, smart cities strive to apply and implement technology, real-time data, and up-to-date information to enhance the quality and functionality of their infrastructure, operations, services, and maintenance. In the case of implementing Open Data and the Internet of Things (IoT), the above-mentioned goals can be achieved by adopting the following features in a city:

- Smart Home;
- Smart Infrastructure;
- Smart Operations;
- Smart Services;
- Smart Utilities;
- Smart Energy;
- Smart Governance;
- Smart Lifestyle;
- Smart Business; and
- Smart Mobility.

There are cities in which a wide range of smart city technologies and programs have been implemented. New York City in North America, Singapore in Asia, Dubai in the Middle East, London, Vienna, Amsterdam, Barcelona, and Stockholm in Europe are just a few examples of smart cities in the world. Manville et al. [11] introduce Amsterdam, Barcelona, Copenhagen, Helsinki, Manchester, and Vienna as among the most successful cities from the point of view of smart city initiatives.

For instance, in the city of Amsterdam, more than 170 projects with the aim of alleviating traffic congestion, enhancing public safety, and saving energy were developed [12]. The city applies smart traffic management by dynamically monitoring traffic and disseminating information about actual travel times on certain roads, which enables motorists to decide on taking the optimum path en route. A report made by IESE Business School at the University of Nevara [13] compares the smart city features of London (UK), Amsterdam (the Netherlands), and Vienna (Austria) by incorporating the pillars of the economy, human capital, international projection, mobility, and transportation, environment, technology, urban planning, governance, and social cohesion in 2020.

When it comes to smart mobility, citizens live and are involved in diverse smart city ecosystems by using their smartphones and experiencing their vehicles connected to other vehicles (V2V) as well as to roadside infrastructure (V2I). Thales [14] indicates that pairing devices and data with the physical infrastructure and services of a smart city can decrease costs and improve sustainability for the city residents. By leveraging IoT, it would also be beneficial for communities since this leads to energy dispatching enhancement, streamlining waste collection, alleviating traffic congestion, and improving air quality. Peterson et al. [15] mention Enterprise Architecture Frameworks (EAF) and data availability as they believe proper utilization of data, plays a crucial role in the smart city by providing value-added services to the citizens of the smart cities.

Basically, a smart city is an advanced urbanized development in which diverse forms of electronic technologies for data collection are applied. The intention is to manage assets, resources, and services of urban areas smartly by utilizing the collected data to improve the operations across the smart city. A wide range of data i.e. from types of equipment such as PTZ cameras, sensors, count stations, telecom stations, vehicles, buildings and assets, and even citizens' smartphones needs to be collected, cleansed and its outliers filtered. The analyzed data is leveraged to screen and manage, power plants, utilities, water supply networks, waste collection, traffic, and public transportation systems.

Hence, a collaboration between various stakeholders is essential. Ahlers et al. [16] indicate the smart city concepts which are fundamentally multidisciplinary and require the collaboration of various stakeholders from different domains including residents. Lytras et al. [17] conducted a study in the context of services for smart cities by linking the perception of the end-users of a smart city with those of the industry’s awareness to find out how to accommodate their needs by building capacities. They refer to services offered in a smart city as an integrated value carrier for the incorporation of citizens’ and communities’ quality of life, happiness, and convenience based on advanced technologies and ICTs.

Visvizi and Lytras, [18] propose a discussion between academia and politicians in the context of sustainable development in urbanized areas. They recommend policies and strategies to be adopted to strengthen urban citizens' capability of taking advantage of smart city development. They also indicate the concept of “demand-responsive smart cities” which can accommodate the elementary needs of residents of both urbanized agglomeration and rural areas. Khan et al. [19] point out the existing challenges and future orientations toward multi-scale modeling in smart cities. They indicate the importance of providing a roadmap for the optimized operation of smart city systems particularly in megacities. Orejon-Sanchez et al. [20] made a comparison for smart city development in the Spanish cities of Valencia and Malaga by referring to European case studies. They concluded that no smart city models may take all of the above-mentioned pillars in their action plan. Nonetheless, they found out that the Spanish cities have predominantly made their action plan based on the axes of urban planning, social cohesion, technology implementation, and international outreach. The outcomes will be a commitment to tourism and quality of life. Mobility, health, housing, environment, and security are the main challenges that they take into consideration.

As part of the UN Sustainable Development Goals, there are several political debates in the context of cities, urban governance, and economics at a number of multilateral forums such as OECD[*] [21] as well as the UN [22].

3. Smart Mobility- Definition, and Implication for ITS Requirements

The improvement of the quality of life and business development of smart city citizens demands implementing a smart transportation system. Therefore, smart services have to be integrated into the transport system of the city enabling citizens to access emerging transportation technologies and real-time transportation information.

Dorchery et al. [23] define smart mobility as a capable system providing access to transportation services using integrated platforms. Such platforms would aggregate the community to estimate transport demand properly. Furthermore, they point out the smart infrastructure i.e. connected vehicles. Similarly, Dell’Era [24] refers to the adoption of digital technologies in smart cities with the aim of providing higher accessibility to their citizens. Salvia et al. [25] indicate sustainability and safety as two pillars to fulfill the transportation needs of smart city citizens. Moreover, they point out the integration of mobility with intelligent systems to make traffic information available for citizens.

Munhoz et al. [26] investigate the main drivers with the capability of enhancing the intelligence of urban mobility. Based on survey results containing information on the respondents’ socio-economic profile e.g. demographic data, education, and occupation in Brazil, they categorize drivers which need attention i.e. governance, technical solutions, and technological resources. In the city governance domain, they outline urban mobility plans, public policies, and environmentally friendly policies as priorities. In the technical solutions domain, they indicate multimodal integration, ride and car sharing, accessibility, walkability, and logistic solutions. In the technological solutions domain, data collection systems, cybersecurity, traffic accident detection and support system, public accessibility to real-time information, and smart traffic lights are stated as extremely important drivers in creating intelligent mobility and assigning them a priority.

[*] The Organisation for Economic Co-operation and Development

Pribyl et al. [27] portray an overview of challenges and trends within smart mobility. They indicate services, quality of life, safety, sustainability, and new technologies as key challenges of the implementation of smart mobility. Furthermore, MaaS (Mobility-as-a- Service), parking management, disaster management, urbanism and land use, city traffic management, autonomous vehicles, mobility by electric vehicles, and city logistics are referred to as trends in smart mobility by them.

Intelligent transportation systems (ITS), including features such as car parking management and smart parking guidance, intelligent speed adaptation and variable speed limit (VSL), lane control signs, dynamic route guidance systems, and public transportation priority systems, are key elements of smart mobility. Furthermore, establishing a real-time travel information system, particularly for motorists and public transport users, multimodal journey planning facilities, and an integrated ticketing and fare collection system are other essential components of a smart transportation network.

4. Case Study: Lusail City- Visions and Goals

4.1. Introduction of the Lusail City

Lusail city is a 38 square kilometer waterfront land and is being developed by Lusail Real Estate Development Company (LREDC) on behalf of Qatari Diar Real Estate Company*. As the largest single development in the State of Qatar, the Lusail City vision is to build an advanced modern sustainable city to reinforce the Qatar National Vision 2030 (SNV Qatar [28]). The city is designed with adequate infrastructure to accommodate up to almost half a million people including workers and visitors (Smart City 2021) from which more than 200,000 residents will live in Lusail's scenic surroundings. Furthermore, Lusail's design features diverse land use including four island resorts, 19 multi-purpose residential, marinas, commercial districts, luxury shopping, and leisure facilities, and a golf course community alongside several entertaining neighborhoods. The city also includes 22 hotels, with different international star ratings, which will be attractive for investors in the State of Qatar. Figure 1 exhibits the location of Lusail city together with a satellite image recently taken.

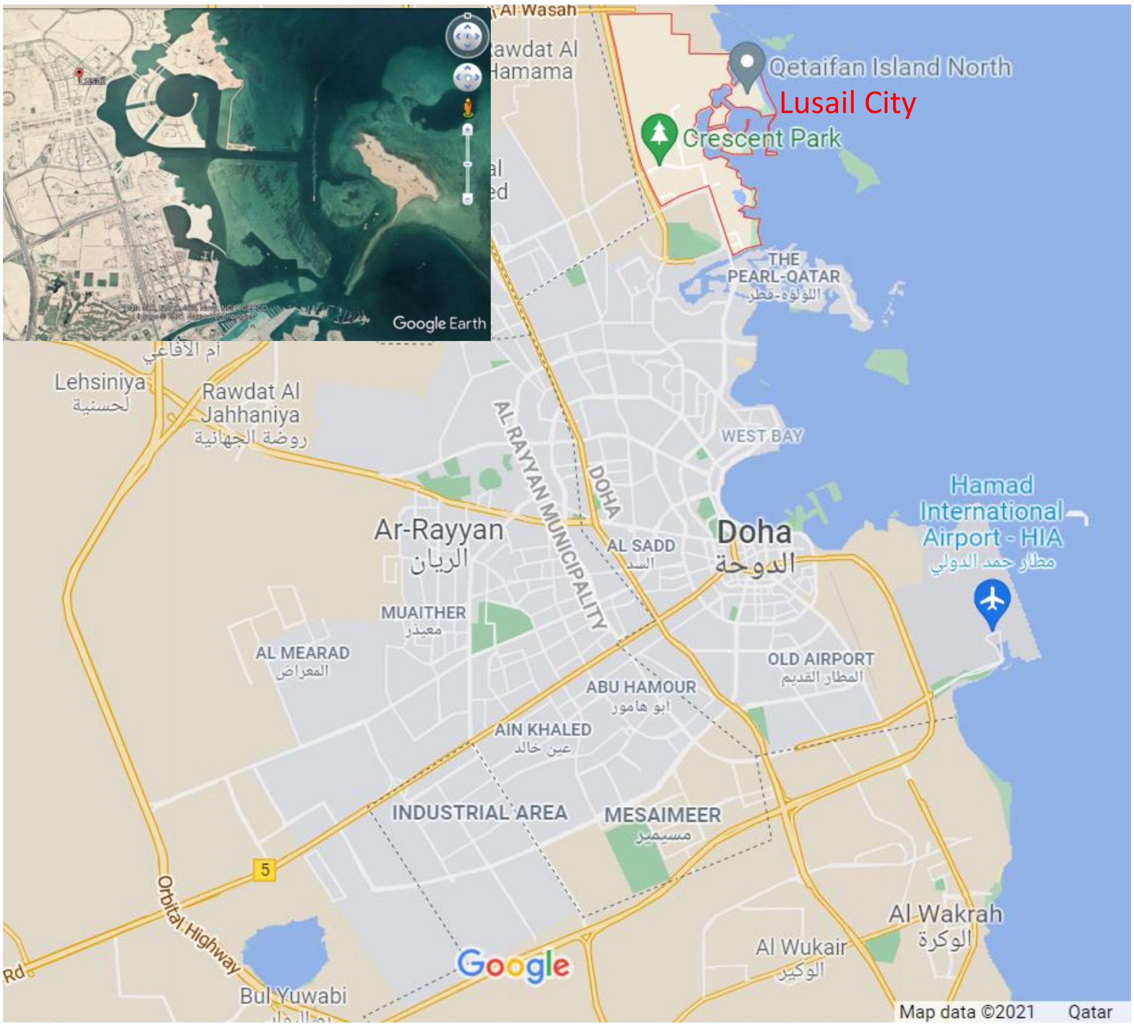

Figure 1. Lusail City in the State of Qatar together with satellite imagery

* Qatari Diar Real Estate Company was established in 2005 by the Qatar Investment Authority which is the sovereign wealth fund of the State of Qatar.

4.2. Masterplan of the Lusail City

The Lusail city masterplan has been sub-divided into 4,929 plots. The community facilities of Lusail comprise mosques, retails, schools, cultural facilities, petrol stations, medical facilities, public spaces, and special accommodation. As per the current masterplan, Lusail Boulevard District, the Commercial Waterfront District, Waterfront residential, Northern Villas Districts, Education / Hospital District, Entertainment District and island, Energy cities, Golf District, Marina District, Qetaifan Islands, Al Kharaej Towers, and Qatar Petroleum district are seen. In developing the master plan of Lusail City, a sustainable lifestyle was taken into consideration. Hence, a hierarchal scheme in which 19 major districts, smaller neighborhoods within a 5-minute walking distance, and support services such as schools, retail shops, and community facilities have been foreseen. Figure 2 exhibits the land use as well as the masterplan of Lusail City.

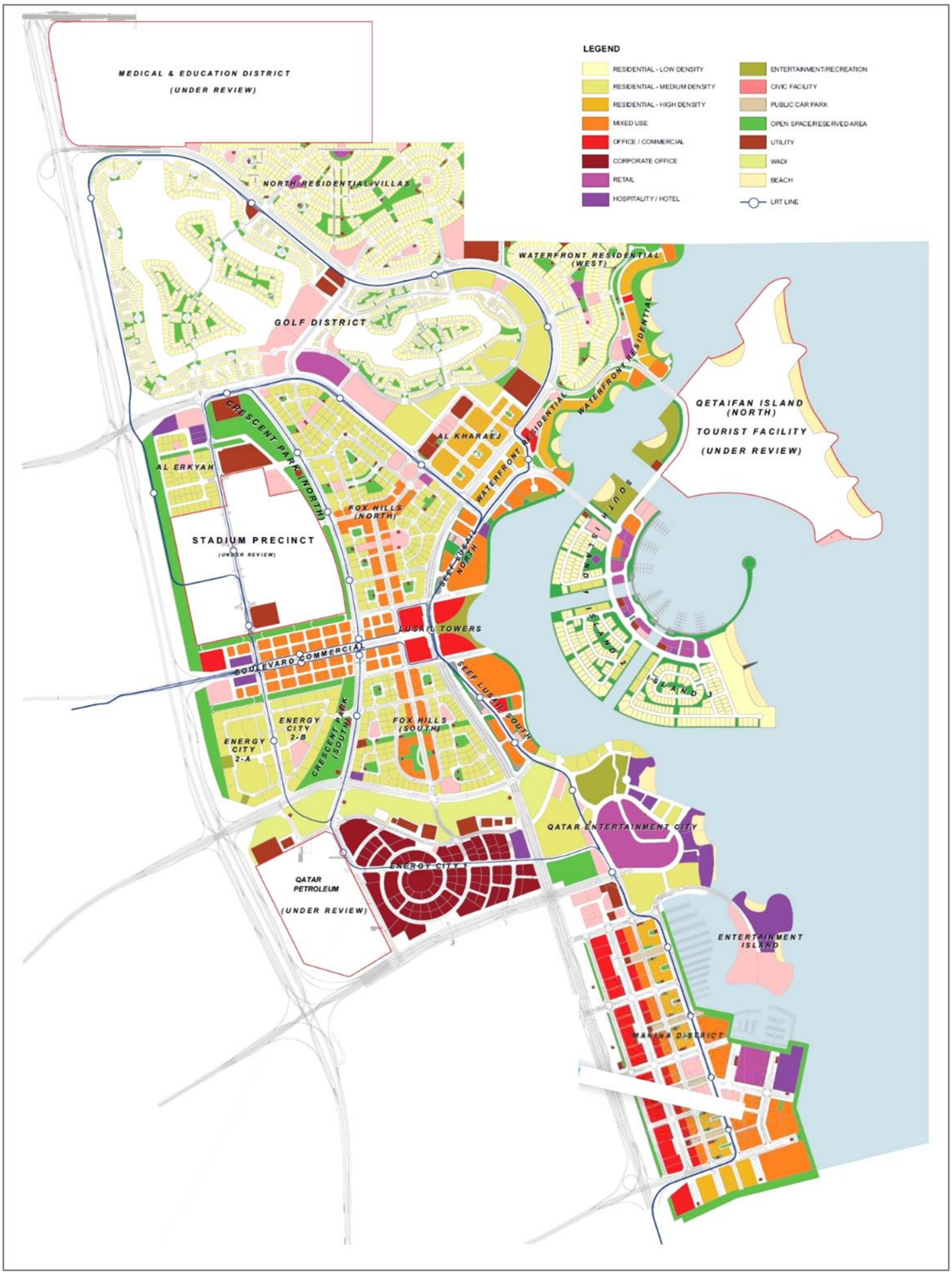

Figure 2. Lusail City Master Plan (Manarat Lusail as of 2020)

4.3. Lusail City Smart City Vision

The Lusail smart city vision originates from the idea of building a future city of Qatar by 2022 that improves Qatari citizens' and residents' lifestyles and promotes business development via implementing efficient and sustainable services. It is envisaged that Lusail becomes an iconic example of the cultural and natural qualities of the State of Qatar and the region [29].

According to Lusail city developers, Lusail envisions a smart city by creating a modern, smart, and sustainable 21st-century city in the region. Furthermore, Lusail eyes becoming a destination for Qatar visitors, residents, and businesses. In other words, a brilliant example of the high quality of a new and modern city in Qatar and the Gulf Region. To achieve the aforementioned goals, Lusail Smart City Pillars look into smart operation, smart people, smart economy, smart environment, smart governance, smart living, smart construction, and smart mobility.

The Lusail smart city vision focuses on four pillars i.e. future, people, business, and integration, which are in line with the Qatar National Vision 2030 in the contexts of (1) human development, (2) social development, (3) economic development, and (4) environmental development. For instance, the Future pillar reflects the principles stated in the Human Development of QNV 2030. Similarly, the People pillar, which looks into the enhancement of citizens' and residents' quality of life, conforms to the Social Development targeted in QNV 2030. The Business deals with the country's vision for economic development. Finally, a balance among various Lusail city elements is aligned with the Environment Development pillar of QNV 2030.

The smart services and systems to be offered in Lusail City have been defined in line with the Lusail smart city vision discussed above, i.e. Future, People, Business, and Integration. Figure 3 outlines the main domains for implementing smart services and their features in the Lusail smart city.

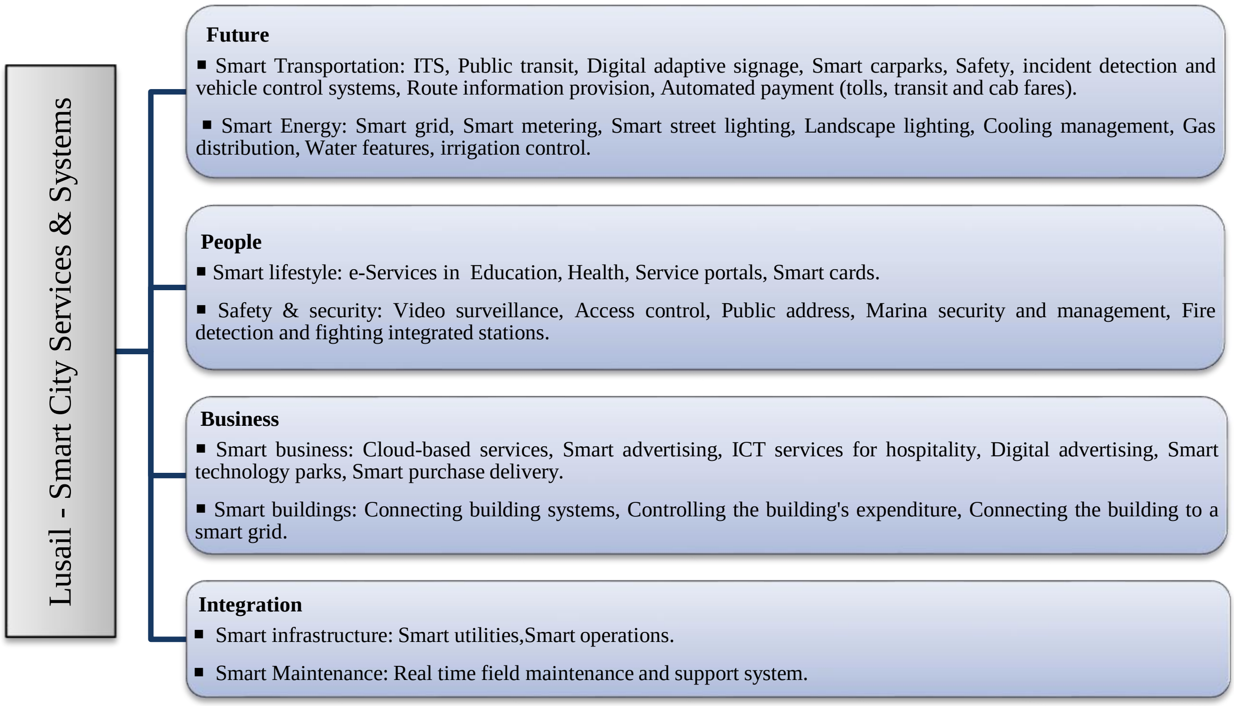

Figure 3. Flow chart of implementing smart services and their features in Lusail

5. Smart Mobility in Lusail

Intelligent transportation systems (ITS) is an essential tool in implementing smart solutions to the transportation challenges today and in the future. Given the increased investment in emerging transportation technologies and through the use of ITS, an improvement is anticipated in the quality of life and health, and well-being of all those who live, work in or visit Lusail City.

Cities are facing increasingly more challenges with the projected population growth and the resulting increased urban travel demand. Information and communication technologies (ICT) enable the development of efficient smart intelligent transport systems (ITS), and interoperable interconnected transportation solutions for multimodal transportation systems. In this regard, this study focuses on the following applicable ITS features in Lusail city:

- Car park management and guidance;
- Real-time traffic signal control;

- Traffic information system;
- Active modes arrangement in promenades and busy urban avenues;
- LRT, Buses, Taxis, and Water Taxis information system;
- Multimodal journey planning facilities.

5.1. Car Park Management and Guidance- Implication for the Lusail City

Mangiaracina et al. [30] present the smart parking concept as a strategy that incorporates road sensors utilization, VMSs, PTZ cameras, parking meter devices, as well as software for carpark management. As such, collecting real-time carpark occupancy and disseminating the information to parking users and drivers are essential for the carpark located in trip attraction points e.g. shopping malls, and recreational facilities in Lusail City A smart car park management should recognize vehicles' license plates at both entry and exit gates. Furthermore, it is important to display the available spaces and occupied spaces of a car park at the entry gate and within parking premises. This could be achieved via digital signs. Talari et al. [31] indicate advancements in technologies that are being implemented at car parks with the aim of minimizing free parking space search time and thus alleviating traffic congestion. To reduce traffic congestion within a parking premise they recommend automated verification systems of parking permits for residents and business owners.

For multi-storey car parks, parking availability needs to be displayed for each level to minimize free parking space searching time within car park facilities and reduce traffic congestion during peak hours. In order to navigate drivers to available parking spaces, a dynamic wayfinding and car park guidance system providing information on the location and availability of carpark spaces have to be implemented. Such a system should be equipped with digital signs. Figure 4 shows parking management for Hamad Bin Khalifa Medical City Multistorey Carpark.

Figure 4. A typical parking management and guidance system in MultiStorey car parks in Qatar (source: Traffic Tech Gulf)

Intelligent parking management is needed for the shopping malls in Lusail such as Lagoona mall and Place Vendôme. Place Vendôme, which is a multibillion-Qatari Riyal mixed-use project, consists of a mall that contains more than 600 retail outlets as well as 5-star hotels, and residences. It also includes an entertaining center and other leisure attractions. [32]. Place Vendôme, which is among the biggest and the most luxurious mall for shopping and entertainment in Qatar, is located along the Lusail coast and is connected directly to the sea via a canal. The seamless connection makes the open promenade a charming plaza full of eateries, and restaurants. It is anticipated that Place Vendôme attracts a significant number of visitors including tourists along with the country residents.

Moreover, the drivers of parked vehicles should be able to find the location of their vehicle by using their smartphone and digital kiosk provided at the car park premise. Finally, carpark users should be able to reserve in advance and pre-pay parking fees before embarking on their journey. Carpark fee payment on the Internet as well as via smartphone applications shall be considered. By securing a parking space at a particular car park facility before arriving at the premise, a parking pre-reservation system can lead to better confidence for car park users.

5.2. Real-time Traffic Signal Control- Implication for the Lusail City

As a feature of an intelligent transportation system, a real-time traffic signal control system automatically monitors traffic signals cycle and their phases and consequently optimizes the traffic stream. This is achieved by processing data, which are generated by vehicle detection system equipment such as magnetometers, inductive loops, and PTZ cameras. Implementing adaptive traffic control (ATC) could lead to integration across modes, such as road and public transportation systems. Onboard transponders for public buses communicating to signals provide priority for buses and LRT, paving mass transit movement, with a reduction in impacts on the environment.

Bao et al. [33] undertook an experimental study consisting of scenarios e.g. diverse traffic compositions and free-flow, synchronized flow, and traffic jams. The study results demonstrated the benefits of magnetic technology to detect and count vehicular traffic. The advantages were indicated by the low-cost and quick installation/replacement and maintenance, energy efficiency, the impact of weather conditions, wireless communication, as well as all-day operation. More importantly, they indicate the capability of magnetic technology in multi-functional traffic data detection.

The magnetometer is a cost-efficient vehicle detector, particularly for signalized junctions. The magnetometer constitutes small wireless sensor nodes (SN) with the purpose of transmitting detections to a roadside receiver/transmitter so-called an “Access Point” (AP). A typical magnetometer detection system consists of a magnetic sensor to be embedded in a ten-centimeter diameter core drilled into the pavement, a microprocessor, and a radio. They are battery-operated. The Access Point is approximately a 7.5 cm by 12.7 cm by 2.5 cm box, which may be placed inside a cabinet. Upon operation, it receives signals from sensor nodes. The sensor nodes process real-time information and send it to Access Point. Figure 5 shows a typical magnetometer traffic sensor.

Figure 5. The M100 wireless vehicle detection system (Magnetometer)

5.3. Traffic information system- Implication for the Lusail City

Optimizing traffic streams is achievable if real-time traffic information is adequately provided. Traffic flow conditions, weather information, information about detours, diversions, construction zones, accidents, and incidents have to be disseminated to drivers. Mtoi et al. [34] and Min et al. [35] indicate to new technologies, such as cameras with bright long-range night vision, drones, and also sensors enhance the system’s ability to identify incidents and associated severity which ultimately leads to aiding the victim’s life and alleviating traffic conditions to normalcy.

Digital signage and variable message signs (VMSs) should be deployed to provide the above-mentioned information on a real-time basis. For motorists, real-time information could reduce vehicle delays, alleviate traffic congestion, improve mobility and potentially enhance traffic safety by reducing incidents. The ultimate outcome would be less energy waste and a carbon cut caused by congestion. This helps reduce the impact on the environment by reducing consumption and emissions, regardless of choice.

Advancements in over-roadway sensor design have been promising for road transport authorities to implement sensor technologies such as cameras interfaced with image processing systems and laser radars. Cameras have the potential to be used for traffic data collection in temporary as well as permanent locations. This is a non-intrusive data collection technology based on recorded video (historical) as well as real-time. Transportation authorities may leverage existing PTZ or mountable cameras for speed and vehicle counts. The PTZ cameras can be installed citywide and utilized for traffic data collection i.e. lane occupancy rates, an average rate of speed, and monitoring situations including incidents monitoring and detection, construction zones monitoring, traffic violations such as wrong-way drivers, and stopped/parked vehicles, debris in the roadway for more than a specified period. It is also beneficial for problematic areas requiring quantified data points i.e. pinch-points, pedestrians on the road, traffic flow increases and decreases, and traffic congestion. The idea is to automate highway traffic monitoring for transport authorities such as DOTs and TMCs by utilizing existing PTZ cameras as highway sensors. Figure 6 shows a prototype traffic intelligence from video software utilizing traffic data recorded by PTZ cameras.

Figure 6. Traffic Intelligence from Video (Image Source: Traffic Vision)

As a practical case, the MTO collected summer traffic data prior to the 2015 PanAmerican Games for benchmarking Greater Toronto Area traffic status using video-based technology [36] in addition to other techniques such as loop detectors, Bluetooth sensors, GPS Units, and screen line count stations. Compared to traditional methods of data collection, utilizing traffic monitoring cameras as a non-intrusive technique demonstrated a plausible and efficient solution, considering the time constraints and the ability to mount cameras on existing structures.

5.4. Active Modes and Crowd Arrangement in Promenade and Busy Urban Avenues- Implications for the Lusail City

Kamel [37] mentions infrastructure projects for newly developed areas that should fulfill criteria such as public transport facility, safety, accessibility, and convenient mobility. He also emphasizes walking as the most simple and sustainable transportation mode. Therefore, the implementation of intelligent mobility systems could secure an active modes friendly environment for smart cities [38].

People counting, which is the process of counting the number of people who enter and leave areas such as shopping centers, stadiums, promenades, parks, resorts, etc., is an essential management element for walkability in smart cities. As an advantage, shopping centers and store owners can benefit from a better understanding and uptake of the popularity of their business and for example the retail outcome of a store. Moreover, it gives an impression about the customer requirement. Advanced technologies such as high-definition cameras together with their proprietary analytical software tools have enabled organizations, stores, and mall management to maintain and uphold the security and safety of their premises. Furthermore, by implementing innovative solutions crowd management has become plausible for mall and promenade operators. In smart cities such as Lusail City, crowd-management can be achieved by implementing advanced technologies such as RFID (Radio-frequency identification), Overhead sensors, HD surveillance cameras as well as analytical software.

When it comes to outdoor activities such as biking, scootering, and jogging, the placement and, accordingly, installation of the stations on urban corridors, including cycle tracks and paths, could provide real-time data as well as historical and data analytics for active modes, i.e., cyclists and pedestrians. A combination of infrared sensors and sensitive inductive loops may arrange such counting stations. This could be an ideal solution for counting pedestrians and cyclists on shared paths and is obviously essential in smart cities, where data provision plays an important role in creating smart mobility. The stations may be battery-operated and independent of supplying power outlets, and function in all types of weather conditions. Several cities around the world are using this type of technology. For example, in Arlington, Virginia, fifteen pedestrian and cyclist counting stations monitor pedestrians and cyclists on a network of trails. Other examples are Northampton, Seattle, St. Louis, San Diego, Austin, Moscow, Edmonton, Houston, Montreal, Calgary, Vancouver, Izmir, and Bordeaux. The counts (historical as well as real-time data) can be displayed on digital signs for public awareness. For example, the city of Izmir in Turkey has motivated its residents for several years to have an active lifestyle by encouraging them to cycle and walk. The city has installed digital signs to display count data in real-time. Besides the real-time data, dynamic information is displayed to the public and those who pass by. This includes the daily weather and messages encouraging active transportation. The signs are pieces of street furniture and are visible at night. The historical counts, such as cumulative daily, monthly, and yearly counts, can be exhibited on the signs as well for public awareness of future decisions based on data-driven bicycle network and pedestrian analyses.

Thermal sensors technology resolved the aforementioned shortcoming. Figure 7 shows a typical CITX 3D thermal sensor for counting crowds with a high level of accuracy. The detection range can reach up to 20m, while it is non-intrusive, anonymously collecting and covering multiple lanes. As practical case studies, CITIX cameras are used to monitor downtown activity in open promenades in cities such as *Victoria BC, Halifax NS, Calgary AB, and Philadelphia in the United States* [39]. The cameras function based on detecting the heat emitted by people moving through the detection area below the camera's coverage. According to its vendor (Eco-Counter a French-based company), the unparalleled precision of the system makes it ideal for counting pedestrians on promenades and even open shopping malls and streets. Furthermore, there will be no privacy breach, as the proprietary cameras do not use images to detect folks.

In Lusail City there is a large open promenade named Marina, which attracts the crowd and thus requires crowd management and emergency evacuation arrangements. Lusail Marina is an accessible promenade that is 6 meters wide main pier. It is a long boardwalk built over an area of larger than 142 thousand sq m offering services such as parks and shops. The Lusail Marina promenade has been suggested as an appropriate and safe place for walking, jogging, and cycling according to Trip Advisor users (2020-2021) [40]. It is an extension of the innovative Lusail City which can host 93 yachts up to 40 meters. The Lusail Marina provides 5 covered floating lounge areas (shaded) which makes it convenient for its visitors by reducing temperatures.

The Lusail Marina promenade is recommended as a convenient place for night hangouts with family, friends, or couples. It is a great place for walking or jogging as its visitors can also watch yachting. Visitors can enjoy many restaurants and kiosks for fast food, ice cream, and beverages. LightMe Lusail Festival which was held just before the start of the Covid 19 pandemic in Jan 2020 from 5:30 pm to 11:30 pm at Eastern and South Promenade of Lusail Marina, was a four-day celebration of light works, featured 2 kilometers of art light Installations, LML Cars and Food & Beverages [41].

Figure 7. Citix 3D counter (Eco-Counter-Image: https://www.eco-compteur.com/)

Figure 8. LightMe Lusail Festival along Lusail Marina Promenade (2020), Image source: Peninsula Qatar

For the case of Marina, the implementation of thermal systems seems to be a perfect choice for crowd counting. Thermal imaging sensors generate infrared images of body heat. Their functionality is similar to passive infrared counters. The main difference is the thermal imaging sensors are normally mounted above the detection area. The overhead placement enables thermal sensors to observe and screen the moving objects besides counting. By implementing the 3D wide-angle optical sensor technology in the surveillance cameras, greater accuracy than traditional video analysis is achievable. The technology allows for automatically counting and classifying pedestrians, cyclists, and vehicles simultaneously by collecting imageries from mountable cameras. This is particularly beneficial for busy streets and promenades when a platoon of pedestrian groups forms. Counting the crowd by the Infrared sensors (active and passive) results in a considerable degree of inaccuracy due to side-by-side walking. For instance, a study undertaken by UC Berkeley in the city of Berkeley, California showed the passive infra-red device systematically undercount pedestrians, resulting in an overall error rate of between -9% and -19% (Greene-Roesel et al. [42]). The counters were installed in three sites (represent varying pedestrian flows, ranging between 56 and 654 pedestrians per hour) for four-hour periods (12:00 PM to 4:00 PM) on 3 consecutive weekdays.

5.5. LRT, Buses, Taxis Information System- Implication for the Lusail City

Advanced mobility technologies should be involved in several transportation planning phases including the identification of redundant bus stops, the provision of real-time bus routes and schedules, and dynamic bus operation adjustments [43]. The authors highlight the necessity for appraising smart mobility plans and route optimization. To increase public transit patronage, the provision of real-time information plays an important role. The information about actual arrival and departure time at terminals and main stations, present vehicle location, anticipated arrival time at the next stops, and information on transfer to other service lines at main stops could enhance the quality of public transit services. Global Positioning Systems (GPS) and automatic vehicle location (AVL) are facilitating the provision of real-time information in public transportation.

Caulfield & O'Mahony [44] highlight the role of passenger information display systems on buses and stops in improving the service quality perceived by passengers. They also point out passengers may take advantage of real-time public transport information displayed at stations, stops, and also on transit modes. In Lusail, way-out guide screens are provided for metro and LRT users at Legtafiya, and Lusail QNB stations for metro users. Those screens provide guidance and navigate metro riders to find the closest exit gate (e.g. gate 1, gate 2, gate 3, etc.) depending on their destination.

For the case of Lusail, light rail transit and public bus riders have access to a real-time schedule, estimated arrival time routes, and timetables. The aforementioned information is disseminated to travelers via diverse methods e.g. variable message signs placed at bus stops and terminals, smartphone apps, telephone, and the internet. Furthermore, on-demand arrival time information has to be provided for the taxi, and water taxi users in Lusail City incl. Qetifan Island. The real-time locations of the buses and LRT cars are detected and monitored via onboard units at the Lusail metro station, and Leqtafia metro/LRT station. The provision of accurate and convenient real-time information for public transportation will eventually lead to a growth in transit ridership and will consequently increase the revenue of transit operators in Lusail and Doha. Moreover, it may promote and strengthen the role of public transportation as viable transportation means for the passenger car for Lusail city citizens and visitors. Figure 9 illustrates the connection between the Doha metro and the Lusail tram system toward Energy City. Lusail will have an extensive transit network.

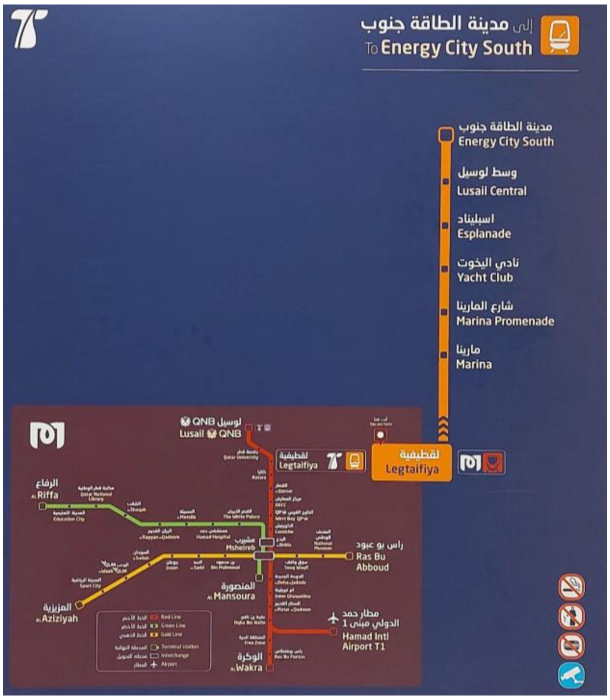

Figure 9. Railbound public transit network connection (metro and tram) in Lusail

The tram network, which consists of four lines distinguished by color (Orange, Turquoise, Pink, and Purple) serving 25 stations, is interconnected to the Doha Metro Red Line at the Legtaifiya and Lusail metro stations (Figure 10).

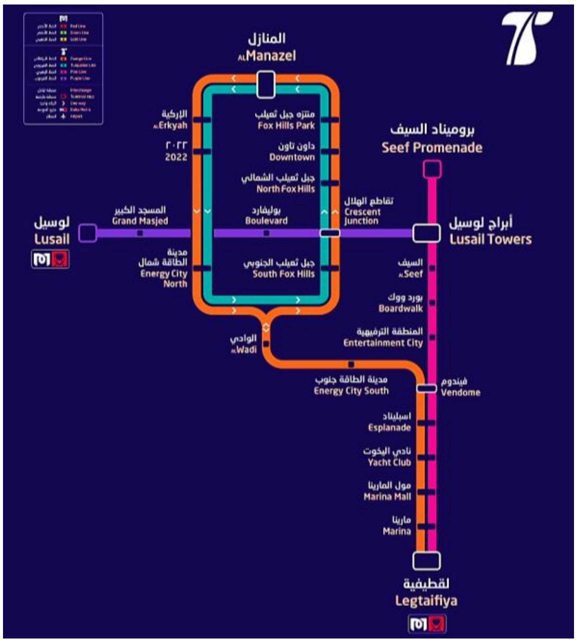

Figure 10. The tram network in Lusail City- Source: Qatar Rail

5.6. A hybrid system of Personal Rapid Transit and Water Taxi

Integrated Demand Responsive modes can contribute to the modal shift to public transport by creating a feeder network to mass transit and providing last-mile connectivity for users. They can also alleviate the spatial inefficiencies of private individual motorized transport by providing ubiquitous check-in/check-out user access.

The implementation of demand-responsive modes of transportation providing a direct link between Lusail City islands and its mainland and connecting the residential complexes to commercial and entrainment districts would be a great choice of public transportation for visitors as well as residents of Lusail City. A hybrid network of Personal Rapid Transit (PRT) and water taxis as an emerging on-demand, quality, quick with minimum waiting time, and convenient public transportation could be an appropriate mobility option for Lusail (Figure 11).

Figure 11. A proposal for implementing a hybrid demand-responsive PRT+WaterTaxi transportation in Lusail City

PRT is a state-of-the-art form of the public transportation system that uses small automated electric podcars to provide a taxi-like service for individuals or small groups of travelers and to offer demand-responsive feeder and shuttle services connecting facilities, such as parking lots, with major transport terminals and other facilities, such as shopping or exhibition centers. Passengers can ideally board a pod almost instantly upon arriving at a station and can take relatively direct routes to their destination without having to stop [45]. Hence, the main advantage of PRT is its demand-responsive, safety and reliability, and short waiting time characteristics, which are especially relevant during off-peak hours. PRT can be a 24-hour service that can be summoned during off-peak hours, which eliminates the need of running empty services during night and off-peak hours. The other important advantages of operating a PRT system are as follows [46-48].

- Low operating costs, as drivers are not required;
- Pollution reduction as vehicles are automated, electric, and quiet;
- Direct origin to destination stop services, i.e. no intermediate stops;
- Simple, accessible services similar to an elevator;
- Congestion-free transport, due to an exclusive right of way;
- Substantial modal shift from single-occupant vehicles and thus a potential reduction in parking; and,
- Reliability, because modern technologies using sensors and onboard diagnostics provide early warnings of possible problems in a PRT system.

The water taxi is a demand-responsive taxi like watercraft offering public or private transport, usually, an urbanized environment. Water Taxi service may be direct or alternatively scheduled by offering multiple stops, operating likewise public buses, or demand responsive to many locations like a taxi.

From Public transportation point of view, Hossain and Chowdhury [49] evaluated the service quality of Hatirjheel water taxi in Dhaka and provided recommendations for further developments. Their findings were based on field observations and passenger survey data. Dhaka city launched a water taxi service with several routes on Hatirjheel Lake located at the Dhaka center to accommodate high public transportation demand in Dhaka CBD. The Hatirjheel Lake connects central business districts including offices, retail and commercial sectors.

In February 2017 Water Taxi launched on Yas Island in Abu Dhabi, United Arab Emirates [50]. The demand-responsive service, which is operated by Jalboot, offers transport around Yas Marina, Al Bandar and Al Muneera. The Water Taxi is also connected with the high-speed ferry service being operated around Abu Dhabi city, stopping at Yas Marina, Abu Dhabi Mall, Etihad Towers and Fairmont Hotel. Improving accessibility and connectivity among major attractions and locations around Abu Dhabi Yas Island, and offering the diversified feeder transport means to provide last-mile connectivity for the Yas Island are the main intentions of the implementation of Water Taxi with the purpose of creating a unique and exciting experience for residents and visitors to the island.

In Qatar, The Pearl-Qatar operates Doha's first water taxi service [51]. Both Visitors and Residents of The Pearl-Qatar are able to ride the water taxi and commute around the Island. Operating from Porto Arabia, the service runs from 8:00 am to 12:00 a.m. every day. According to the Pearl Qatar the service is a popular means of transportation amongst residents and visitors to get speedily around the marina. The shuttle can take up to 10 guests. The fare is QAR25 per person for a single round trip. The round trip takes around 20-25 minutes. It is believed that Water Taxi can promote Sea tourism.

5.7. Multimodal Journey Planning Facilities- Implication for the Lusail City

Groth [52] emphasizes smart mobility as a key factor to encourage people to switch from "ownership" to "usership" and the concept of Mobility-as-a-Service (MaaS). The disruptive technology that promotes asset sharing (e.g., Collaborative Transportation Management) also revolutionizes the transportation system by blurring the traditional division between private and public transport, shifting from an ownership model to Mobility as a Service (MaaS). Through the interconnection of all types of transportation services, sustainability will improve consequently.

Basically, trip planning is a crucial requirement for the implementation of an attractive, and well-organized multimodal mobility system. Rao and Prasad [53] highlight that multimodal journey planning facilities have the capability of optimizing people and freight transportation. This becomes even bolder when it comes to the smart city concept.

The intention of trip planning facilities is to assist travelers and particularly visitors in finding an efficient, safe, affordable, and convenient way of travel using available modes. An efficient multimodal trip planner should be capable to combine public transport (scheduled-based, demand-responsive, and micro-mobility modes) with private transportation modes, mainly passenger cars. The system should be well-integrated and perform on a real-time basis and should provide convenient last-mile connectivity. Ridesharing is related to the use of bicycles, scooters, and car-sharing systems. Ceruti et al. [54] highlight the emerging trends in transport modes sharing systems globally while their flexibility has made them an attractive choice for non-passenger car users.

Over the last decade, the Qatar Ministry of Transport and Communications (MOTC) has developed various strategies to provide answers to current and future mobility challenges. In the Qatar National Vision 2030 launched in 2008, a development plan on delivering an overhaul of current bus services having full integration with other multimodal transport systems was proposed. The ministry has further committed to promoting digital inclusion and increasing ICT access rates among various sectors of Qatari society, in support of, among other things, priority Action A of the ministry, thus supporting national economic and social development, providing a seamless travel experience, and, in turn, realizing the National Vision 2030. This commitment recognizes the need for innovative, multimodal networks and information integrating platforms in order to create favorable conditions for more efficiently, conveniently, and affordably organized transport patterns, locally as well as nationwide, e.g., through an effective Mobility as a Service paradigm. This ambition will require numerous stakeholders, from mobility consumers to providers, as well as developers of new mobility concepts and information technology, to work together in open collaboration towards novel answers to these challenges.

In this regard and to achieve efficient multi-modal journey planning, different transport modes have to be combined and constitute a multimodal transport system in Lusail City. Besides a mobile application, Karwa, the taxi operator in Doha, recently began offering multimodal transportation services to Doha residents using digital boards physically. In coordination with Qatar Rail, the company has installed digital reservation boards at metro stations' entrance/exit platforms to book taxis. Metro riders can simply book a taxi and get a 20% discount as well. Figures 12 and 13 portray multimodal travel reservation facilities brought by Karwa, Mowasalat for metro users in Doha.

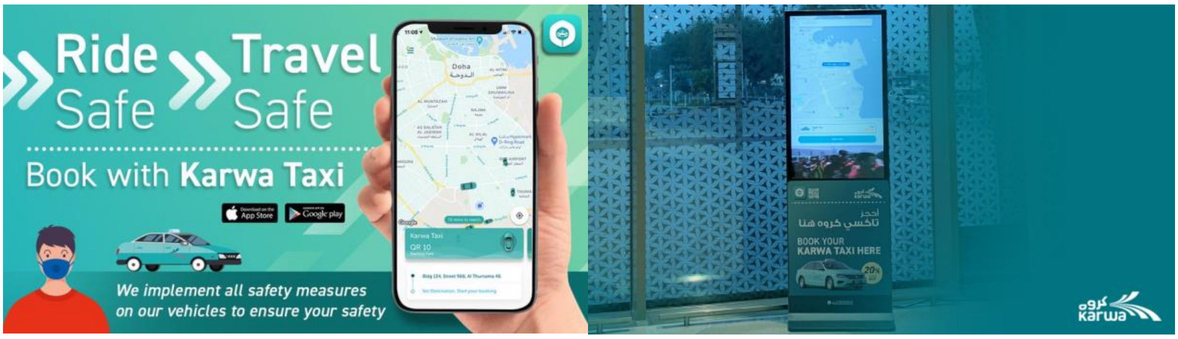

Figure 12. Multimodal transportation facilities offered by Mowasalat in Doha (Image source: Karwa)

Figure 13. Metrolink transportation for last mile connectivity (*https://thepeninsulaqatar.com/*)

Similarly, Qatar Rail has established feeder shuttle services that provide access/egress connectivity to Qatar Rail customers within a 2 and 5-kilometer radius of the Doha Metro stations. The services are free of charge, and a fleet of metrolink-branded buses and vans operates on 15 routes, including 2 routes in Lusail and Pearl Qatar [55] (Figure 14). Riders can simply log in to the "Plan My Journey" section of the Qatar Rail website and mobile application. On the map, the rider needs to zoom into a relevant station to see the associated metrolink routes and stops. Furthermore, the Karwa Bus App enables its users to track the routes and buses in real-time.

Figure 14. Overview of the urban railbound transit facilities in Doha (Image source: dohaguides.com)

E-scooters and bikes for rent could provide micromobility for the riders of metro and tram lines. The integration between these modes could boost transit's ridership. The use of e-scooters in Qatar has increased in recent years, mainly because of the mobile app-based e-scooter sharing schemes introduced by private companies, e.g., Loop Mobility, Falcon Ride, TIER Mobility, Spin. Being an environmentally friendly short-distance transport mode, e-scooters can bring about numerous social, economic, and environmental benefits, such as the reduction of congestion by reducing the number of single-occupancy vehicles for non-essential short trips, the reduction of greenhouse emissions, the encouragement of an active lifestyle, and therefore the improvement of health and social connections in urban environments. Figure 15 depicts the arrangement for micromobility and the provision of last-mile connectivity between the metro station and the Lagoona mall in Lusail City.

Figure 15. Micromobility arrangement in Lusail- Leghtifiya metro and tram station

6. Conclusions

This technical paper investigated the characteristics of smart cities, particularly from the mobility aspect and its implications for ICT-enabled transportation and the implementation of intelligent transportation systems (ITS). The study demonstrated the role of (1) car park management such as wayfinding facilities, smart navigation, pre-paid fee facilities, and pre-reservation parking systems, (2) real-time traffic signal control, including an automated monitoring system, (3) traffic information systems, i.e., dissemination of real-time information to road users, (4) active modes and crowd management, (5) public transit real-time information at stops and transit modes, and (6) multimodal journey planning facilities in developing smart cities. The aforementioned features were further studied for the newly built city of Lusail in Qatar. The paper also highlighted the role of intelligent transportation systems (ITS) to facilitate smart mobility. Wayfinding and smart navigation, smart payment systems, traffic signal optimization, and dynamic journey planning can be achieved by utilizing ICT.

In the Qatar National Vision 2030 launched in 2010, a development plan on delivering an overhaul of current bus services with full integration with other multi-modal transport systems was proposed to support national economic and social development, provide a seamless travel experience, and in turn realize the National Vision 2030. This commitment recognizes the need for innovative, multi-modal networks and information-integrating platforms to create favorable conditions for more efficiently, conveniently, and affordably organized transport patterns, locally and nationwide, e.g., through an effective MaaS paradigm. The MaaS platform may enhance accessibility to transportation by enabling people to travel affordably, predominantly by forming a multimodal transportation system, such as public Transport Services (bus, tram, metro), shared bicycles, shared electric scooters, shared cars, ride-hailing modes (e.g., Uber), and taxis under a single platform.

This study can be further enhanced by identifying Transport Demand Management (TDM) practices for smart cities. The objective of TDM strategies is to avoid the negative consequences of congestion and promote efficiency within the transportation system by encouraging either a behavioral change shift away from private vehicle usage to more sustainable transport modes, a change of departure time, or the removal of the requirement to travel. As the way forward, this study will be extended to investigate TDM strategies, i.e., cost-based strategies, supply-based strategies, and supportive strategies, which would result in increasing travel options, providing incentives and information to encourage and help individuals modify their travel behavior, and/or reducing their physical needs to travel. TDM would ultimately reduce Vehicle Kilometers Travelled (VKT) through a transportation-efficient land use plan.

The findings of this study could be considered the first step toward the implementation of Mobility-as-a-Service (MaaS) in Qatar given the existing ICT-enabled mobility features, telecommunications infrastructure, and intelligent transportation systems (ITS) in the country.

7. Declarations

7.1. Data Availability Statement

Data sharing is not applicable to this article.

7.2. Funding

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7.4. Conflicts of Interest

The author declares no conflict of interest.

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