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Moving Forward: An Assessment of Qatar's Public Transportation System and Recommendations for Future Development

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Abstract

Qatar, like many other quickly rising countries, is confronted with enormous issues in controlling population expansion and transportation congestion. Increased population has resulted in greater transportation demand, leading to increased traffic, poorer quality of life, and a rising need for sustainable transportation solutions. The purpose of this study is to investigate into the Qatar's existing transportation network and to identify potential improvements and sustainable strategies for future transportation development in the country, to analyze the current transportation system, including public transportation, private vehicles, and non-motorized transportation modes, and assess their strengths and weaknesses. By identifying the challenges and opportunities, this study seeks to provide recommendations for a more efficient, environmentally-friendly, and sustainable transportation system in Qatar.

Furthermore, as alternatives to personal automobiles, the government with its transportation Master Plan for 2050 is investigating future forms of transportation such as BRT (Bus Rapid Transit), water taxis, park and ride systems, and improving cycling network. However, to successfully handle transportation difficulties, diverse modes of transportation must be integrated, and a balanced transportation system must be implemented. To promote sustainability and enhance the entire transportation system, the QABM (Qatar Activity Based Model) developed by ministry of Transportation, State of Qatar considers a variety of elements such as travel behavior, transit alternatives, and land use plans. The concept aspires to establish a balanced and integrated transportation system that fulfills the demands of Qatar's rising population, minimizes congestion, and improves inhabitants' overall quality of life.

To establish a more livable and sustainable future for the population of Qatar, it is imperative to not only strengthen the transportation infrastructure, but also to minimize or stabilize the usage of private vehicles and enhance public transit. This can be achieved through the adoption of improved land use techniques, such as promoting compact and mixed-use development, as well as implementing the author's recommended strategies. The country's efforts towards achieving a more sustainable transportation system, which includes encouraging public transit, exploring alternative forms of transportation, and studying sustainable transportation options, will play a critical role in achieving this goal.

Keywords: Sustainable transport system, QABM (Qatar Activity Based Model).

Abstract in italiano

Il Qatar, come molti altri paesi in rapida crescita, deve affrontare enormi problemi nel controllare l'espansione della popolazione e la congestione dei trasporti. L'aumento della popolazione ha portato a una maggiore domanda di trasporto, portando a un aumento del traffico, a una qualità della vita peggiore e a una crescente necessità di soluzioni di trasporto sostenibili. Lo scopo di questo studio è indagare la rete di trasporto esistente e identificare potenziali miglioramenti e strategie sostenibili per il futuro sviluppo dei trasporti nel paese. Per fa ciò, è stato analizzato l'attuale sistema di trasporto, compresi i trasporti pubblici, i veicoli privati e le modalità di trasporto non motorizzate valutando i loro punti di forza e di debolezza. Identificando le sfide e le opportunità, questo studio cerca di fornire raccomandazioni per un sistema di trasporto più efficiente, rispettoso dell'ambiente e sostenibile in Qatar.

Inoltre, come alternative alle automobili private, il governo con il suo piano generale dei trasporti per il 2050 sta studiando forme di trasporto future come BRT (Bus Rapid Transit), taxi d'acqua, sistemi di parcheggio e corsa e miglioramento della rete ciclabile. Tuttavia, per gestire con successo le difficoltà di trasporto, è necessario integrare diverse modalità di trasporto e implementare un sistema di trasporto equilibrato. Per promuovere la sostenibilità e migliorare l'intero sistema di trasporto, il modello sviluppato dal ministero dei Trasporti del Qatar (QABM - Qatar Activity Based Model), considera una varietà di elementi come il comportamento di viaggio, le alternative di transito e i piani di utilizzo del territorio. Il concetto aspira a stabilire un sistema di trasporto equilibrato e integrato che soddisfi le esigenze della crescente popolazione del Qatar, riduca al minimo la congestione e migliori la qualità generale della vita degli abitanti.

Per stabilire un futuro più vivibile e sostenibile per la popolazione del Qatar, è importante non solo rafforzare le infrastrutture di trasporto, ma anche ridurre al minimo o stabilizzare l'uso dei veicoli privati e migliorare il trasporto pubblico. Ciò può essere ottenuto attraverso l'adozione di migliori tecniche di utilizzo del suolo, come la promozione di uno sviluppo compatto e ad uso misto. Gli sforzi del paese verso il raggiungimento di un sistema di trasporto più sostenibile che includa l'incoraggiamento all'uso del trasporto pubblico, l'esplorazione di forme alternative di trasporto e lo studio di opzioni di trasporto sostenibili, giocheranno un ruolo fondamentale nel raggiungimento di questo obiettivo.

Parole chiave: Sistema di trasporto sostenibile, QABM (Qatar Activity Based Model).

Contents

Introduction

In recent years, the State of Qatar has witnessed tremendous economic growth, and the country's transportation infrastructure has played an important part in this expansion. Qatar's aviation and seaports have been significant drivers of the country's economic growth, and the government is aiming to enhance and extend these facilities to support the country's continuing expansion. The creation of an integrated transportation network is one of the primary initiatives performed to support the expansion of Qatar's transportation infrastructure. This network is intended to boost internal connection as well as connect Qatar to other nations in the area. In preparation for the 2022 FIFA World Cup, which held in Qatar, the government has stepped up efforts to improve the country's transportation infrastructure. This includes the creation of a comprehensive and contemporary transportation system that is safe, efficient, and environmentally friendly.

Another significant project being constructed in Qatar is a large-scale rail project aimed at connecting the Gulf Cooperation Council (GCC) countries. The GCC Railway Authority is developing this enormous project, which is projected to have a substantial influence on the region's transportation environment. In addition to these measures, the Qatari government has prioritized sustainability in the transportation industry as part of its Qatar National Vision 2030. (QNV). The QNV is a long-term development plan that describes Qatar's economic, social, and environmental goals and policies, and it includes various transportation initiatives. These programs attempt to provide environmentally friendly infrastructure and services that will help the country's long-term economic growth.

The transportation industry in Qatar is projected to continue playing an important part in the country's economic growth, and the government is trying to establish a modern and efficient transportation system that is sustainable and promotes the country's progress. In the coming chapters, Evolution of transportation in Qatar is highlighted, followed with the transportation trends in the Middle East and the rest of the world. Chapter 1 of the study delves into the evolution of public transportation in Qatar, while Chapter 2 provides a literature review to support the research. The following two chapters, Chapter 3 and 4, examine the reformed and sustainable transportation systems across the world and highlight trends in the Middle East. Finally, Chapter 5 showcases the state-of-the-art transportation system in Qatar. Chapter 6 and 7 will deep dive into Qatar's future for transportation and its Activity based model formulated for the country's seamless transport integration.

Statement of the Problem

The unprecedented economic and population growth in Qatar over recent years has posed challenges to service providers in terms of maintaining economic prosperity and high living standards. Since 2008 the population of Qatar has grown from 1.7 million to more than 2.7 million by 2017, mostly in Greater Doha. New development areas are emerging outside Doha, such as Lusail City, Al Wakra City, and Al Khor City, as well as new Economic and Logistic Zones. Over the same period, economic growth has been continuous. More recently Gross Domestic Product (GDP) has grown at around 3% per year, and is anticipated to rise further, retaining Qatar's first place in the world ranking for highest GDP per Capita (World Bank). To sustain both the population and economic growth, the State of Qatar is investing in the improvement of the transportation system. It is investing in the construction of a network of expressways and freeways, to improve the existing road network, a country-wide rail network (freight and passenger), and a comprehensive public transport system that includes metro, Light Rail Transit (LRT), and bus network enhancements.

Rapid and unplanned population growth in major cities and developing countries is a major concern when it comes to transportation as it leads to increased demand for mobility. This can be seen in the rising trend of private car ownership in Doha and the most of Middle-East as more and more people are able to afford them. As urban areas continue to expand, it is becoming increasingly important for effective city planning to address these issues. Effective city planning can help to address the challenges of increased population density, high energy consumption, and the demands of urban environments. This can include measures such as promoting sustainable modes of transportation, implementing congestion pricing, and creating more walkable and bike-friendly cities. Additionally, by encouraging more compact and efficient land-use patterns, city planners can help to reduce the need for long commutes and reduce the amount of energy consumed by transportation.

1 Evolution of Public Transportation in Qatar

1.1. The Traditional Phase – Pre-oil Era to 1950

Qatar's early inhabitants were known to be seafarers and merchants with skills. The country's deep-sea water and its shape fascinated fishermen. Primarily, the country was known as a fishing hub of the Middle East along with pearl diving and other nomadic activities. Commodities were imported to Iran and India during the period. Inadequate land state and restricted water supplies impacted the initial distribution of population in Qatar. The pearling industry was on the rise steadily which transformed Doha into a trade hub after ports were established. Ever since the economic stability with the same Doha became Qatar's capital and emerged as headquarters for ruling tribes.

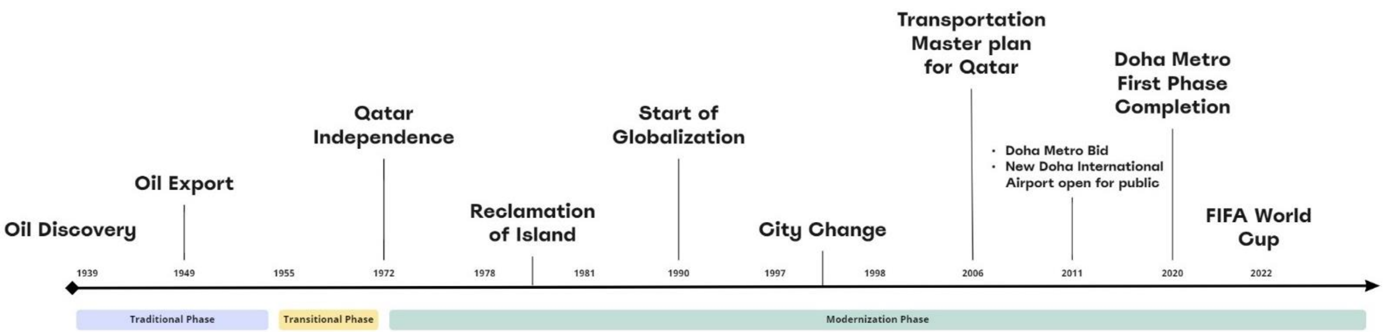

Figure 1.1: Qatar's Development Timeline since 1939 to 2022
Source: [1]

1.2. The Transitional Phase – Post-oil Era (1960's)

Before discovering oil within its borders, Qatar's population was one of the poorest in world depending on pearling and fishing trade as a main way to make a living. Oil was first discovered in the north of the country in the Dukhan Field in 1939. By 1940 around 4,000 barrels were being produced per day. The exploitation was stalled between 1942 and 1947 due to the aftermath of World War II, hence exports did not begin until 1949.The oil wealth was the catalyst in urban development ever since 1955 when the expatriate accommodation situation emerged. The period between 1949 to 1969 saw a population increase and requirements for administrative centers to oversee enormous proceeds.

1.3. The Modernization Phase – 1950 to Current Day

Since Qatar's independence on September 3, 1971, from the British Regime, Doha the capital of newly independent state was successful in attracting foreign professionals and were employed in engineering and construction industries. Since 1970, the focus on modern engineering foresaw an installation of Radial Ring Road patterns to accommodate the ever-increasing number of motor vehicles. The continuous growth of the city had led the travel distance to also increase with its rising numbers of travelers. Hence the construction industry turned to heavier vehicles like trucks and pick-ups to facilitate mobility for the workers, while a very small number of people were transported using taxis.

In 2004, Qatar's public transportation was established as it began to shape up after Mowasalat, a state-owned company introduced the national bus service. The transportation network was limited to certain routes in the beginning, but the system saw improvement in the anticipation of Asian Games in 2006. They were the official mode of transportation to the tournament venue. Before the tournament began, a major bus terminal – Old Al Ghanim was introduced to be the core of all bus network interchanges. In 2007, the company setup a plan for the bus service stating that it would serve a minimum walking distance of 700 to 800 meters for the serving location.

The existing road network consists of Ring Roads and Highways connecting the City of Doha from within and its neighboring cities. Ever since in the rise in population in the country, due to its expatriate workforce, the county has uncovered its diversity in economic growth namely in Banking, Aviation and Real estate industry. This instead has also given rise to the number of motor vehicles on the road and hence all the ring roads currently suffer from traffic congestion during peak hours. The Public Works Authority has undertaken many developments to reduce this situation within the city's Ring Roads. Continuous expansions of road lanes from two to four-lane roads serves the country in a better way.

Qatar's only international Airport situated in Doha is the hub of the local airway and many international airlines. Ever since the rapid economic growth of Qatar, the airport was deemed to be small and inadequate to fully function at capacity of air traffic it attracted. The issue was addressed with a large expansion in the anticipation of 2006 Asian Games. This expansion had temporarily eased the problem but has not been enough to permanently solve the problem because of the limit space available for expansion. As of 2010, Doha International Airport was the world's 27th busiest airport in terms of cargo traffic [1].

2 Literature Review

The theoretical foundation and literature review of this study focuses on the relationship between urban development, the physical form of cities, and transportation systems. The chapter particularly highlights the role of land use in shaping transportation options, with a focus on inter-modal transport systems as a sustainable transportation option.

2.1. Urbanization and Transport

Urbanization creates a need for new transportation options and drives the development of transportation infrastructure, which in turn shapes the layout of cities. Transportation plays a critical role in facilitating urbanization by allowing people and goods to move easily between different areas, and the presence of efficient transportation options can lead to the concentration of economic and residential activity. However, the development of urbanization also affects transportation demand, influencing the growth of the transportation industry [2].Urbanization is typically characterized by an increase in the proportion of the population living in urban areas. This can be measured statistically by looking at the percentage of the population living in urban settlements [3]. Urbanization is a major trend of our time, with an increasing number of people living in cities. It is estimated that by 2050, about 68% of the global population, or around 6.68 billion people, will be living in urban areas. This represents a significant shift in the way people live and work and has significant implications for the development of infrastructure and services in cities [4].

Urbanization is often closely linked to the development of transportation networks, such as highways, rail systems, and walking paths. These networks play a central role in the complex and diverse transportation systems found in urban areas, which are characterized by many sources, destinations, and a high volume of traffic. Historically, urban transportation has focused primarily on passenger traffic, as cities are centers of social interaction, with a wide range of activities including travel, commerce, culture, and leisure. There are many factors that contribute to urbanization, including economic, demographic, and technological changes. One of the main drivers of urbanization is the growth of GDP per capita, which can be facilitated by the development of transportation systems and the availability of air conditioning, which allows people to live in hot climates such as the Middle East. Urbanization can lead to new job opportunities, economic growth, and changes in lifestyle [5].

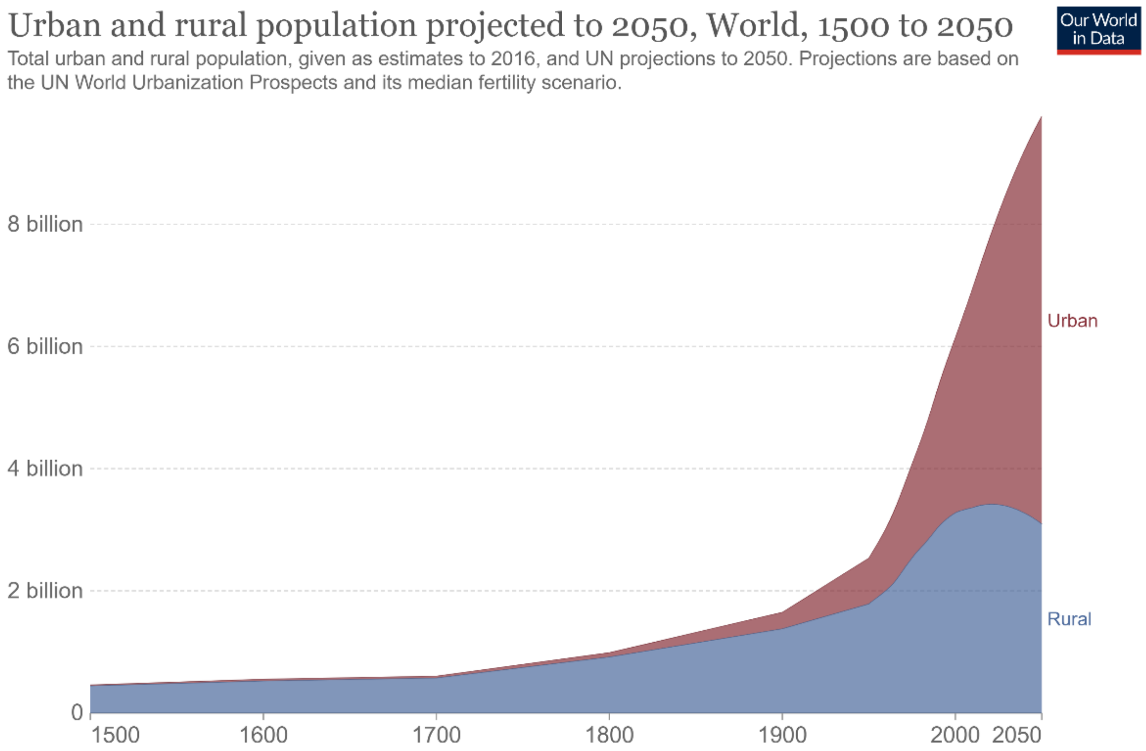

Figure 2.1: Urban and rural population projected to 2050
Source: [4]

2.2. Urban form and its models

Urban form refers to the physical characteristics of a city or other built-up area, including its shape, size, density, and layout. It is an important aspect of the overall structure and function of urban areas and can have a significant impact on the quality of life and well-being of the people who live there. Factors that influence urban form include transportation networks, land use patterns, economic development, and cultural and historical influences [6]. To understand the structure of urban areas, it is useful to examine these different models of urban spatial structure. The models focus on the patterns of development and functional distribution within a community, as well as the relationship between residential location and socio-economic characteristics in an urban area. By considering the models, it is possible to gain insight into the way that cities are organized and how different factors shape the way they function.

The models share common assumptions: (1) that cities are growing in population and economic activity; (2) a relatively free land market that is driven by supply and demand, with minimal government regulation; (3) an economic base that is primarily composed of industrial and commercial activities; (4) private ownership of property; (5) specialization in land use; (6) a transportation system that is fast and efficient, and generally accessible to the majority of the population; and (7) freedom of residential choice, at least for higher socio-economic groups. These assumptions help to shape the way that these models view the structure and function of urban areas [7].

2.2.1. Concentric Zone Model

The concentric zone model of urban land use was developed by American urban sociologist E.W. Burgess in 1925, based on his studies of American cities, particularly Chicago. It was first published as a chapter in the book "The City," written with R.E. Park in 1925. This model, also known as the zonal theory of urban land use patterns, is one of the earliest theoretical models to explain urban social structures and is the earliest descriptive urban land use model to divide cities into concentric circles radiating out from the downtown area to the suburbs. It is based on the idea that cities develop outward from their central areas to form a series of concentric zones [8].

In this model **Error! Reference source not found.**, the center of the city (Zone A) is h ome to the business and cultural district. The next zone (Zone B) is composed of former wealthy homes that have been divided into cheap apartments for new immigrant populations, as well as small manufacturers, pawn shops, and other marginal businesses. Zone C is populated by the homes of the working class and established ethnic enclaves, while Zone D is home to wealthy homes, white-collar workers, and shopping centers. The outermost zone (Zone E) consists of the estates of the upper class in the suburbs and exurbs.

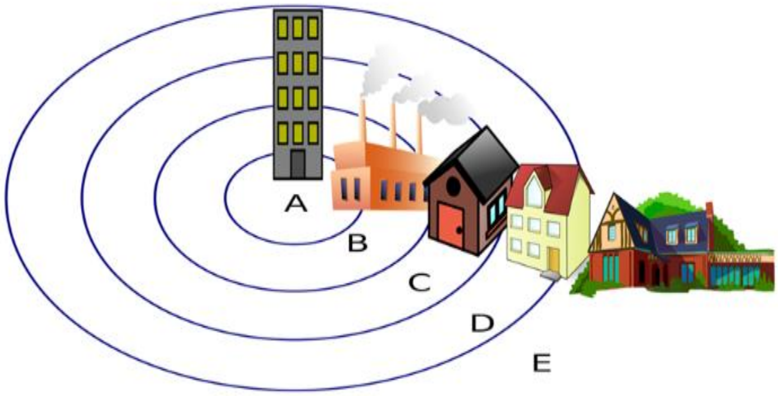

Figure 2.2 Concentric zone model depiction.
Courtesy: Zeimusu/Wikimedia Commons

According to the concentric zone model, the movement of people and activities from one zone to another resembles the pattern created when a pebble is tossed into a lake and creates concentric ripples that overlap as they spread outward. The rate at which urban neighborhoods change from one population type or activity type to another is influenced by several factors. These include the rate of growth in the demand for housing or buildings, the rate of construction of dwellings, industrial buildings, and commercial spaces, and the investment decisions made by developers, financial institutions, and political regimes. If construction lags population and economic growth, demand for developed land increases and land prices go up, leading to stagnation and a build-up of people and activities. On the other hand, if construction outpaces population and economic growth, vacancy rates rise and land prices decline, but new opportunities may be created that attract future growth. In extreme cases, high vacancies and little growth can lead to the collapse of the local development economy and economic depression [7]. Nowadays, there are urban realms within larger metropolitan areas that operate independently in some ways but are connected as part of a larger whole. Production and distribution are key activities in these areas. In the suburban sector, regional shopping centers (e.g., malls) have become the new central business districts (CBDs) located outside of the traditional CBD. These shopping centers and offices create realms that can function autonomously [9].

2.2.2. Sector Model

The sector model, also known as the Hoyt model or Hoyt sector model, is an urban land use model that explains the spatial arrangement of activities in an urban area. It was proposed by Homer Hoyt in 1939 and is based on the idea that cities do not develop in the form of simple rings as described in the concentric zone model, but rather have "sectors" that radiate out along major transportation routes. These sectors are defined by the types of activities that take place within them, such as housing, industrial activities, or commercial establishments. Hoyt argued that land use within each sector remains the same because like attracts like, with high-class sectors attracting wealthy residents and industrial sectors located near transportation routes or waterways. The sector model helps to understand the organization of urban areas and the factors that influence the location of different activities within a city [10]. Although these models have been widely criticized, they are still considered classical models of urban growth [11].

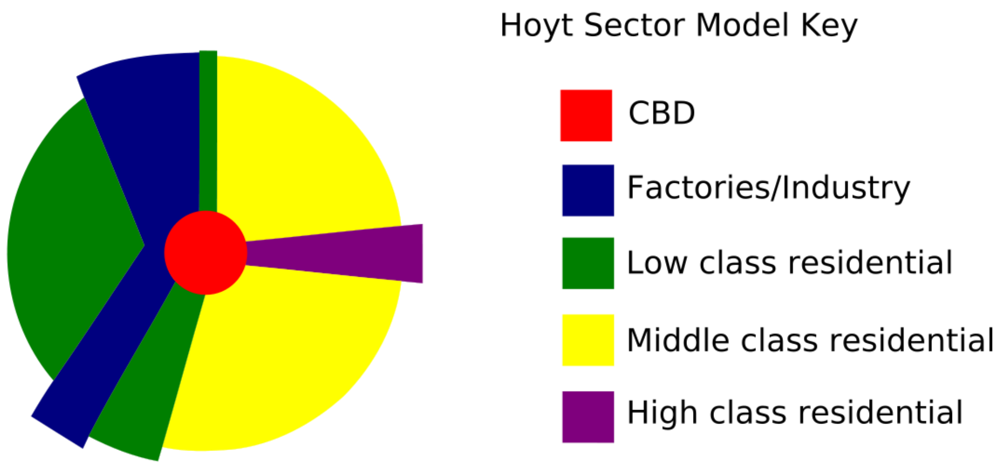

Figure 2.3: Concentric zone model depiction.
Courtesy: Zeimusu/Wikimedia Commons

The Hoyt model is significant because it incorporates ecological factors and the concept of economic rent to explain land use patterns in urban areas. It also highlights the impact of transportation routes on the spatial arrangement of a city, considering both the distance and direction of growth from the city center. The model also considers the location of industrial and environmental amenity values as important factors in the placement of residential areas, such as sectors of high-class residential areas tending to grow towards higher ground, sites with a better view, more open space, the homes of influential leaders within the community, and existing outlying, smaller settlements [10]. Hoyt's model is based on outdated transportation methods, specifically rail, and does not consider the widespread use of personal cars that allows people to commute from low-cost land outside city boundaries. The model also does not consider the concept of edge cities, which are urban complexes with a large concentration of office buildings and more workers than residents. As a result, the central business district (CBD) has lost some of its importance, with many retail and office buildings moving into the suburbs. This means that older cities are more likely to follow the Hoyt segment model, while newer cities tend to follow Burgess's concentric zone model [12].

2.2.3. Multiple Nuclei Model

The Multiple Nuclei Model, also known as the Harris-Ullman Model, is an urban land use model that suggests that cities are not centered around a single central business district (CBD), but rather consist of multiple commercial centers or nuclei. These nuclei can vary in size and specialize in different activities such as retail, manufacturing, education, and health services. The model proposes that as cities grow, they absorb smaller settlements around the edge, and as travel between the outskirts and the CBD becomes impractical, smaller centers begin to emerge throughout the city. The Multiple Nuclei Model recognizes the complex, multi-nodal nature of urban growth and can account for the presence of multiple CBDs in a city. It also acknowledges the influence of transportation networks and specialized land uses on the spatial arrangement of a city [13].

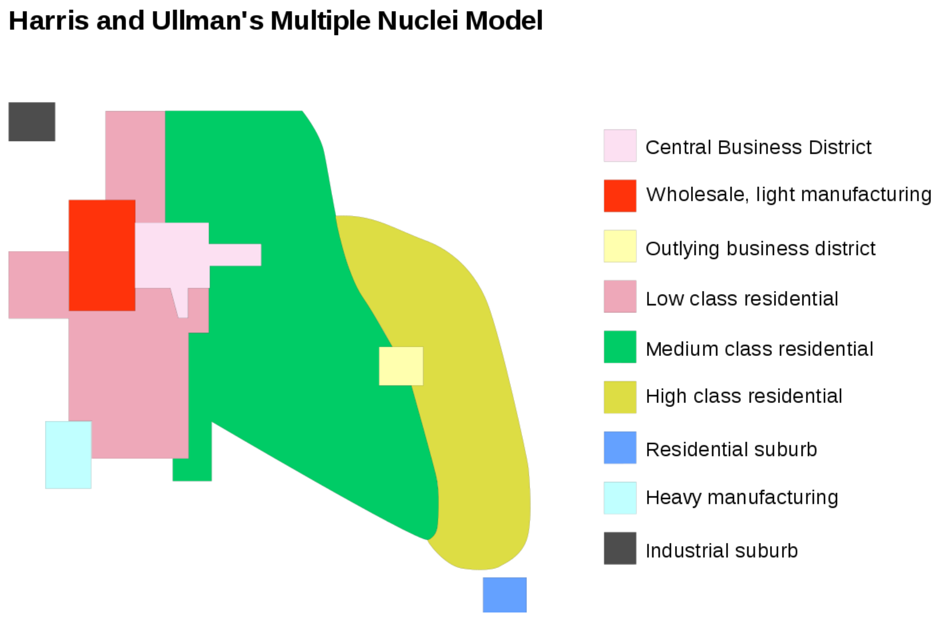

Figure 2.4: Multiple Nuclei Model.
Source: https://en.wikipedia.org/wiki/User:SuzanneKn

These centers, or nuclei, can vary in size and specialize in different types of activities, from retail and manufacturing to education and healthcare. The model views the city as a patchwork of these different nuclei, rather than being organized around a single central point. The central business district is just one of several important nuclei in this model [14]. As a result, smaller centers develop throughout the city, often around transportation hubs that enable industries to be located nearby with reduced shipping costs. This model also led to the development of the Transit Oriented Development (TOD) model, which involves the creation of mixed-use communities around transit hubs to promote sustainable living. Land values are typically highest at the intersections of transportation lines, and housing tends to become more expensive as it gets farther away from the CBD. Hotels often locate near airports because travelers generally prefer to be close to their source of transportation [15].

2.2.4. Urban Realms Model

As cities expanded, it became increasingly difficult to travel to and from the traditional central business district, and the availability of jobs outside of this area became important to serve the growing populations in these areas. This led to the development of transportation hubs and the growth of businesses such as wholesale, manufacturing, retail, and offices in these outer areas. The expansion of these industries and services also contributed to the growth of residential areas in these areas [16].

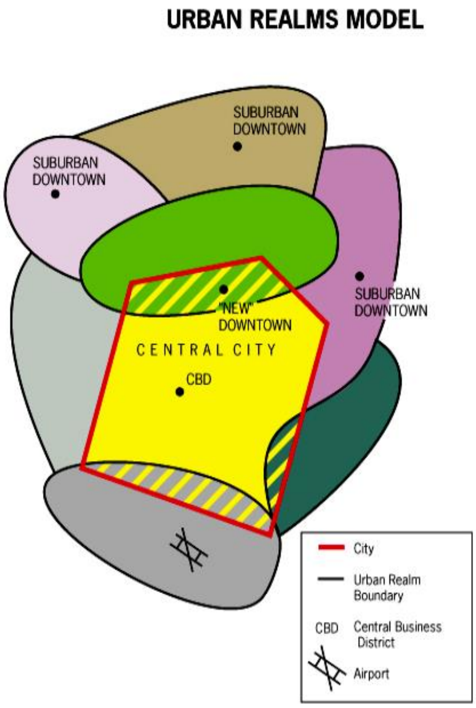

Figure 2.5: Urban Realms Model
Source: [17]

The development of urban realms, or large connected urban areas that function independently in some ways but are connected to a larger metropolitan area, has led to the emergence of suburban centers that have become independent from the central business district. These centers, often in the form of regional shopping malls, have become the new centers of activity for outer nuclei, or suburban areas, and have contributed to a reduction in interaction between the central city and these suburbs [17]. The urban realms model suggests that mega-cities are made up of several smaller cities or realms that are connected to each other, while the multiple nuclei model proposes that a city is a single entity with several distinct commercial districts within it. The main difference between the urban realms model and the multiple nuclei model is that the former conceives of a city as being made up of several smaller, self-sustaining cities that are interconnected, while the latter sees a city as a single entity with multiple commercial districts within it. The multiple nuclei model struggled to explain the layout of rapidly expanding American cities in the post-war period. The urban realms model, on the other hand, posits that each realm contains four types of land use: residential, commercial, industrial, and public/semi-public.

The urban realms model has been criticized for not considering the role of race and ethnicity in shaping patterns of urban settlement. It also has been described as overly simplistic, as it divides land use into just four categories and does not account for innovative solutions, such as SOHO units, that may blur traditional distinctions between commercial and residential use. These limitations suggest that the urban realms model may not be sufficient to fully understand the complexity of contemporary urban areas [14].

2.2.5. Correlation of Urban Models with Doha

Doha, the capital and largest city of Qatar, has experienced rapid urban growth over the past few decades. The city has transformed from a small fishing village into a major hub for business, finance, and tourism in the Gulf region. The Urban Realm Model is a better fit for the urban growth of Doha, as it involves the development of multiple centers within the city, including a CBD and smaller urban centers near valued residential areas for shorter commutes. The growth of Doha has been driven by vehicle transportation, leading to increased urbanization and a diverse, sprawling city.

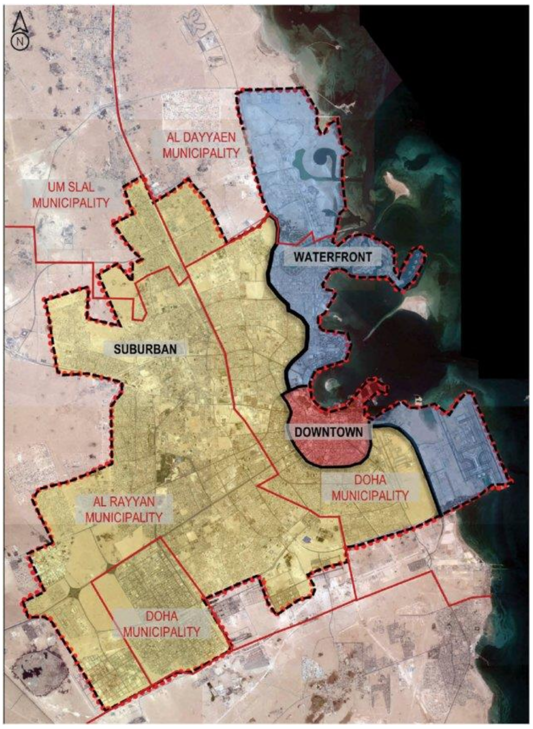

Figure 2.6: Urban and Suburban Districts of Doha City
Source: Ministry of Municipality and Environment, 2015

Figure 2.7: Doha points of interest map
Source: https://livingnomads.com/2022/04/qatar-travel-blog/

Edited by Author

Referring to Figure 2.7 (7,8,9,14) West Bay is the bustling business district and home to the iconic skyline of Doha, (11,12,13) Pearl Qatar, an artificial island on north waterfront of the city, is made of expensive residential development on the island is intended to incorporate various national and international themes, including aspects of Arabic, Mediterranean, and European culture, (16) Msheireb downtown, strategically located at the heart of Doha will serve as the core of transportation modal shift. Referring to **Error! Reference source not found.**, the yellow regions of the map m ostly comprise of small businesses, middle-class residential housing, public parks, sports centers, and shopping malls. The Al Rayyan municipality is on track to be an economic and growth hotspot with affordable housings on the rise.

2.3. Sustainable Urban Mobility

There has been increasing focus on sustainability and sustainable development in academic and policy circles in recent years. These concepts have been influential in shaping international development policy for over 20 years [18]. To ensure sustainability, a transportation system must offer safe and environmentally friendly options for all city residents to easily access. This can be a challenge as the needs and preferences of people with different incomes may vary and sometimes conflict. For instance, if a large portion of the population cannot afford to use private vehicles or public buses, they may have to walk or bike to work. To provide safe infrastructure for these individuals, there may need to be separate road spaces for pedestrians and bikers or a reduction in vehicle speeds. Both measures could potentially limit the mobility of car users [19].

The creation of sustainable urban environments involves addressing climate change by using an interdisciplinary approach in the planning and development of transit villages or neighborhoods. These areas should be adaptable to the constantly changing factors of demographics, the environment, society, and the economy. There are 15 core principles that guide the examination of important factors, ideas, and variables and their connections with one another in this process [20].

Figure 2.8: 15 Core principles of Sustainable Urbanism
Source: [21]

The key to making transportation more sustainable is to focus on four key areas: good governance of land use and transportation, fair and efficient funding, strategic infrastructure investments, and the design of neighborhoods. Investment in public transportation infrastructure alone may not be effective if land use and neighborhood design do not support it [22].

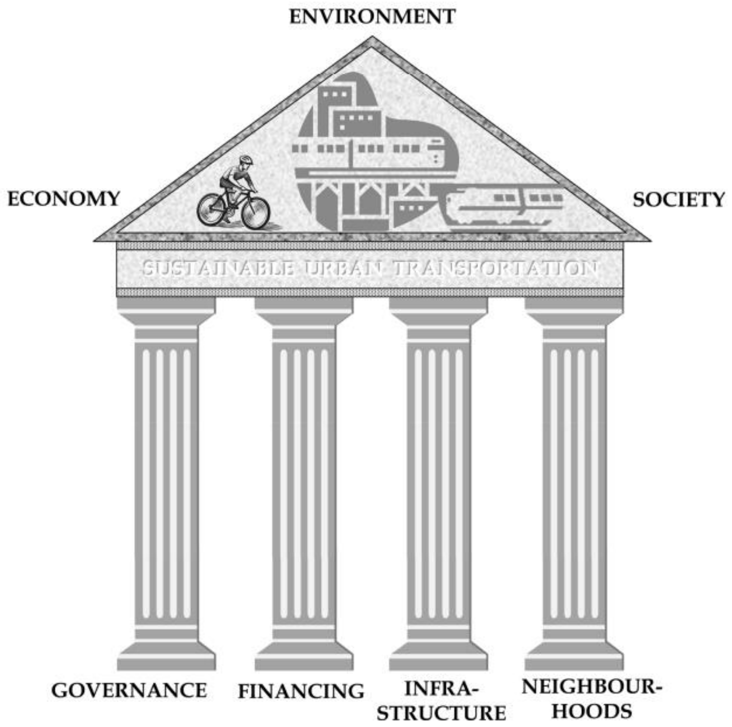

Figure 2.9: Four Pillars of Sustainable Mobility
Source: [22]

2.3.1. Good governance of land use and transportation

Effective governance of land use and transportation is essential for achieving sustainable cities. A few cities, such as those in the Netherlands, have been successful in implementing integrated land use and transportation planning, which involves a cooperative approach with commitment from government, the public, and the private sector. The Dutch system also prioritizes accessibility in transportation planning and uses innovative techniques to classify locations based on accessibility [22]. However, most urban regions struggle to establish effective governance for land use and transportation planning due to issues with distribution of responsibilities and cultural, geographical, and political factors. To be effective, the governing body for regional transportation should consider factors such as spatial representation, structure, democracy, and market philosophy. Transit-oriented development (TOD) is a strategy for urban development that is focused on creating communities around public transportation stations. This approach is based on three key factors: density, diversity, and design. Increasing density around stations within a certain radius (usually 400-800 meters) helps to create a sense of community and make public transportation more convenient. Diversity, in terms of mixed land use and a variety of housing and commuting options, helps to create a more vibrant and livable community. Design elements, such as pedestrian-friendly environments, also contribute to the livability of the community. By addressing these factors in the development of transit villages, it is possible to achieve environmental protection, economic efficiency, and social equality while also creating a more sustainable urban development [21].

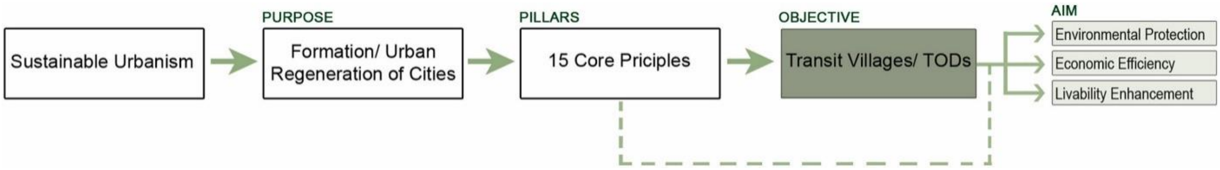

Figure 2.10: Sustainable Urbanism through TOD flowchart
Source: [21]

The development of sustainable urbanism is seen as addressing the environmental and ecological challenges of climate change where the formation and/or urban regeneration of transit villages and/or neighborhoods is best based on an interdisciplinary planning approach with the flexibility to weather ever-changing demographic, environmental, social, and economic issues.

2.3.2. Efficient and Long-Term Financing

Cities need secure, long-term funding for transportation projects and maintenance, both for building new infrastructure and keeping existing systems running. In recent years, decreasing support from central governments has made it harder to finance transportation infrastructure.

Efficient financing is necessary for investment in new transportation infrastructure and for the operation and maintenance of existing systems in cities. The World Bank notes that there are three main complications that can distort the pricing and funding of urban transportation: 1) separation of infrastructure financing from pricing, 2) separation of responsibility for infrastructure from service provision, and 3) dispersed responsibility for interacting modes of transport. To address these issues, cities should establish regional transportation and land use planning organizations with responsibility for financing infrastructure and stable operations for all modes of transportation [23].

	NON-VEHICLE RELATED	VEHICLE RELATED
NON-LOCATION-RELATED	General tax base	Fuel Taxes
	Local transportation levy	Vehicle license fees
		Vehicle use fees
		Emission fees
LOCATION-RELATED	Development fees	Road tolls
	Transit impact fees	Congestion pricing
	Right of way fees	Parking fees
		Transit user fees

Table 2.1: Potential Funding Mechanisms

There are various funding mechanisms as mentioned **Error! Reference source not found.** for urban transportation systems, which can be divided into those that are unrelated to vehicle use and location, and those that are related to vehicle use and location. Funding from the general tax base, local transit levies, and fuel taxes are examples of mechanisms that are unrelated to vehicle use and location. These mechanisms can provide flexibility to governments to implement national policies and control government spending but may also allow governments to avoid making long-term investments in infrastructure. Vehicle-related, location-independent mechanisms include vehicle license fees, higher sales taxes on new vehicles or vehicle parts, and fees based on distance travelled, weight, vehicle value, or emissions. Vehicle- and location-related mechanisms, which reflect the value that users place on transportation services, include toll roads, parking fees, transit user fees, and congestion pricing. The use of congestion pricing, which charges a fee for using a congested road or area at a specific time, is increasing due to technological advances However, the implementation and acceptance of congestion pricing can be challenging due to issues of fairness and the potential for evasion. Other strategies that can be used to fund transportation infrastructure include leveraging real estate assets and development.

2.3.2.1. Public-Private Partnerships (PPP)

Public-private partnerships (PPPs) are long-term collaborations between the public and private sectors to provide public services, with the aim of achieving mutual social and commercial benefits. It involves cooperation between the public and private sectors to provide public services. PPP can bring benefits to both parties, including partial financing of project costs for the public sector, access to financing and expertise for the private sector, and the possibility for both parties to gain knowledge and experience. PPP projects can also involve the use of more modern technologies and efficient project and HR management. However, effective risk management is crucial for the success of PPP projects, as the sharing of risks must be carefully managed. PPP projects can also bring marketing benefits for both the public and private sectors. [24].

It has been used in transportation for many years and can bring benefits such as timely project completion, expertise, cost-effective service delivery, and access to financing. Though, there are also disadvantages to using PPPs, such as increased lending rates and user costs. There is also evidence to suggest that mixed private/public firms may be less efficient and profitable than private companies and perform worse than state-owned firms. Ultimately, the most suitable funding mechanism for a particular region will depend on its unique circumstances [23].

2.3.3. Investment in High-Impact Infrastructure

Sustainable transportation refers to transportation methods that reduce the reliance on automobiles, while still maintaining the accessibility and mobility of individuals. To achieve this, it is essential for sustainable transportation systems to include a comprehensive and efficient public transit system. This system should be able to offer a high level of service to a significant portion of urban residents. One of the key challenges in implementing a successful transit system is designing it in a way that attracts travelers and encourages them to use it over other modes of transportation. This may involve factors such as low fares, convenient payment methods, a wide coverage area, and high frequency of service. It may also involve ensuring that the system is well-integrated with other modes of transportation and that it serves areas with high population density [23]. A study [25] shows that Light rail systems are expensive to build and maintain, but they can be made more cost-effective by increasing ridership. This can be achieved by focusing on community building and implementing consistent development policies that support the growth of high-density areas near light rail stations. In addition, implementing effective parking and toll policies, such as pricing parking to cover all costs and varying toll charges between peak and off-peak hours, can help increase ridership by encouraging people to use public transportation rather than driving their own vehicles. However, it is important to note that light rail is unlikely to significantly reduce traffic congestion, particularly in areas where it is not extensively used. To better understand the successes and failures of light rail systems, it is important to conduct thorough, objective evaluations of existing systems. This information can be used to inform the development of new light rail systems and improve their cost-effectiveness and ridership.

Additionally, the configuration and overall structure of the transit network, as well as the integration of different modes of transportation, can also play a role in attracting riders. To be truly sustainable, transportation systems should also consider the long-term environmental and social impacts of their operations and strive to minimize negative impacts while maximizing benefits for all stakeholders [22].

2.3.4. Local Investment in Infrastructure Design

Effective investment in public transit systems is dependent on the presence of supportive land use and neighborhood designs. This includes ensuring that houses, jobs, and other important locations are conveniently connected to transportation facilities through the design of streets and neighborhoods. Without this support, investments in public transit may not be effective in promoting sustainable urban transportation. The design of the built environment is therefore an important factor to consider in the planning and implementation of public transit systems [23]. Designing urban areas to be pedestrian and cyclist friendly, and implementing local policies and investments to support sustainability, such as incentives for mixed land use and car-restraint measures, can contribute to the development of sustainable urban transportation. Research on ways to make urban areas more accessible and attractive for pedestrians and cyclists while maintaining economic vibrancy is also important. Measures such as giving transit priority through reserved lanes, reduced parking and signal pre-emption can increase the attractiveness of public transit [22].

Using a GIS tool can help in the design of more sustainable and pedestrian-friendly neighborhoods by allowing for the analysis of various land use and street patterns in terms of walking accessibility. This was demonstrated through the analysis of a small subdivision, which showed a moderate improvement in pedestrian accessibility through a more sustainable redesign compared to the original layout. However, the study also found that many neighborhood destinations may still be too far for walking for many residents, even in a smaller neighborhood. Therefore, design that minimizes walking distances within neighborhoods should be encouraged to promote more walking and a reduction in automobile travel [26]. To ensure local decisions contribute to regional sustainability goals, some form of regional mechanism is necessary. The design of streets, pedestrian connections to transit, and other micro-neighborhood factors should be influenced by the broader regional design concepts and zoning, or "macro urban form." Unless neighborhoods offer convenient access to major transit systems, investments in these systems will likely not be financially sustainable. To effectively connect micro-neighborhood design with macro urban form, effective regional governance of land use and transportation is necessary.

2.4. Integrating Modes for Sustainable Urban Transportation

Urban transportation is facing challenges due to increased personal car use, traffic congestion, scarce parking, and air pollution and noise. To address these challenges and meet the increasing demand for mobility in urban areas, new and more sustainable modes of transport, such as car-sharing and bike-sharing, have emerged and been aided by the rise of the sharing economy. These modes, along with public transport, can be combined in a single journey, referred to as multimodal and intermodal travel [27].

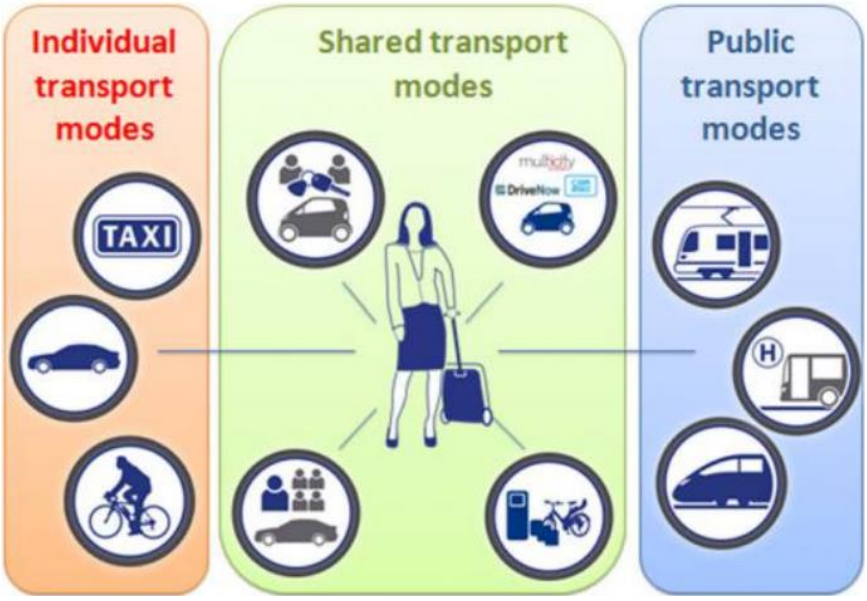

Figure 2.11: Individual, Public and Shared Transport Modes
Source: [28]

This chapter focuses on ways to encourage people to use more environmentally friendly modes of transport, such as public transport, car-sharing, ridesharing, walking, and cycling, instead of private cars. This shift requires the availability of a range of transport options and the ability for people to combine them in intermodal mobility networks. Shared mobility services, such as car-sharing, ridesharing, and bike-sharing, can play a crucial role in these networks by providing a link between public and individual transport. Intermodal mobility networks can be described as infrastructure that enables the integration of different transport modes in a door-to-door transport chain. Shared mobility options, while not part of the traditional public transport system, can be considered a semi-public or "hybrid" mode of transport. In recent decades, these types of hybrid mobility platforms have grown in popularity and have helped to create a rising number of local intermodal mobility networks [28].

2.4.1. Car Sharing

Car sharing is a key element in intermodal mobility networks because it promotes a shift away from private car use towards a combination of more environmentally friendly modes of transportation, including public transport, ride sharing, and car sharing. There are three main types of car sharing: stationary car sharing, where cars are parked in dedicated spaces; free-floating, one-way car sharing, where cars can be booked spontaneously and parked anywhere within a certain area; and peer-to-peer car sharing, where private car owners offer their car to other private users on an internet platform. Car sharing services are available in over 1,100 cities in 26 countries and have passed the experimentation and growth phases and have entered the commercial mainstream. There is a growing body of literature on car sharing, which has focused on acceptance and adaptation of car sharing services, development and market potentials of car sharing, and effects of car sharing on mobility patterns and modal split. However, there is a lack of empirical studies on the actual effects of car sharing and how to integrate it into intermodal mobility networks [28].

2.4.2. Bike Sharing

Bike sharing programs (BSPs) have become a popular transportation option in cities around the world. BSPs are seen to reduce traffic congestion and air pollution, as well as promoting physical activity and creating a healthier society. There are two main types of BSPs: station-based, where bikes must be returned to a designated location, and dock-less, where bikes can be left anywhere within a certain area [29]. The first comprehensive programs were introduced in the early 2000s, with the DB-Deutsche Bahn's "Call a Bike" system in Germany being a notable example. Bicycle sharing has since spread to cities worldwide, with some programs testing the inclusion of electric bikes. While technically a carbon-free mode of transportation, the logistics of relocating bikes from popular return spots to popular pickup spots can result in greenhouse gas emissions. Therefore, for conventional and electric bicycle sharing programs to be considered carbon-free, all operational vehicles must be electric and charged with green energy [28]. BSPs have evolved over time, with the third generation introducing telecommunication systems and the fourth generation incorporating smart systems for sustainability, efficiency, and quality. The success of BSPs depends on various factors including infrastructure, technology, user behavior, and government support. BSPs can be used to encourage the transition to cycling and create more sustainable cities [29].

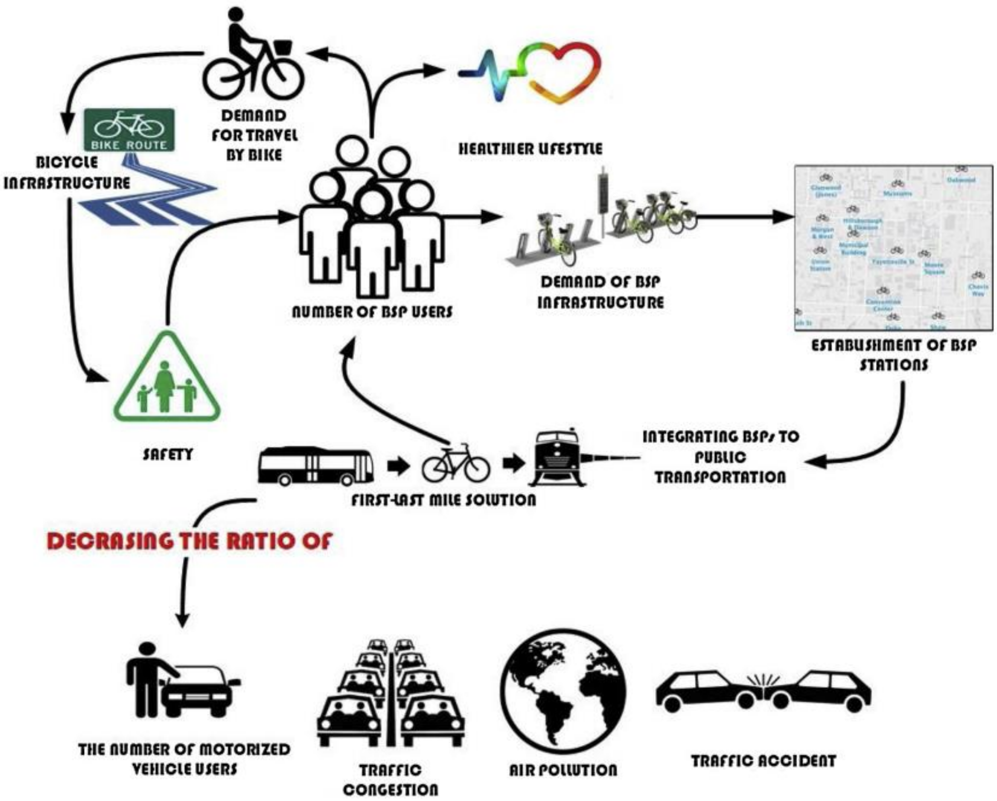

Figure 2.12: Integrating BSP to Public Transportation
Source: [29]

To implement a successful bike-sharing program, cities should focus on promoting cycling and developing infrastructure for safe and convenient cycling. Involving stakeholders such as rail operators and local authorities is also important. Bike-sharing schemes may face challenges, including the need to educate the public and the costs associated with operating and maintaining the program. Smart bike-sharing systems, which use technology to track and manage shared bikes, have become popular in recent years. To be successful, bike-sharing schemes should be integrated with other modes of transportation and supported by extensive bike lanes or car-free networks in a bike-friendly topography and climate [30].

2.4.3. Ride Sharing

Ride sharing, or carpooling, is a transportation option that involves multiple people sharing a ride in the same vehicle. It has the potential to reduce journey times and vehicle kilometers traveled, as well as shared fuel costs and emissions. The promotion of ride sharing in conjunction with other modes such as public transportation can reduce dependence on oil [31]. The main objectives of ride-sharing are to reduce total travel costs, minimize system-wide vehicle miles, minimize system-wide travel time, and maximize the number of participants. These objectives can be achieved using fiscal measures such as reduced fuel tax for ride-sharers and the provision of ride-share lanes and priority parking [32].

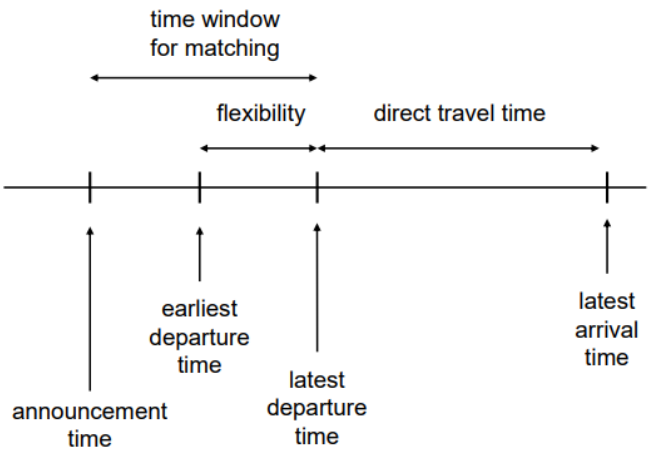

Figure 2.13: Time Schedule information in ride-sharing
Source: [32]

Optimizing the matching of drivers and riders and fairly dividing the costs and benefits of ride-sharing can be challenging, particularly in dynamic environments where ride requests and offers are continually arriving.

	Single Rider	**Multiple Riders**
Single Driver	Matching of pairs of drivers and riders: *Easy*	Routing of drivers to pickup and deliver riders: *Difficult*
Multiple Drivers	Routing of riders to transfer between drivers: *Difficult*	Routing of riders and drivers: *Difficult*

Table 2.2: Ride Share Variants
Source: [32]

There are four main types of ride-sharing systems referred in **Error! Reference source n ot found.**: single driver-single rider, single driver-multiple riders, multiple drivers-single rider, and multiple drivers-multiple riders. Matching drivers and riders and allocating cost savings is simpler in the single driver-single rider system, but more complex in the other systems [33]. Dynamic ride-sharing systems are a form of on-demand passenger transportation, like taxis and dial-a-ride services, in which drivers and riders are matched in real-time to share a ride, have the potential to provide significant societal and environmental benefits. However, there are many challenges to be addressed in the development of technology to support these systems, including issues of dynamics, multi-modality, and pricing. These challenges offer opportunities for research in the transportation science and logistics field.

2.4.4. Park and Ride

Park & Ride (P+R) is a public transport service that allows private car users to park their vehicles in a secured area and use public transport to reach their destination. P+R facilities are typically located at end stations and at critical intersections on the public transport network and can include multi-story parking garages or open-air protected areas with complementary services such as toilets and telephones. P+R is meant to reduce car traffic in city centers and is often free or less expensive than regular car parking. However, it can also increase centralized vehicle traffic as motorists make additional trips to reach P+R facilities.

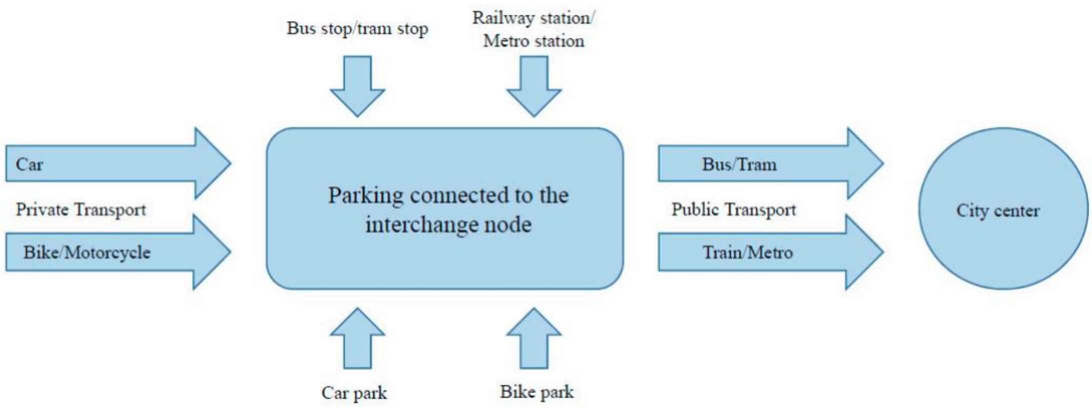

Figure 2.14: The idea of travels made using parking type P&R and various means of transport
Source: [34]

One of the main benefits of park and ride schemes is that they can enable plans for economic and environmental enhancement. By providing parking spaces at the edge of a city, park and ride schemes can help to reduce congestion and pollution in the city center and provide an opportunity to use central land for more economically beneficial purposes. Additionally, these schemes can help to win political support for other plans to transform city centers, such as pedestrianization, which may otherwise be resisted.

Another benefit of park and ride schemes is that they can increase the overall supply of parking spaces, while also allowing for the reduction of central parking supply. This can be beneficial in terms of economic development and land use, as it allows central land to be used for other purposes. Additionally, Park and ride schemes can increase accessibility to the city center without increasing congestion or environmental intrusion. Even if the volume of car use in the center is not reduced, it is possible to increase the total number of people traveling to the center without causing additional congestion or pollution, as these people can use public transport instead of driving. Additionally, motorists often report positive experiences with park and ride, as they can travel in a stress-free manner, often via bus lanes, and have access to preferential parking upon arrival.

However, there are also drawbacks to park and ride schemes. One significant disadvantage is the environmental impact of constructing large car parks in green belt land on the urban fringe. Additionally, park and ride schemes have not been effective in reducing traffic levels in the long term, as they have not led to lasting reductions in traffic. In addition, there are often costs associated with these schemes, including the need for subsidies, which may be borne by urban residents. There are also equity concerns, as residents may be denied the opportunity to use the park and ride facilities without arriving by car. Finally, park and ride schemes may lead to an increase in total trips, as they make it easier for people to travel to the city center by car from greater distances, which can lead to more traffic and pollution [35].

2.4.5. Challenges

Shared mobility options, such as car sharing and bike sharing, can be integrated into an intermodal mobility network to provide a range of transportation options for individuals in major cities like Paris, London, Shanghai, and San Francisco. In Berlin, for example, travelers can choose between car sharing, bike sharing, and ride sharing, as well as bike and car rentals and other taxi services. These shared mobility options fill the gap between public and private transport and can meet the need for intermodal and multimodal mobility patterns in many cities. However, introducing new modes of transport can also lead to disruptive changes in existing transport systems, and may not always result in sustainable mobility.

The current system lacks convenient facilities and integration between modes, and lacks information dissemination, leading to difficulties for passengers using multiple modes of transport for a single journey. Inefficiencies in the system also come from outdated and unattractive equipment, counterproductive competition between modes, and a fare policy that is not integrated across modes. Additionally, the lack of efficient intermodal terminal facilities hinders the development of an intermodal system [36]. To improve the system, public transport terminals need to provide infrastructure facilities for connecting transport modes, such as private parking, separate access lanes, and dedicated stops. Currently, the predominant "system" consists of shared taxis and public buses stopping in the vicinity of terminals without proper intermodal facilities.

To understand the environmental impacts of intermodal mobility patterns, it is important to consider how people use shared mobility options, and whether they are substituting environmentally-friendly modes of transportation for less sustainable ones. To promote sustainable mobility, it is necessary for individuals to reduce their number of car trips in favor of intermodal or multimodal trips, and to find that they no longer need a private car due to their modified inter- and multimodal mobility behavior. Users' behavior is therefore crucial to understanding the sustainability effects of intermodal mobility [28].

2.4.6. Supporting Measures

The software component of an intermodal public transport system is important to integrate individual public transport services into a single system. This includes an integrated fare policy and single ticketing system, integrated timetables, and internal and external information and dissemination.

An integrated fare policy and single ticketing system refers to a system in which multiple modes of public transportation, such as buses and trains, use the same ticket and have a unified pricing structure. This allows passengers to easily transfer between different modes of transportation without having to purchase separate tickets. Single ticketing systems have been implemented in many cities around the world and have been found to be effective in increasing the use of public transportation and improving the overall efficiency of the transportation system. The introduction of single tickets would require the use of modern technologies to validate and control the tickets, and a detailed study would be necessary to determine the costs and logistics of implementing such a system.

Integrated timetables are important for optimizing interconnectivity between different rail-based public transport systems. This involves minimizing the time intervals between the arrival of one mode and the departure of the connecting link, while considering the necessary transit time for passengers to transfer between modes. This can be more difficult to achieve with bus services, which may need to be transformed into feeder services for the main intermodal terminals in the future public transport system. It will be necessary to conduct a detailed study of the main feeder lines to determine the optimal frequency and timing to ensure efficient integration. Information exchange between operators is also important for consolidating and integrating mode-specific timetables and controlling traffic flows.

The Intermodal Public Transport System needs to have effective information dissemination and exchange to be successful. Dissemination is the external aspect, where the public is informed about the different public transport services and their schedules. Information exchange is the internal aspect and involves constant and structured communication between the different operators to compare schedules, prices, and services offered to the public. It is also important to involve the public in the planning and operation of the transport system by seeking their input through community meetings and on-board surveys. In the future, more advanced information systems such as sensor-based arrival time updates and internet-based route planning could be implemented [36].

3 Focus on reformed Sustainable Transportation Systems around the World

Urban mobility, or the movement of people and goods within cities, is becoming a major challenge for many large cities around the world. Managing traffic and finding solutions to accommodate growing populations can be complex tasks. According to projections from the United Nations, more than 55% of the world's population currently lives in urban areas, and this number is expected to increase to 68% by 2050. To support the needs of urban residents, it is often necessary to have a high-quality public transportation system in place. This can help to reduce congestion on roads and improve the efficiency of the transportation system, as well as provide a convenient and affordable way for people to get around. For many cities, investing in public transportation infrastructure and promoting the use of alternatives to private car use can be important strategies for addressing the challenges of urban mobility and supporting the continued growth and development of the city.

3.1. Tokyo City, Japan

In Japan, particularly in crowded cities like Tokyo, there has been a focus on promoting public transportation to address the increasing demand for mobility and support the pursuit of a sustainable transportation system. This has included efforts to encourage the use of environmentally friendly modes of transportation such as rail, metro, bus rapid transit, and bus services. The goal of these policies has been to encourage a shift from private car use to public transportation to reduce congestion and improve sustainability, particularly in cities like Tokyo where traffic congestion is a significant problem with negative economic and environmental impacts. Overall, the promotion of public transportation is seen as an important way to address the challenges of urban mobility and support the continued growth and development of cities in Japan [37].

3.1.1. Tokyo City's public transport prioritization

Tokyo has a dense and complex urban railway transport system that helps to alleviate traffic congestion in the city. The system is made up of various forms of urban rail transit, including subways, light rails, monorails, and automated guided transport systems. The city's rail line network is the densest in the world, with a coverage rate of 100% in the central area and more than 112 transfer nodes within the Musashi loop line. The network's speed levels range from high-speed Shinkansen to ordinary light rail, and the average distance between subway stations is about 1 km. These features have made the urban rail transit network an important part of Tokyo's public transport system and have helped to encourage people to use public transportation instead of cars.

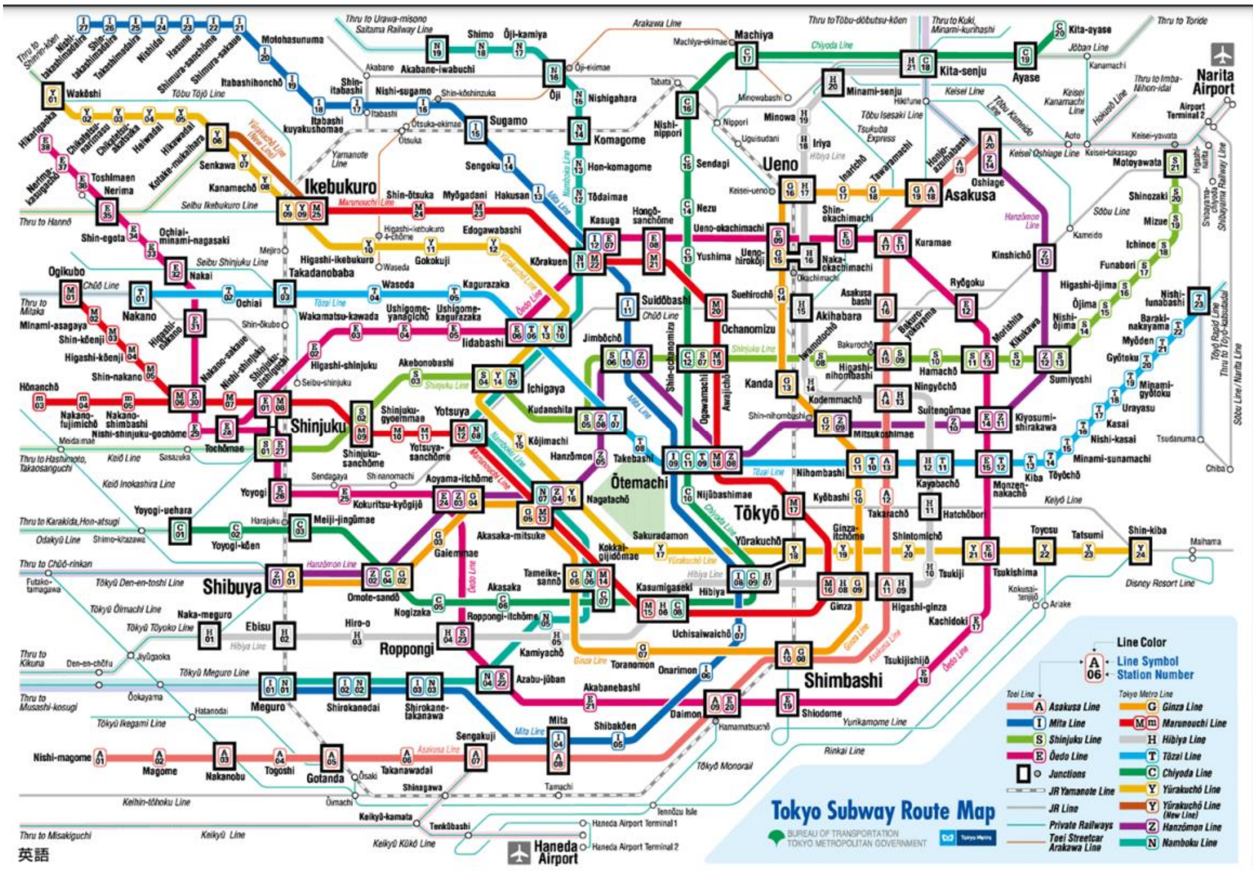

Figure 3.1: Tokyo Subway Route map
Source: [38].

As urbanization has progressed, cities around the world have faced challenges with congestion. Tokyo is no exception, and despite being known for its car culture, the city has struggled with traffic problems. To address these issues, there is a global consensus that prioritizing the development of public transportation is important. Tokyo, as one of the wealthiest and most developed countries in the world, has a particularly complex and extensive urban railway transportation system that serves the densely populated city center and extends to all parts of the capital. This system is designed to encourage people to use public transportation instead of private vehicles, and it is seen as a keyway to ease congestion and improve mobility in the city. However, it can be difficult to shift people away from private car use and towards public transportation, especially in a country like Japan where the car culture is deeply ingrained [38].

To address the challenges of congestion and support the shift towards sustainable transportation, Tokyo has been expanding its already extensive urban rail network in all directions of the city. This expansion includes integration with high-speed lines, monorail lines, Bus Rapid Transit, and bus service infrastructure. As a result, the central city coverage rate is now 100%, meaning that there is nodal coverage of the city with at least 2 transfer lines in each node, and a metro station is within a 15-minute walk of most locations. Downtown Tokyo alone has 17 Shinkansen lines and 13 private rail lines to support the prioritization of public transportation use. These various forms of urban rail transit offer a combination of network speed and accessibility, making it easier for people to get around the city using public transportation.

	high-speed Shinkansen	fast intercity lines	medium-speed train lines	ordinary light rail line
Speed per hour [km]	260	100	80	50～70

Table 3.1: Rail Transit network speed in Tokyo
Source: [38]

In Tokyo, there are 32 major transport hubs that integrate urban rail transit, regular bus, National Railway JR lines, and other transportation systems to ensure convenient travel for residents and visitors. These hubs provide seamless connections for traffic inside and outside the city, improving the efficiency of urban life. In addition to addressing traffic congestion challenges, these transport hubs have become important centers of activity in the city and play a comprehensive role in city life. They are not just places to transfer between different modes of transportation, but also serve as destinations, with a range of amenities and services available for people to use. [38].

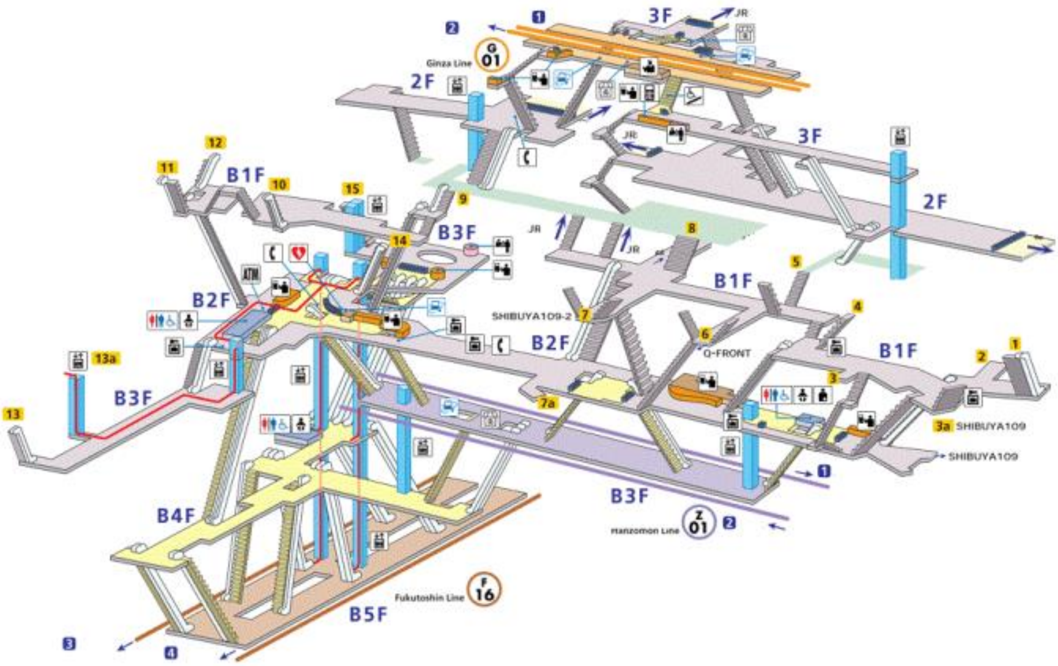

Figure 3.2: Shibuya station transfer system
Source: [38]

An increase in car ownership is a major contributor to traffic congestion in cities. People often choose to own cars for convenience, as they can avoid having to carry anything and have their own private space. This has led policy makers and mobility service providers to understand the motivations behind car ownership and the emotional factors that influence people's decisions. In response to these trends, the automotive industry is undergoing a transformation known as CASE (Connected, Autonomous, Shared & Services, Electrification) to promote sustainability. This transformation is aimed at addressing the convenience and emotional factors that drive car ownership, while also addressing the need for more sustainable transportation options [39].

In Tokyo, there are a few measures in place to encourage the use of public transportation over private cars. One way this is achieved is by limiting the use of private cars through various policies. This includes improving high-capacity bus facilities, such as dedicated lanes, and implementing measures like raising taxes and increasing charges for cars in the form of higher fuel prices, parking premiums, and highway tolls. These "soft" supporting methods aim to make public transportation a more attractive option for commuters, while also helping to reduce traffic congestion and promote sustainability [38].

The placement of residential areas near urban rail lines has helped to boost business and promote Transit Oriented Developments (TOD). TOD aims to create walkable, mixed-use communities centered around public transportation. This approach has been successful in Tokyo, with about 90% of residents and office workers living within a 400-meter radius of rail or ground transit service. This helps to make public transportation more convenient and accessible, encouraging more people to use it as a primary mode of transportation. By positioning residential areas near public transportation, Tokyo has been able to create a more sustainable and efficient transportation system.

3.2. Hong Kong

Home to one of the densest and most heavily used road networks in the world, HK has taken efforts in recent years to reduce traffic congestion and road risks towards data-driven, efficient, and environmentally friendly urban transport system. A car centric city with scarce space and private car ownership comes with challenges, from higher import rates, insurance, road tolls, parking and maintenance of the car being the factor for ownership for the few who are willing to afford. Hence motorization rate is low with just 76.5 registered private vehicles per 1000 inhabitants [40]. By comparison Germany is at 575 passenger cars per 1000 inhabitants in 2019, according to European Automobile Manufacturers Association (ACEA)

With the increasing number of population and the capability of the people to afford private vehicles improving, the city has seen the overall number of private cars from 400,000 in 2006 to 640,000 in 2020 indicating a 60% rise – the parking spaces has been seen to decrease from 1.51 to 1.07 per vehicle in the same period. The acute shortage of car parking spots has become an increasingly prominent issue in recent years. While previous research and indicators suggest Hong Kong to be already a sustainable in the transportation sector, the problem arises with the pollution of motor vehicles per square meter being highest in the world and the noise levels in many parts of the city being higher than the desired level suggested by WHO, hence questioning the complete sustainability. A possible problem to this solution generally is expanding and widening the road network which will reduce the density levels, leading to lesser pollution per square meter of the road. The issue being Hong Kong has no adequate room for any of such developments, being forced to push towards greener initiatives of alternate and cleaner source of fuel for long term sustainability [41]

3.2.1. Smart Transportation in Hong Kong

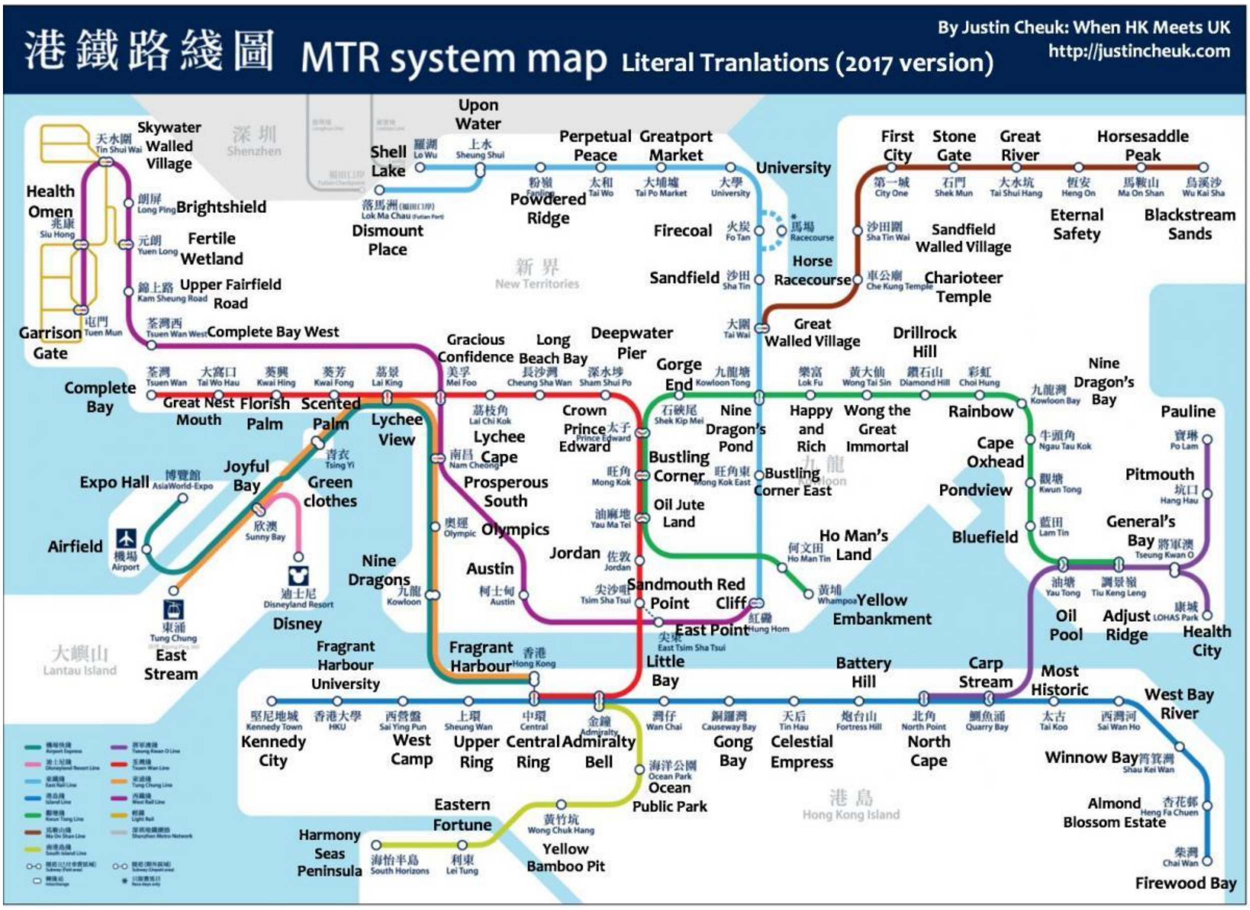

Figure 3.3: Honk Kong's MRT system
Source: www.justincheuk.com

About 90% of all passenger movements in Hong Kong is accounted by public transportation. The most frequently used mode being railways (3.58 million journeys each day), followed by buses (3.04 million), minibuses (1.29 million), taxis and ferries (720,000). Around 95% of people use Octopus Card for seamless travel on various modes of transport, while different operators have their own fare systems in places, storing and analyzing their respective passenger data separately. In December 2020, Government's Innovation and Technology Bureau released the Smart City Blueprint for Hong Kong 2.0, with 130 initiatives and strategies with a vision "to build a world-famed Smart Hong Kong characterized by a strong economy and high-quality living."

Smart Mobility makes up one of the six pillars of the blueprint, with the key goal to implement intelligent transport and traffic management through smart data and technology. These include smart tolls, real-time adaptive traffic signal systems for pedestrians and vehicles, arrival information system for green minibuses and trial and use of autonomous vehicles in various locations across the city. The Blueprint 2.0 also expects the development of a Traffic Data Analytics system to enhance traffic management capabilities by reducing road congestion and better protect road users [42].

By 2030, Hong Kong expects to cut its carbon emission as much as 70% and achieve carbon neutrality by 2050 by directing mobility measures towards by making Hong Kong's new towns more bicycle-friendly, upgraded ferry services with green technology applications and electrifying public transport and commercial vehicles, this includes electrified minibuses to connect the city with rail network, since the rail cannot access all the places. To boost private e-vehicle registrations in Hong Kong, incentive measures for EV have been implemented with first registration tax concession – 100% profits tax reduction, lower licensing fees as well as free charging services in public car parks.

3.3. Zurich, Switzerland

Zurich has a well-developed public transportation system that includes both a surface-level system and an underground system. This two-level approach has helped to address the growing demand for public transportation in the city, which is a global center for banking and finance. The surface-level system includes buses, trams, and trolleybuses, while the underground system consists of a network of trains and trams that run beneath the city. The quality and efficiency of this public transportation system is a major factor in its attractiveness to commuters, who rely on it to get around the city. [43].

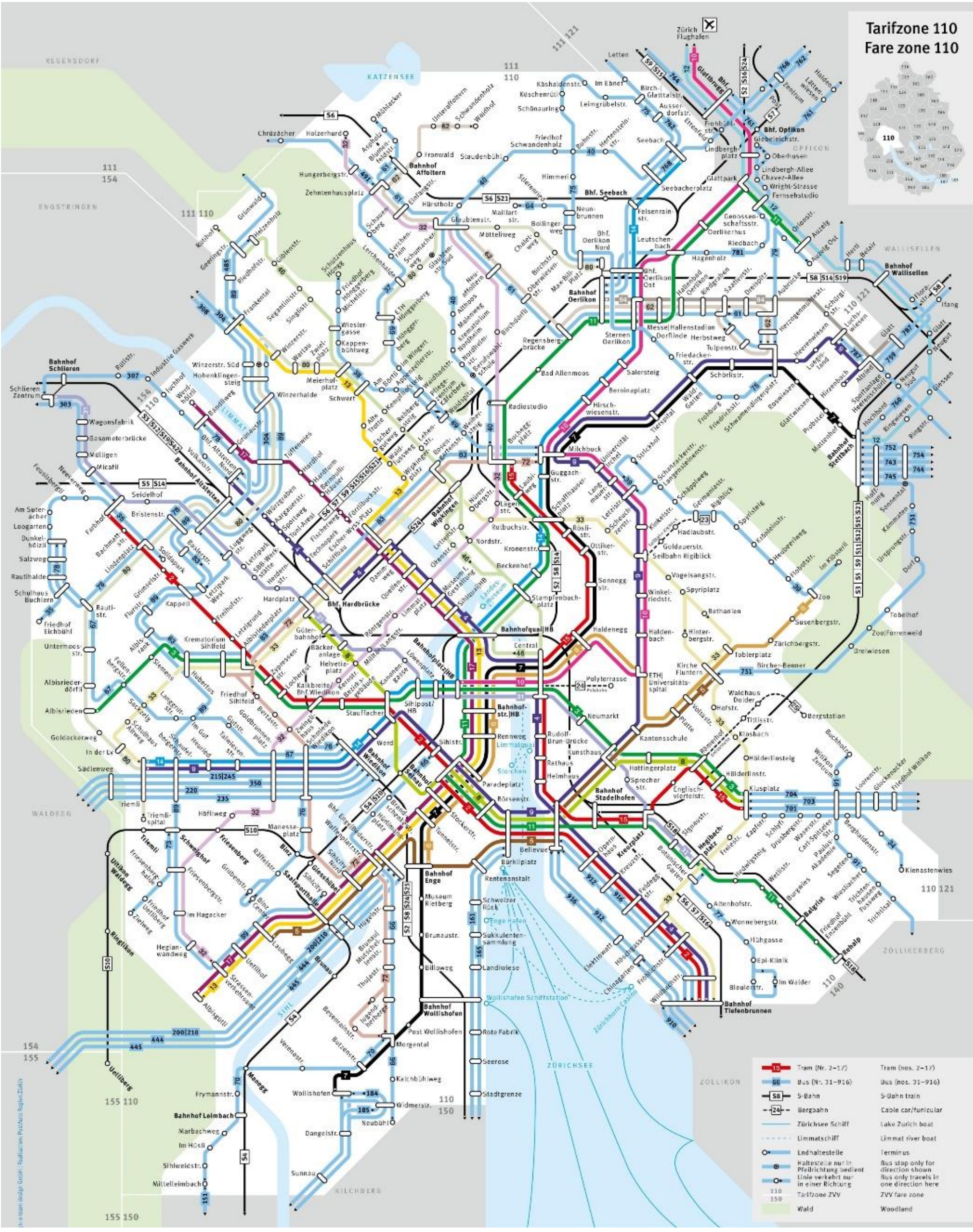

Figure 3.4: Zurich's Transportation Network Map
Source: https://ontheworldmap.com/switzerland/city/zurich/zurich-transport-map.jpg

Zurich's public transportation is limited to two levels, with the surface transportation covered by buses and trams serving short and intermediate-distance trips and S-Bahn providing the more distant regional service. Usually in different cities, urban rail (metro) is used to serve fast intermediate trips, but in Zurich this is backed up by increasing the speed of surface buses and trams and increasing the number of S-Bahn stops in the city, hence reducing the capital costs of metro while having a lower capacity of public transport infrastructure than a traditional three-level system. The combination of surface-level and underground systems also helps to reduce congestion and make travel more convenient for residents and tourists alike [44].

3.3.1. Stadtverkehr 2025: Zurich's Sustainable Mobility Plan

Zurich has implemented a range of measures to prioritize public transport and improve the urban environment for its residents. These measures include the systematic implementation of public transport in the 1980s, combined with improvements to the S-Bahn system within the city. This has resulted in the creation of one of the highest quality urban transport systems in the world. However, the city also faces significant transportation challenges, including increasing transport demand due to rapid population growth and a demand for better active transport and improved public spaces. To address these challenges, Zurich has been continuously improving its public transport system and implementing measures to increase walking, cycling, and the overall urban environment. These efforts have led to a fully integrated transport network, but the city is now focusing on prioritizing sustainable mobility plans to address the ongoing challenges of urban transportation. [44].

Zurich's sustainable mobility plan aims to improve the city's transportation infrastructure and make it more sustainable by promoting the use of public transportation, pedestrian and bicycle modes of transportation and limiting private transportation. The plan includes 39 measures across 9 categories, with the goal of increasing the mode share of public transportation to 80% by 2025. These measures include implementing a city center traffic concept and upgrading urban areas in neighborhood centers, a bicycle master plan, mobility management programs, a noise reduction program in city centers to limit vehicular speed to 30 km/h, parking planning and control to limit available parking spaces and use them to enhance public space, a traffic management system to provide control measures for sustainable transportation modes including cycling and public transport, a railway station improvement program, and the use of electric propulsion for goods transportation. [45].

3.4. Copenhagen, Denmark

The most well-known city to showcase sustainable transportation internationally, the Danish capital has been in a pioneer in city-central pedestrianization, the city's public transport system performance has been the critical component of the city's sustainable mobility credentials. The main improvement made to Denmark's urban public transport infrastructure in the last decade is the Copenhagen Metro. The main argument for its implementation was to increase market share for public transport, thus reducing car traffic, environmental impact, and enhancing urban development, especially on the island of Amager.

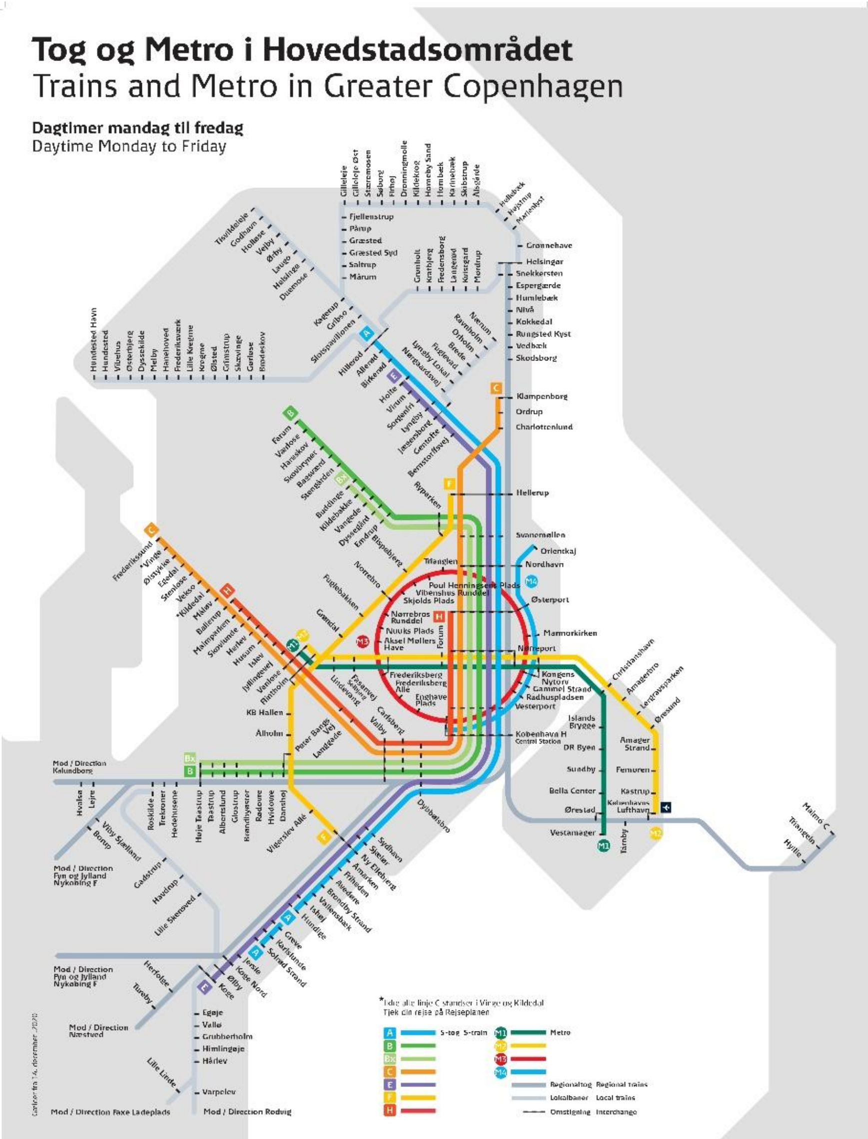

Figure 3.5: Copenhagen Rail Network
Source: https://dinoffentligetransport.dk/tourist/plan

According to existing literature on the subject, new public transport systems often result in positive public transport-induced traffic and most new mode passengers shift from pre-existing public transport modes, while former car users make up a considerably smaller market share. New infrastructures also tend to affect bus traffic, as seen in the example of 70% of Croydon Tram link passengers being former bus users. The percentage shift from car traffic ranges from 16% in Athens to 26% in Madrid. However, some studies [46] suggest that new public transport infrastructure systems have less impact than expected on reducing car traffic.

The city of Copenhagen and the Greater Copenhagen Area have a long history of strategic planning regarding localization and traffic planning, with a report existing as early as 1947, known as the Finger Plan, which outlined conditions for the city's future expansion and the development of surrounding towns along a regional train network and city train network. This plan helped ensure the best possible passenger transport between housing areas and inner-city jobs, resulting in Copenhagen being a unique European capital with minimal traffic congestion.[47].

Copenhagen had already set in motion the idea of sustainable mobility in 2009 to be a carbon neutral city by 2025, which includes creating a more sustainable mobility solution in pushing citizens to use bikes or public transport and converting remaining carparks and buses to be electrically driven. Over the last century, the demand for mobility in the city has risen since the population and surrounding suburbs have expanded in size, leading to a lengthier mobility behavior. Eliminating fossil fuel driven vehicles including cars, buses, vans, and trucks being the forefront of this movement which has had negative impacts on the 3 pillars of sustainability – Environment, Society, and the Economy.

3.4.1. Urban Transport Transition towards Sustainability

Rail transit is the dominant mode of transportation in Copenhagen. Due to the "Finger Planning" land use principle adopted by Copenhagen, the traffic corridors supported by the rail transit radiate from the city center to the peripheral areas in five directions. In the process of the city's extension to these peripheral areas, the development and construction of most infrastructure is concentrated near the railway stations, such as residential buildings and main roadways. Thus, the formation of the "Finger Planning" is formulated. Copenhagen's public transport and land use system is configured in a way that maximizes the reach of 30-minute journey with the overall presence of public travel opportunities being higher than any other European city for its size. The dense network relies on heavy rail modes to facilitate movement across its metropolitan area to a great extent with the network coverage of 73.7% of residents and jobs across the city. Proving to have good nodal connectivity and a good geographical spread of public transport nodes with opportunities of land use intensification, the city better indicates ease of movement comparable to most of its European peers [47].

The European Green capital is associated with a much greater role of bicycles, where the public transport in the inner area is outcompeted by them when it comes to shorter journeys what seems to be substituted by potential bus trips. The investment in bicycle infrastructure and the establishment of a driverless metro system with short station spacing in the inner areas, was designed in a way to seamlessly integrate the public transport to penetrate the currently bicycle dominated market.

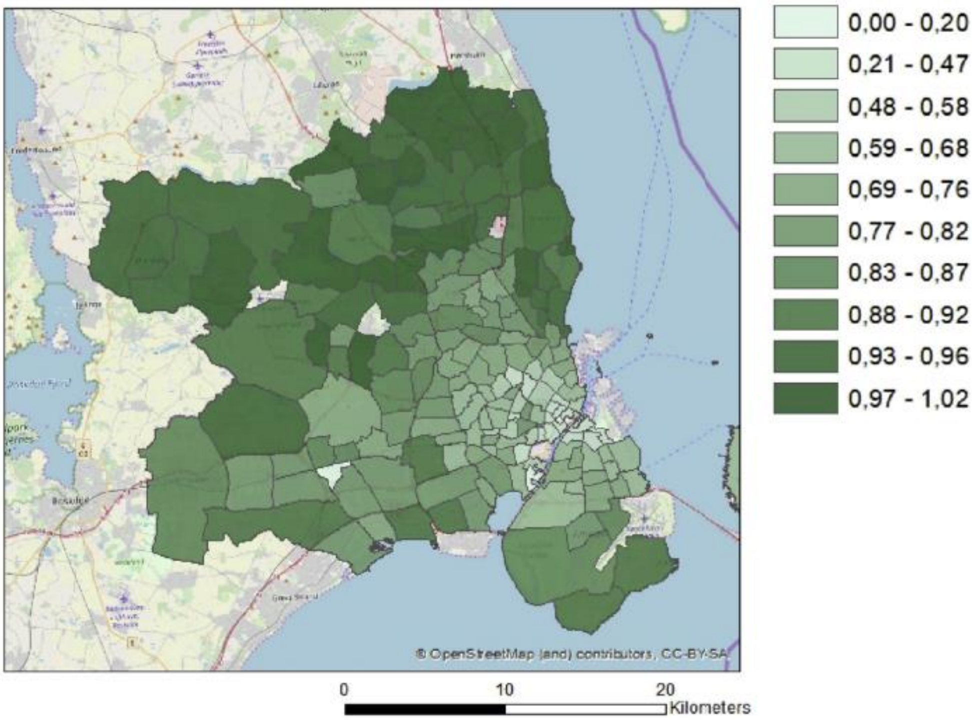

Figure 3.6: Car ownership in Greater Copenhagen Area
Source: [48]

When it comes to motor vehicles policy, the city adopts a restrictive approach to impel people to abandon private cars altogether and switch to greener modes of transport [49]. These restrictions are reflected mainly in two aspects – purchase and parking. With car taxes being roughly three times the car price, it certainly limits the people's ability towards private vehicle ownership, hence low frequency on total vehicle ownership was recorded accounting for only 14.9% overall in 2012. For parking, the city government has adopted a politically wise parking policy approach, focusing on reducing parking spaces in the central urban area to avoid the strong opposition of car owners by decreasing 2-3% of parking spaces every year. In addition, parking prices are dynamically defined by supply and demand of the area and level of public transportation available surrounding the parking region.

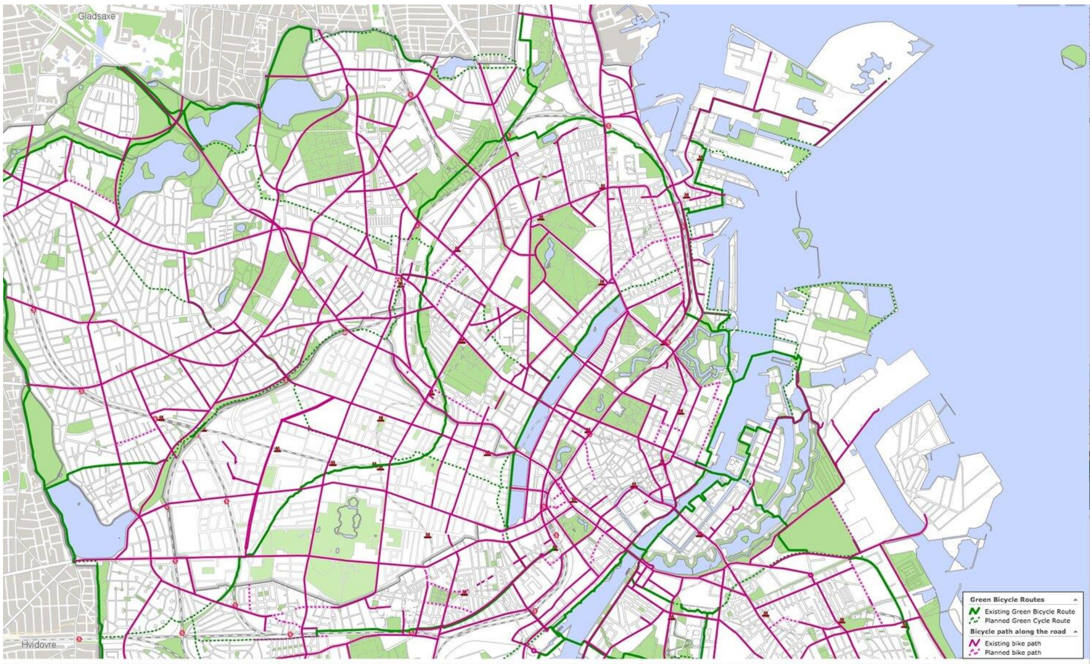

Figure 3.7: Bicycle network of Copenhagen
Source: [50]

Cycle highways are high-quality, dedicated bicycle paths designed for fast and efficient long-distance cycling. They are built to encourage cycling as a mode of transportation, reduce traffic congestion, and decrease carbon emissions from commuting. Denmark and the Netherlands have the most extensive networks of cycle highways [51] . A "Green Bicycle Route" is a designated bike path that is marked in green, and it also includes locations for bike rental and bike racks. Bike lanes in Copenhagen are becoming wider to accommodate more cyclists, with the newest lanes being 2.8 meters wide to allow for faster-moving cyclists to overtake cargo bikes or other cyclists without moving into car traffic. Studies have shown that the construction of new bicycle lanes can increase bike traffic on the road by 10-20%. Overall, these initiatives aim to encourage more people to cycle instead of driving, which can help reduce traffic congestion and CO_2 emissions. [50]

4 Transportation trends in the Middle East

The Gulf Council Community (GCC) is a regional organization comprising several Middle Eastern countries, including Qatar, Saudi Arabia, and the United Arab Emirates. For many years, the transportation systems in these countries have primarily focused on the development of road networks to support the large import market for vehicles. The only forms of public transportation have been buses and taxis. However, as traffic congestion has become a growing concern in the capital cities of these countries, the GCC has recently begun to focus on improving and developing its public transportation systems to promote sustainability and address issues such as congestion, high individual costs for public transport, and low mobility [52].

4.1. United Arab Emirates (UAE)

The United Arab Emirates (UAE) has made significant investments in its transportation infrastructure in recent years, with a focus on building a modern, efficient, and sustainable public transport network. This network includes a range of modes of transport, including buses, metros, trams, taxis, and water transport, all of which are operated by various government authorities. These investments have aimed to improve accessibility and convenience for both residents and tourists, as well as addressing issues of traffic congestion, high individual costs of transport, and low mobility. The UAE's transport infrastructure is one of the most advanced in the Gulf Cooperation Council (GCC) region and includes both road and marine transport. The country's transport network is integrated to provide seamless connections and ease of use for passengers.

4.1.1. Dubai

Dubai's rapid development and population growth in the past decade has put a strain on the city's transportation system, as more and more people have migrated to the city seeking opportunities, higher incomes, and a better lifestyle. This has led to a significant increase in the number of visitors to Dubai, including tourists, which has further exacerbated the burden on the city's transportation system. In response to these challenges, Dubai has developed a state-of-the-art public transportation network that includes seamless integration of buses, metros, trams, taxis, and water transport throughout the city. Each of these facilities is operated by government authorities, ensuring easy access and hassle-free travel for passengers and tourists alike. In general, the development of Dubai's public transportation system has been essential for the city to keep up with its rapid pace of growth and development and has played a crucial role in supporting its economic development and improving the quality of life for its residents and visitors.

In response, the city has sought to expand its road network and has implemented various forms of public transportation, including buses, taxis, and marine transport. Buses are the most frequently used mode of public transport, covering 82% of the city's urban areas and transporting around 396,248 passengers per day. Taxis are also widely available but are more expensive than buses. Marine transport in Dubai includes the use of small boats known as Abra, water buses, and water taxis, which offer similar services but differ in terms of fare, comfort, and capacity. The Dubai Tram is a ground-based electric tramway system that connects to the red line of the Dubai Metro. It is the first tramway design outside of Europe to use ground-based electric traction [53]

Figure 4.1: Dubai Metro Network Map
Source: [53]

The Dubai metro system is a rapid transit network that currently has three lines with a total length of 89.6 kilometers and 13 kilometers of which are underground. It was the first metro system to be operational in the United Arab Emirates (UAE) and the Gulf Cooperation Council (GCC) region. The demand for transportation in Dubai has grown rapidly in recent years, especially due to the popularity of the metro line among both locals and tourists. Many international companies have also chosen to relocate their businesses along the metro line, contributing to the city's economic growth. The Dubai metro is also notable for being the world's longest automated driverless metro train system, having been built in less than four years. The system is connected to other modes of transportation, such as buses and taxis, to provide a comprehensive network for residents and visitors. The driverless nature of the system allows for fast and reliable service, making it a popular choice for commuters. Additionally, the metro has helped to alleviate traffic congestion on Dubai's roads and has contributed to the city's economic development by making it more accessible for businesses and tourists.

Figure 4.2: Dubai Metro Network Map 2030
Source: [53]

The Dubai metro, the first ever metro line to be operational in the United Arab Emirates (UAE) and the Gulf Cooperation Council (GCC), currently operates three lines with a total length of 89.6km and 13km underground. The transportation demands in Dubai are growing rapidly due to the increase in demand caused by the metro line, which has attracted many international companies to relocate to the city, leading to a rise in economic activity and tourism. The Dubai metro is also the world's longest automated driverless metro train system, built in less than four years. In preparation for the major event of EXPO 2020, the second construction phase of the Dubai metro was focused on connecting to the communities hosting the event, which was postponed to 2021 due to the COVID-19 pandemic. The third construction phase is focused on improving the metro system even further. The future phase of the metro network will have six major lines with an additional 221km of rail system by the end of 2030, for a total length of 421km and 197 metro stations around the metropolitan area. This expansion is in line with the Dubai Rail Integrated Master Plan, which aims to connect the regional high-speed rail with the urban rail. Upon completion, it is expected to remove cars from the roads and reduce traffic congestion, as the first phase of the metro has been a major success due to its high quality of service. The Integrated Transport Center (ITC) has also introduced DARBI, an interactive map that provides commuters with all the information they need to plan their travel itinerary within the UAE, whether by land, air, or sea. This map improves rider satisfaction and convenience by providing transparency and timely updates on the transportation network. With the anticipation of the GCC Rail Network Development, all the metro lines will converge at Meydan, which is expected to have a station for the Etihad Rail. This network will further connect the regional high-speed rail with the urban rail and is expected to contribute to the sustainability of the transportation system in Dubai [53]

4.1.2. Etihad Rail

Etihad Rail is the national railway company of the United Arab Emirates (UAE). It was established in 2009 under Federal Law Number 2 to ease pressure on the transportation sector in the UAE, particularly in the Emirate of Abu Dhabi. The company's vision is to provide safe and sustainable rail transport and its mission is to provide a safe and sustainable passenger and freight transport rail system in the UAE through innovation and continuous improvement of technologies and practices. The company values safety, connectivity, and efficiency and sustainability and has set clear safety principles to prevent accidents at the construction site [54]. The railway network in the UAE is an ambitious project that aims to connect the GCC railway network from both ends of the border: Oman and the Kingdom of Saudi Arabia (KSA).

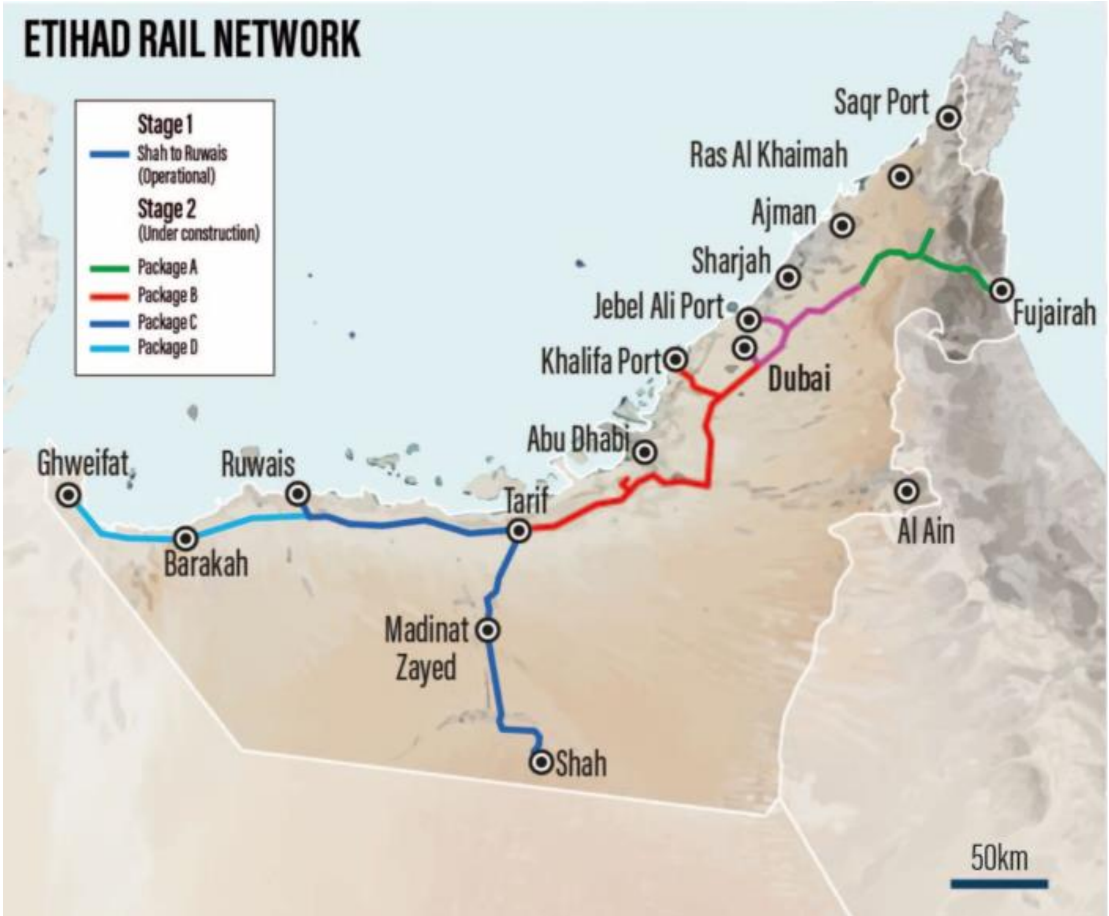

Figure 4.3: Etihad Rail Network Map
Source: https://www.thenationalnews.com/uae/2022/10/13/etihad-rail-map-what-does-the-route-look-like-and-where-does-it-go/

The Etihad rail network will stretch 1,200 km through the UAE, from the borders of Saudi Arabia to Oman's borders and is scheduled to be completed by 2018.

The UAE railway is being built in three stages:

- Stage one: The first stage is 264 km in length and will transfer granulated Sulphur from Shah and Habshan to Ruwais. One line of the first stage is already completed with testing and commissioning of the assets accomplished. Etihad Rail completed all the safety assurance procedures to start operating based on the independent safety assessor. In this stage, one being completed the Federal Transport Authority (FTA) allowed Etihad Rail to start commercial operations in December 2015. Today, it is transporting 3 million tons and more of Sulphur, which equals 200,000 truck trips.

- Stage two: The second stage is 628 km and will connect the rest of the Abu Dhabi network with the connection to Dubai. It will also connect Abu Dhabi to the KSA border via Ghweifat and the Omani border via Al Ain. By covering the borders of the country from the west and east, the network will link the essential parts of the UAE such as Khalifa port, Mussaffah and Jabl Ali port in Dubai.
- Stage three: The third stage is 279 km and will extend the network beyond Dubai to Sharja, Fujairah, and Ras Al Khaimah in the north part of the country. This stage is currently under study and the aim of the proposed railway is to finish the Etihad freight service, which will transport aggregates from the factories in the north. In this phase, passenger trains will also be optimized [55].

Etihad Rail aims to improve the efficiency and sustainability of transportation in the UAE by providing a modern and efficient railway network that reduces reliance on road transportation and reduces emissions. The company also aims to contribute to the economic development of the UAE by providing a transportation option for the movement of goods and passengers, and by creating new job opportunities. They have signed agreements with several major international companies to provide technical and operational expertise for the development and operation of the railway network. The company has also signed agreements with the governments of the UAE, Saudi Arabia, and Oman to ensure the smooth operation and integration of the railway network into the region's transportation systems.

Dubai to Abu Dhabi link completed in March 2022 will be the first passenger service operational by Etihad Rail, taking only 50 minutes of journey time within the cities, while compared to Bus – 1 hour 30 Minutes and 70 Minutes by Car. By 2030, the complete network is expected to have 36.5 million Annual passengers, while reducing carbon emission by 70-80% with 2.2 million Tons of annual carbon savings.

4.2. Kingdom of Saudi Arabia (KSA)

The Kingdom of Saudi Arabia (KSA) is one of the GCC countries with a significant economic growth. The area of the KSA is 2,150,000 km2 and the total population is 28.7 million. The first railway service in KSA was built 40 years ago and in recent years the government has decided to expand the network domestically and outside the country. The main goal of the expansion is to improve transportation of heavy goods and passengers over long distances. The KSA currently has few railway lines powered by diesel and plans to further develop their GCC line using the same fuel. The country is planning to establish a total length of more than 6,000 km with a total investment of $44.8 billion. This includes the railway line as well as the metro line for major cities like Mecca, Medina, Jeddah, Riyadh, etc. The KSA was the first country in the GCC to use railways and has experience in constructing and operating heavy railways [55].

4.2.1. Urban Metro Rail Projects

Metro rail projects in Saudi Arabia are a series of rapid transit systems that are currently under construction or in the planning stages in several cities throughout the country. The metro systems are being developed as part of Saudi Arabia's overall transportation strategy to improve mobility, reduce congestion, and provide better access to key destinations throughout the cities. The metro systems are being built by various companies such as Bombardier Transportation, CRRC and Alstom.

- Riyadh metro: The Riyadh metro is a six-line metro system that is currently under construction in the capital city of Riyadh. The metro will have 85 stations in total and is expected to serve over 3 million passengers per day. The metro is being built in three phases, with the first phase expected to be completed by 2023. The metro will connect key destinations such as the King Khalid International Airport, the King Abdullah Financial District, and the Olaya business district [56].
- Jeddah metro: The Jeddah metro is currently in the planned stages in the coastal city of Jeddah. The metro system will consist of three lines, with a total of 85 stations, and is expected to be completed by 2035. The metro will have over 30 stations in total and is expected to serve over 1 million passengers per day. The metro is being built in two phases and is expected to connect key destinations such as the King Abdulaziz International Airport and the King Abdullah Economic City. Within the city, the MRT connects with the other JPTP (Jeddah Public Transport Program) modes of transportation to form a dense accessibility-grid across the city [57].
- Mecca metro: The Mecca metro is a three-line metro system that is currently in the planning stages in the holy city of Mecca. The metro will have over 30 stations in total and is expected to serve over 2 million passengers per day. The metro is being built in two phases and will connect key destinations such as the Grand Mosque and the Makkah Royal Clock Tower [58].

- Medina metro: The Medina Metro currently in the planning stage is a part of the larger Medina Public Transport (MPT) program, which aims to improve public transportation in the city. The metro system will consist of a single line, with a total of 21 stations, and is expected to be completed by 2025. The metro will serve major landmarks and destinations in the city, including Prince Mohammad bin Abdulaziz International Airport, the Prophet's Mosque, and the city's main bus and railway stations. The metro is expected to serve over 300,000 passengers per day and will help to reduce traffic congestion and air pollution in the city.
- Dammam metro: The Dammam metro is a rapid transit system that is currently under construction in the city of Dammam, Saudi Arabia. The metro system will consist of two lines [55], with a total of 32 stations, and is expected to be completed by 2025. The metro will serve major landmarks and destinations in the city, including King Fahd International Airport, the Dammam Central Market, and the city's main bus and railway stations. The metro is expected to serve over 400,000 passengers per day and will help to reduce traffic congestion and air pollution in the city.

4.2.2. The Intercity Rail Network

The Kingdom of Saudi Arabia (KSA) has five main intercity lines in its railway network. These include:

- North-South project: This is a major railway project that runs north to south across the country and is considered one of the most important infrastructure projects in the KSA. The total length of the railway is around 2,800 km with a total investment of about $5.3 billion. 460 km of the line is shared with mineral traffic operations.
- Jubail-Dammam link: This railway line connects the cities of Jubail and Dammam. It is important for the transportation of goods and people between these two cities.
- Saudi Arabia-Bahrain causeway: This railway line is expected to run parallel to the King Fahd Causeway that links Manama and Al Khobar, and it is expected to connect KSA and Bahrain.
- Haramain high-speed rail: This is the first high-speed railway line in the entire region. It runs from Mecca to Medina via Jeddah, and it is primarily intended

to transport Hajj pilgrims. The total length is around 445 km of which 372 km lies in the Madinah–Jeddah section and 72 km in the Mecca–Jeddah section [59].

- Land Bridge line: The land bridge project is a rail line that will provide access to the Red Sea for GCC member states by connecting with the GCC railway network. It is expected to have the maximum annual traffic in the KSA and to improve trade and transportation between GCC countries and will be an important link for the economic growth of the region [55].

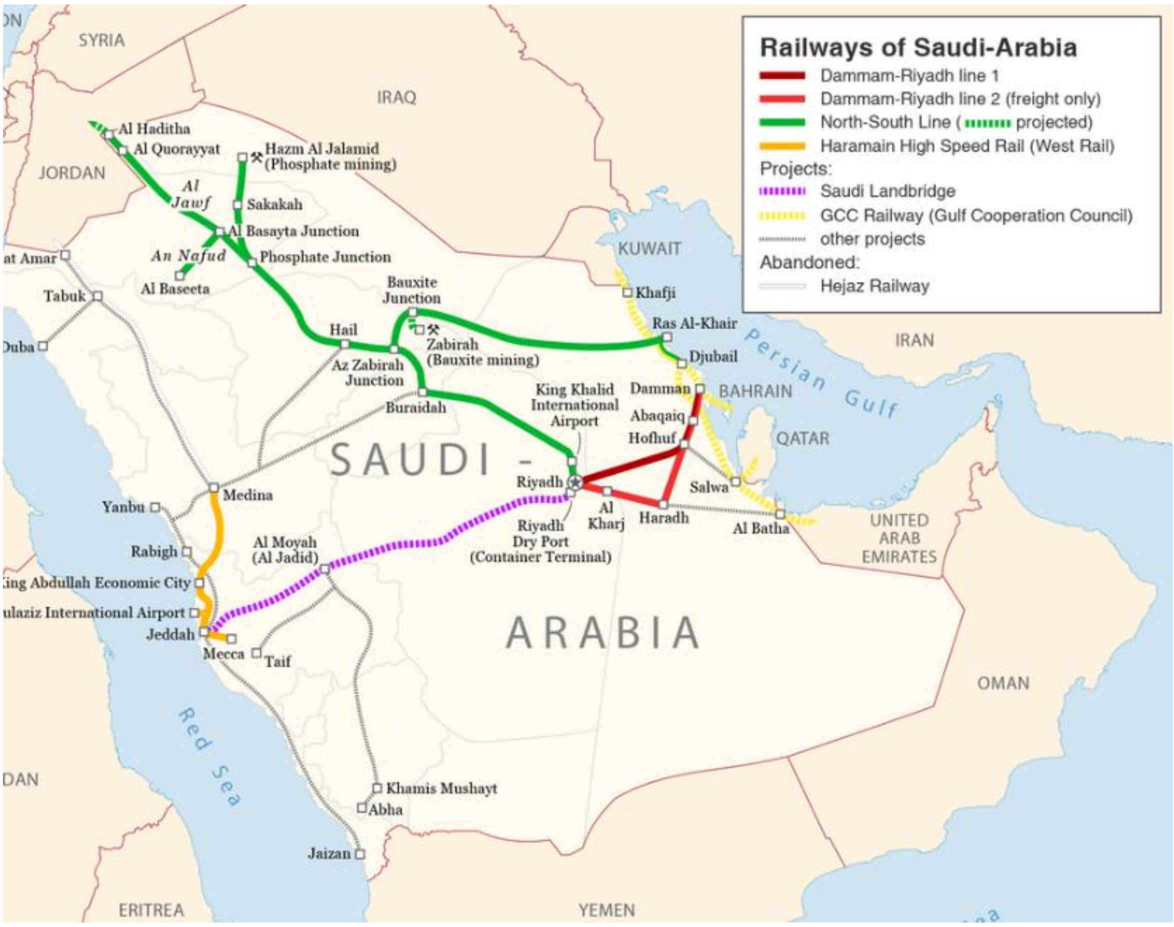

Figure 4.4: Intercity Rail Network in KSA
Source:https://en.wikipedia.org/wiki/Saudi_Railways_Organization#/media/File:Rail_transport_map_of_Saudi_Arabia.png

These intercity lines in the KSA are being developed with the aim of improving transportation of goods and people over long distances and reducing the dependence on road transport. The high-speed rail project is expected to significantly improve the transportation of Hajj pilgrims between Mecca and Medina.

4.3. Oman

The Oman Rail Project is a proposed railway network in Oman that will connect the country's major cities and ports. The project is being developed in three phases, with the goal of improving mobility, reducing congestion, and providing better access to key destinations throughout the country. The Oman Rail project is being developed by the Oman National Railway Company (ONRC) in partnership with various other companies such as Oman National Transport Company and Oman Rail Company. The railway network is expected to be completed by 2040 and will be equipped with advanced technology, including automatic train control and communication-based train control systems, to ensure safety and efficiency [60]. Additionally, the network will include various amenities such as parking, bicycle storage, and retail spaces to make it more convenient for the public.

- The first phase of the project will focus on building a rail link from the port of Sohar to the border of the United Arab Emirates (UAE). This will connect the industrial and commercial hub of Sohar to the rest of the country and provide a direct link to the UAE, allowing for greater trade and commerce between the two countries.
- The second phase will connect the capital city of Muscat to the border of Saudi Arabia. This will provide a direct link between the two countries and will also connect the city of Muscat to the rest of the country. This will also help to promote economic development in the area.
- The third phase will connect the northern region of Oman to the rest of the network. This will provide access to the northern region for both cargo and passengers and will help to promote economic development in the area [61]

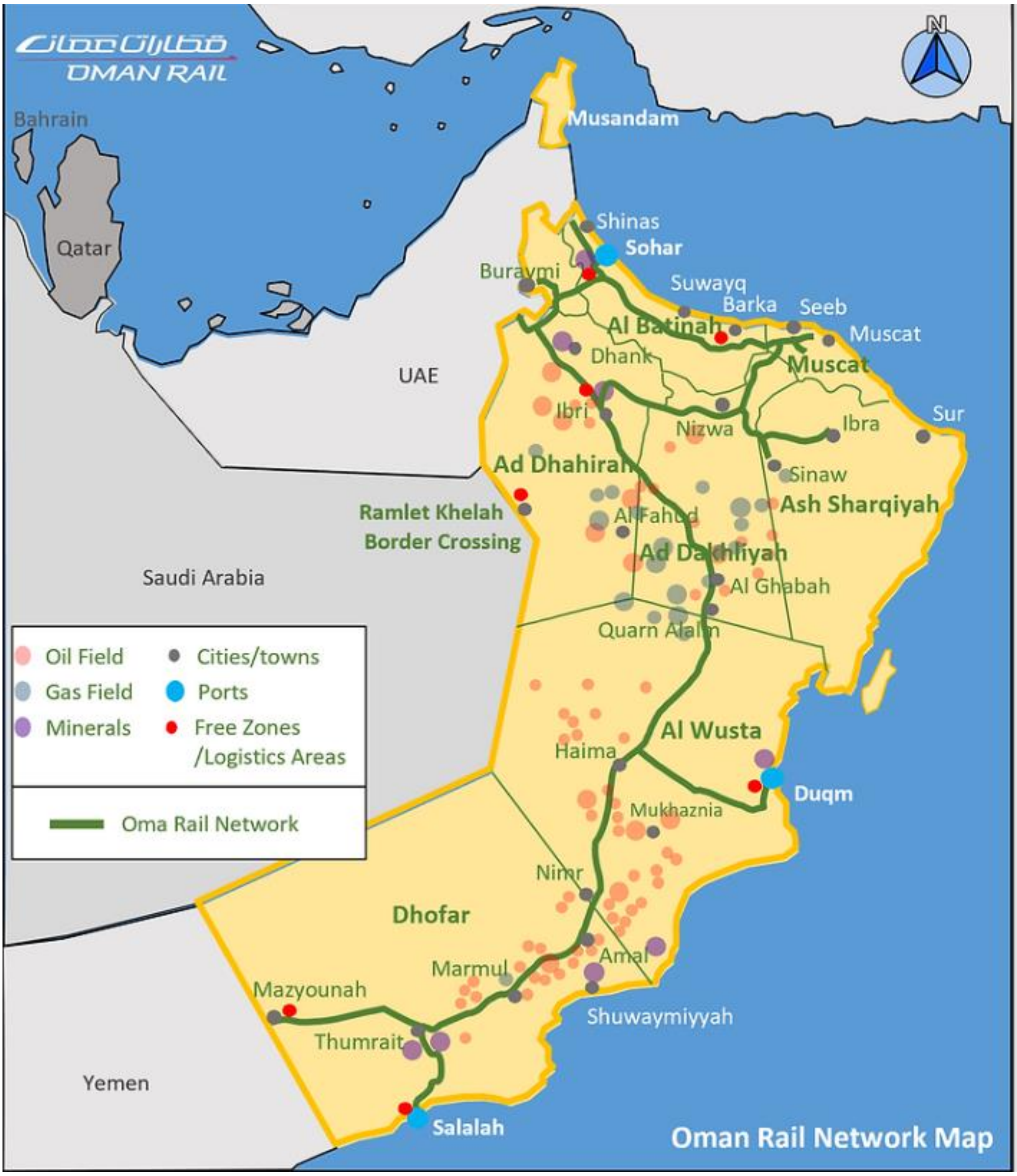

Figure 4.5: Oman Rail Network Map
Source: [60]

5 Current State of the Art

The QNV (Qatar National Vision) 2030 has set out a plan to create a comprehensive transportation system in Doha through various strategies and measures. These include expanding the public transport options, building a high-speed rail network, expanding the road network, and developing sustainable transportation methods. This includes building a metro system, bus network, and ferry system, connecting Doha to other parts of the country via high-speed rail and improving connectivity within the city through road network expansion. Sustainability is also a key focus with efforts to promote the use of non-motorized transportation options such as cycling and walking, as well as incorporating electric and hybrid vehicles. The goal of these efforts is to improve the efficiency and accessibility of transportation in Doha and decrease the reliance on personal vehicles to decrease congestion and improve air quality. The country's bid to host the 2022 FIFA World Cup has acted as a catalyst for these efforts as they aim to complete these transportation improvements before the event.

5.1. Public Transportation Systems in Qatar

5.1.1. Doha Bus

Doha, the capital city of Qatar, has a well-developed bus transportation system that is operated by Mowasalat, the government-owned public transport company. Public transportation in Doha, Qatar emerged in 2004 when the company introduced the beginnings of the national bus system for use by the public [62]. Originally operated on restricted routes, the system had slowly expanded to reduce the number of vehicles moving in Doha. The bus system currently is integrated with the Doha Metro to provide passengers with a seamless travel experience.

The bus system in Doha comprises of a fleet of around 800 buses that operate on more than 90 routes across the city. The buses are equipped with modern amenities such as air conditioning, GPS tracking, and real-time information displays. They run from early morning until late at night, with different frequency of buses depending on the route and the time of day.

The bus system in Doha is divided into several categories: City Buses, Express Buses, and Airport Buses. City buses are the most frequent type of bus and serve the most densely populated areas of the city. Express buses are designed to serve areas that are not covered by the city buses and provide faster and more direct service to major destinations. Airport buses connect the city center to the airport and operate 24/7. The bus system in Doha also includes several feeder routes that connect the metro stations to nearby neighborhoods and other destinations. These feeder buses are operated by Mowasalat and are designed to complement the metro service, providing passengers with a convenient and efficient way to get to and from the metro stations.

Mowasalat also operates several long-distance bus routes that connect Doha to other cities and towns in Qatar. These buses are equipped with comfortable seats and air conditioning, making them a comfortable option for traveling to other parts of the country. The entire bus transportation system of Doha is integrated with the Doha Metro, with many buses stopping at metro stations allowing for easy transfer between the two modes of transportation, also the bus fare system is integrated with the metro fare system, allowing passengers to use a single fare card to travel on both the bus and metro [63]

5.1.2. Doha Taxi

Taxis are considered as a form of public transportation that bridge the gap between private and public transport in terms of time and space. They are generally evaluated based on the performance index used for bus services. In many countries, taxis are owned and operated by private companies, but in some cases, they benefit from subsidies provided by the government to maintain service quality [64]. The taxi system in Doha is operated by Mowasalat, the government-owned public transport company. Taxis in Doha are typically modern, air-conditioned vehicles, equipped with GPS tracking, and are available in various types like Saloon, MPV, SUVs and limousines. They provide an important mode of transportation for residents and visitors of the city. Taxis in Doha can be hailed on the street, booked by phone, or via a mobile app. They also can be found at designated taxi stands located at major destinations such as shopping malls, hotels, airports, and metro stations.

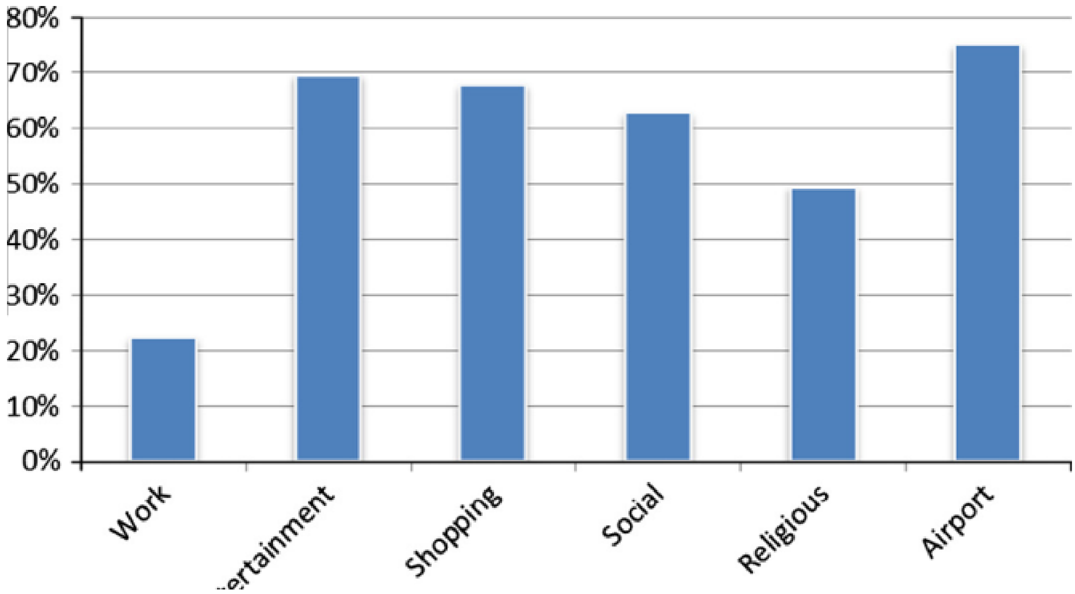

Figure 5.1: Taxi use rate by trip purpose in Doha
Source: [64]

Fares for taxis in Doha are metered, and the rate is determined by the distance traveled, with additional charges for waiting time, extra passengers, and baggage. There is also a flat rate for trips to and from the airport. The fare system is integrated with the metro fare system, allowing passengers to use a single fare card to travel on both the taxi and metro. Mowasalat also operates a premium taxi service called "Karwa Silver" which provides luxury vehicles and professional drivers for high-end customers. This service is typically more expensive than regular taxis but offers a higher level of comfort and convenience.

The taxi system in Doha is also integrated with the public transportation system, with many taxis stopping at metro stations allowing for easy transfer between the two modes of transportation. This integration makes it more convenient for passengers to travel around the city, as they can easily switch between different modes of transportation to reach their destination.

In addition, the taxi service in Doha is available 24/7, providing reliable and efficient service to the passengers. Mowasalat also offers a pre-booking service for passengers who want to book a taxi in advance. Overall, the taxi system in Doha is reliable, convenient, and efficient, providing residents and visitors with an easy and comfortable way to travel around the city, with various options to choose from, depending on the budget and the level of comfort.

5.2. Qatar Rail Development Program

The Qatar Rail Development Program is a multi-billion-dollar project that aims to build a comprehensive railway network in Qatar. The program includes the construction of four new rail lines: the Doha Metro, the Lusail Tram, the Qatar Integrated Rail Project, and the Long-Distance Passenger and Freight Rail. The Doha Metro is a rapid transit system that will serve the city of Doha and its surrounding areas. It will consist of three lines, the Red Line, the Green Line, and the Gold Line, and will have a total length of approximately 180 km. The Lusail Tram is a light rail system that will serve the city of Lusail, located north of Doha. It will have a total length of approximately 19 km and will consist of two lines. The Qatar Integrated Rail Project is a passenger and freight rail line that will connect Doha to the rest of the country, including the border with Saudi Arabia. It will have a total length of approximately 380 km. The Long-Distance Passenger and Freight Rail is a rail line that will connect Qatar to the rest of the Gulf Cooperation Council (GCC) countries. It will have a total length of approximately 2,400 km.

5.2.1. Doha Metro

The Doha Metro is a highly significant and visible project in Qatar, set to be constructed in two phases [65], the 2022 FIFA World Cup being the catalyst for the completion of Phase 1. Most people in Doha used to rely on buses or private motor vehicles to get around. However, with the introduction of the Doha Metro, people will have a new mode of transportation to choose from. The perception of residents towards the metro may not be immediately apparent, as it is a new system, and many people may not have had experience with a metro before. This can make it difficult to predict the possible impacts of the metro on the city and its residents. However, in cities where rail systems are already established, residents have already experienced the benefits of such systems and are more likely to embrace the new transportation option. [66].

The Doha Metro is a modern, state-of-the-art transportation system that aims to provide a reliable and efficient means of transportation for residents and visitors of the city of Doha. The system is designed to accommodate the city's growing population and to support the city's economic development.

The Doha Metro has four lines: the Red Line, the Green Line, the Gold Line, and the Blue Line (under construction). The Doha Metro system features fully automated, driverless trains that are equipped with the latest technology to ensure safety, comfort, and efficiency. The trains are air-conditioned and have a capacity of up to 600 passengers per train. The system will also feature multiple payment options, including smartcards, mobile payments, and QR codes to make the payment process easier for riders.

It is designed to be fully accessible for people with disabilities, with features such as low-floor trains, elevators, and ramps at all stations. The metro system will also provide a park-and-ride service to encourage the use of public transportation and to reduce traffic congestion. It is expected to have a significant impact on the city's transportation system, helping to reduce traffic congestion and air pollution, and making it easier for residents and visitors to get around the city. It will also support the city's economic development by providing a reliable transportation system for businesses and employees, and by making it easier for people to access job opportunities.

5.2.1.1. Phase 1

The Red Line also known as the Sea Line, opened in 2019, runs from Al Wakra to Lusail City, passing through important locations such as Hamad International Airport, Msheireb, and West Bay. The Green Line, also known as the Education Line runs from Al Mansoura to Al Riffa and will connect major residential areas and business districts. The Gold Line also known as the Historic line, will run from Al Aziziyah to Ras Bu Abboud passing through the historic regions of Doha including the Souk Wakif and the National Museum of Qatar. All of which will interchange at the downtown of Msheireb, the heart of the city.

Line	Symbol	Inaugural date	Length km	Stations	Termini	Status
Red Line		8 May 2019 (Al Qassar to Al Wakra) 10 December 2019 (Hamad International Airport, Katara, Qatar University and Lusail)	40	18	Lusail Hamad International Airport Al Wakra	Fully operational.
Green Line		10 December 2019[13]	22	11	Al Riffa Al Mansoura	Fully operational.
Gold Line		21 November 2019[14]	14	11	Al Aziziya Ras Abu Aboud	Fully operational.

Figure 5.2: Summary of Phase 1 Lines
Source: https://en.wikipedia.org/wiki/Doha_Metro

Figure 5.3: Doha Metro Phase 1 Network Map
Source: https://www.tunnel-online.info/en/artikel/tunnel 2680506.html

5.2.1.2. Phase 2

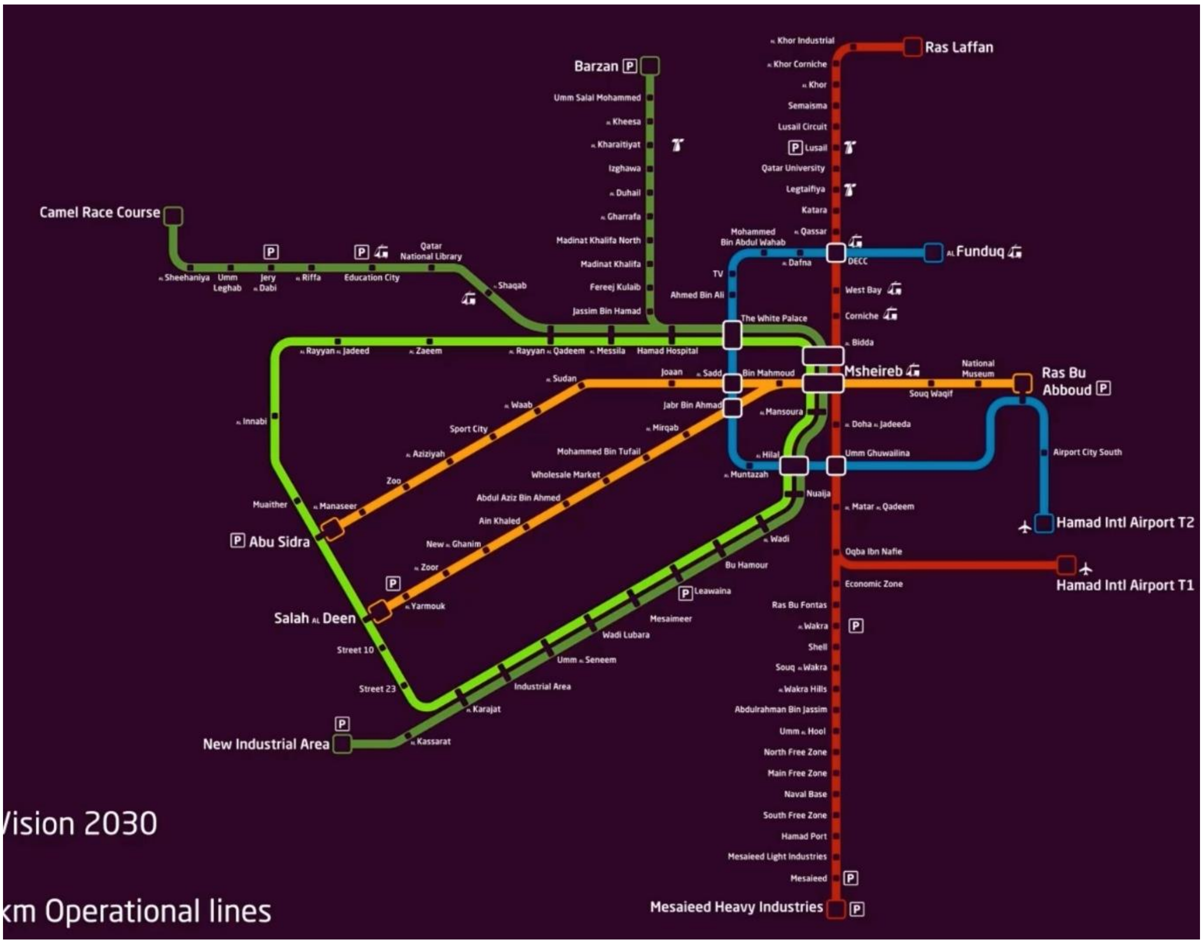

Figure 5.4: Doha Metro Phase 2 Proposed Network Map
Source: https://qezar.com/blog/news/first-phase-of-doha-metro-vows-to-lessen-traffic-on-qatar-roads

The Doha Metro project is an ambitious and ongoing transportation infrastructure development for the city of Doha. While the three main metro lines (Red, Green, and Gold) are fully operational, the city is continuously seeking out new transportation improvements to further develop the metro system towards the end of 2030. The Second Phase of the Doha Metro project, set to begin construction after the 2022 FIFA World Cup, will improve upon the existing Phase 1 network and include a new downtown Blue Line. The future network will expand upon the existing Green Line, extending it from the New Industrial Area in the Southwest to the Suburban Regions, Camel Racecourse Station in the Northwest, and Barzan in the North of Doha. The Red Line will be extended beyond Lusail in the North of Qatar, to Ras Laffan, the Oil Refinery Industrial Area, and the Mesaieed Industrial Area in the South of Qatar. The

Yellow Line will be branched out to Salah Al Deen, improving the network coverage in the city.

The new Blue Line is set to connect to the new International Airport Terminal 2 to Al Funduq through the core boundaries of the city, improving the integration of the whole network by providing seven additional interchange stations across all lines. This will provide a seamless and efficient transportation option for travelers and residents, making it easier for them to move around the city.

The Doha Metro project is a major infrastructure development for the city, and the government of Qatar is investing heavily in the project to ensure its success. The government is also working closely with international partners to bring the latest technology and expertise to the project. The ongoing development of Doha Metro is expected to create thousands of jobs and support the city's economic development. The Doha metro is a clear example of how public transportation can be a significant contributor to the development of a city and its citizens.

5.2.2. Lusail Tram

The Lusail Light Rail Transit (LRT) system is a light rail network being developed by Qatar Rail in the new city of Lusail, located 15km north of Doha, Qatar. The network will consist of four main tram lines that span 33.1km and 37 passenger train stations, including 26 at ground level, ten underground, and one elevated interchange station. The Lusail LRT, along with Doha Metro and the Long-Distance Passenger and Freight Rail transportation system, forms part of Qatar's $30bn integrated transportation system [67]

Figure 5.5: Lusail Tram Infrastructure Map
Source: https://www.protenders.com/projects/lusail-light-rail-transit

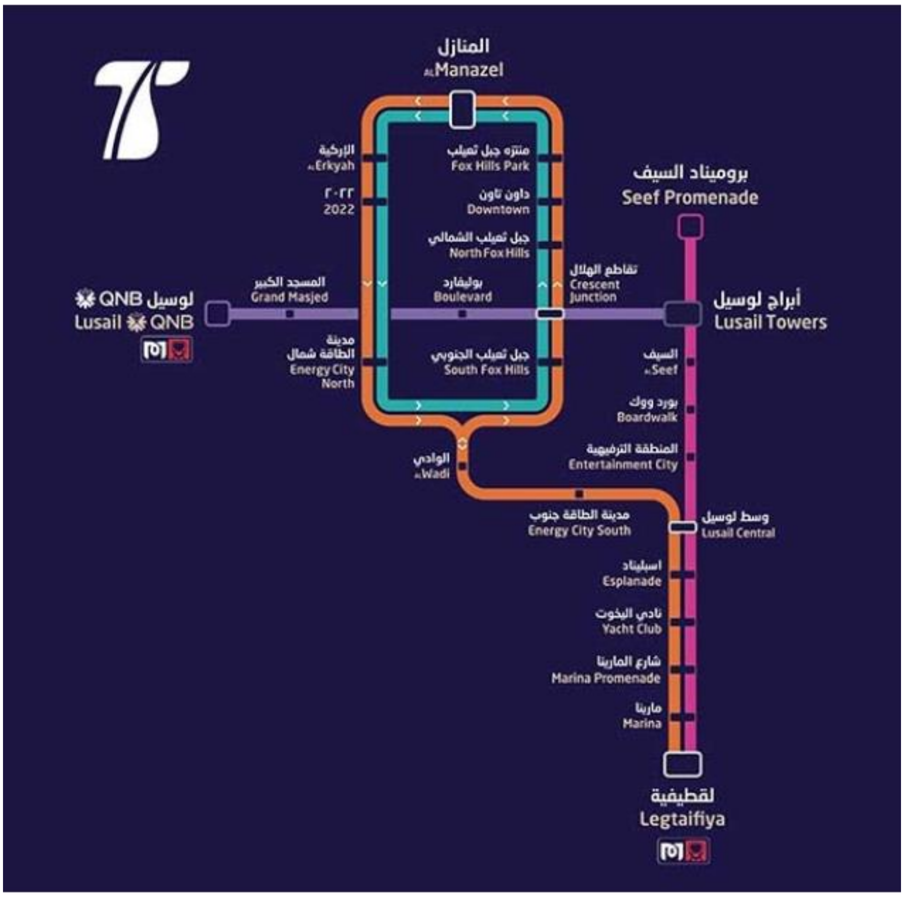

Figure 5.6 Lusail Tram Network Map
Source: https://corp.qr.com.qa/English/Projects/Pages/LusailLightRailTransit.aspx

The first line of the light rail network, the Yellow Line, has been operational since 2018 and the remaining three lines are expected to enter commercial service in 2023. The network will comprise 10.4km of underground track and 22.7km of ground level and elevated tracks, including a 0.5km track between two high-rise buildings. It will include approximately 8km of single track and 25km of double track. The elevated interchange station will serve the tram running on a viaduct across Al Khor Highway.

The northern sector of Lusail City will contain ground-level stations featuring center, side, and split-side platforms. These stations will connect Fox Hills district, the Northern Residential district, the Medical and Educational districts, the Golf district, and Lusail City's plaza. In the southern part of the city, 8km of underground tracks will link various residential districts and serve underground stations in the Marina district, Energy City, Qatar Entertainment City, Qatar Petroleum District, and the Pearl. A service depot with maintenance and storage facilities, as well as a test track, will also be built as part of the project [68].

The LRT was conceived to enhance transportation within the planned city and improve connectivity to entertainment centers such as Lusail Stadium that will host 2022 FIFA World Cup matches. The Lusail LRT will be operated with a fleet of 35 Alstom Citadis trams. The 32m-long, 100% low-floor trams ensure easy access to passengers. The trams will run on catenary-free electrification system except inside the tunnels where a dual-power connection with a catenary system will be installed [69]. The Alimentation Par le Sol (APS) technology installed in the trams will allow ground-level power supply from a third rail, avoiding the need for overhead cables. The QDVC joint venture, comprising Lusail city's developer Qatari Diar and French contractor Vinci Construction Grands Projects, is the main design and build contractor for the project.

5.2.3. Metrolink

The concept of accessibility in the context of transportation refers to the ease with which people can reach the places they need to go, whether it be for work, leisure, or other purposes. This includes the availability and reliability of different modes of transportation, such as buses, trains, or even walking and cycling. It also involves the cost and time it takes to travel between different locations, as well as the ability to connect to other transportation networks or transfer between different modes of transport [70]. All these factors are important in determining the overall quality of a transportation system, and in encouraging people to use public transportation rather than private vehicles. The merger of Qatar Rail and Mowasalat under the name

'Metrolink' is aimed at improving accessibility in the country by providing a more comprehensive and convenient public transportation network.

Metrolink is a feeder bus service that operates within a 2-5km radius of metro stations in Doha, Qatar. It is designed to provide first and last mile connectivity to Qatar Metro customers, allowing them to easily access the metro system and improve their overall travel experience. This means that commuters can use the Metrolink service to reach a metro station and then transfer to the metro to continue their journey, making it easier for them to travel around the city. The service is free of charge and operates on fixed routes, making it easy for commuters to plan their trips and connect to different parts of the city. The fixed routes also ensure that the service is reliable and consistent, which makes it more appealing to commuters. The service is also designed to be accessible, providing convenient boarding and alighting locations at metro stations, and making it easy for commuters to transfer between the Metrolink and the metro.

Metrolink also plays a key role in shifting the country's transportation system from a reliance on bus transportation to a more integrated, multimodal approach. This means that the service is designed to work seamlessly with other modes of transportation, such as the metro, to provide a more comprehensive and efficient transportation system. By integrating different modes of transportation, it has the potential to reduce traffic congestion and improve overall mobility in Doha. This can lead to a reduction in travel time, lower transportation costs, and better accessibility for commuters, making it a more attractive and efficient mode of transportation.

Figure 5.7: Metrolink transportation for last mile connectivity

Source: [71]

6 Qatar's Push to Sustainability

Sustainability is a key focus for Qatar as it works to reduce its dependence on fossil fuels and lower carbon emissions from the transportation sector. The country has implemented a variety of initiatives to promote sustainable transportation, including investing in public transportation infrastructure, promoting electric vehicles, and implementing policies to reduce carbon emissions. Through the expansion of its metro and bus rapid transit systems, as well as the development of a light rail system, Qatar is encouraging the use of public transportation instead of personal vehicles. Additionally, Qatar has set a goal to have at least 20% of the vehicles on the road be electric by 2030 and is offering incentives for the purchase of electric vehicles, such as tax exemptions. Furthermore, Qatar is also investing in the development of a charging infrastructure to support the growth of EVs. These efforts, along with policies to reduce carbon emissions from the transportation sector, are helping Qatar make significant progress in promoting sustainable transportation and reducing its carbon footprint.

6.1. Qatar Transportation Master Plan 2050

Transportation master plans serve as a comprehensive guide for the development and improvement of transportation infrastructure, covering a period of 20 to 30 years. They outline how a state or city will develop its transportation networks, coordinate infrastructure improvements with land use, and address future growth and demands. The goals and policies identified in these plans typically include strategies to improve safety, reduce congestion, and protect the environment. They encompass all aspects of transportation, including highways, public transport, non-motorized transport, parking, travel demand management, and cross-modal integration.

To ensure that the transportation system serves the needs of all users, successful master plans consider the needs of drivers, public transport riders, cyclists, and pedestrians. The development of a master plan typically includes an evaluation of existing conditions, identification of infrastructure needs and financing requirements, development of evaluation criteria to prioritize needs, and an action plan to implement recommended infrastructure investments or improvements. It is common practice to update transportation master plans at regular intervals, usually every ten years, especially when the country or region experiences major economic, social, and demographic changes. This ensures that the transportation system remains responsive to the changing needs of the population and continues to support the overall goals and objectives of the state or city.

Qatar is promoting sustainable transportation as a key component of its Qatar National Vision 2030, with a focus on reducing dependence on fossil fuels and lowering carbon emissions. The Updated Transportation Master Plan for Qatar (TMPQ) aims to balance the requirements of economic growth with protection of the environment, and includes initiatives such as expanding public transportation infrastructure, promoting electric vehicles, and implementing policies to reduce carbon emissions. The TMPQ also considers the need for efficient and sustainable transportation solutions for major international events, such as the 2022 FIFA World Cup. Overall, transportation and sustainability are closely linked in Qatar's efforts to drive sustainable development and economic growth [72].

6.1.1. Strategic Highway Network

The highway schemes proposed in the Updated TMPQ have been designed to increase capacity and reduce congestion, keeping in mind the future growth in demand. A well-functioning road network is important for promoting economic growth and improving the standard of living for the people of Qatar, as well as facilitating the movement of people and goods across the country. The highway network also plays a crucial role in the transportation of freight, with Heavy Goods Vehicles (HGVs) mostly dependent on expressways and arterial links, and Light Goods Vehicles (LGVs) dependent on the entire road network for the distribution of goods to various destinations.

The proposed highway schemes aim to:

- Utilize ring roads to move traffic within the Doha Metropolitan Area (DMA) and reduce reliance on radial roads to enter the DMA.
- Improve parallel roads to existing congested roads outside the DMA.
- Prioritize the completion of remaining parts of highways to have a connected functional highway network within and outside the DMA.

The updated TMPQ includes a total of 86 highway schemes, which include 39 highway infrastructure and facility schemes, 28 service and operation schemes, 9 policies and regulations schemes and 10 planning and technology schemes.

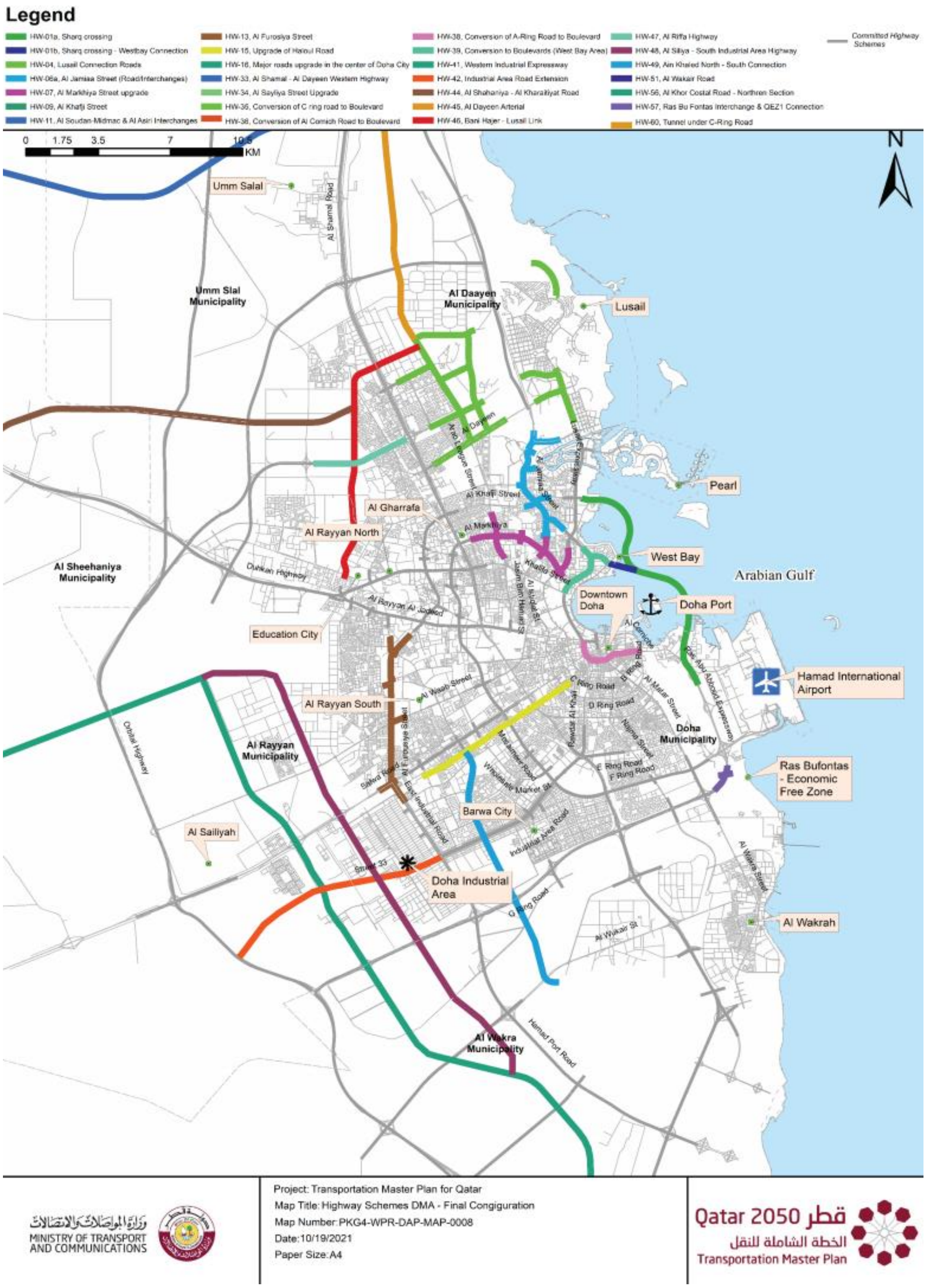

Figure 6.1: Highway Scheme Configuration in Doha Metropolitan Area
Source: Ministry of Transport, State of Qatar

6.1.2. Long distance and Regional Rail Network

The long-distance rail network proposed for Qatar is an important component of the country's transportation system and aims to support the transportation of passengers and freight, promoting economic and social development. The rail network is designed to connect key locations and cities within Qatar, as well as with neighboring countries. The Updated TMPQ includes four schemes in the final list of rail schemes, out of which three are infrastructure schemes and one is regulatory.

The three infrastructure schemes include:

- A passenger rail line connecting Qatar with Saudi Arabia, which will provide a direct and efficient transportation option for people travelling between the two countries and support economic and social development.
- A new Doha Main International Terminal connecting with HIA (Hamad International Airport), which aims to improve the transportation services for passengers arriving and departing from the airport and support the growth of the tourism and aviation sectors.
- A freight rail line connecting Saudi Arabia with Hamad Port and Mesaieed Industrial City, which aims to support the transportation of goods and raw materials and promote economic development by providing efficient and reliable transportation options for businesses and industries.

Five rail schemes have been deferred until 2050, due to lack of demand to justify them. These included two passenger rail lines, two commuter rail, and one freight rail line. This means that these schemes are not currently considered as a priority and will be re-evaluated in the future if the demand for them increases [72].

Figure 6.2: Long Distance Rail Scheme
Source: Ministry of Transport, State of Qatar

6.1.3. Bus Rapid Transits and Key Bus Lines

Existing bus services in Qatar form a relatively extensive network, both in Doha and nationally. The government of Qatar is currently implementing additional services and supporting infrastructure, which will provide further coverage in most areas of Doha. The improvements of bus services, especially those that support the Metro, are raising standards and making bus services more attractive to the public. Once rail-based mass transit radial routes have been developed, bus-based services play a vital role in connecting those radial links and complementing the network. The proposed strategy for bus service improvements in the Updated TMPQ (Transportation Master Plan of Qatar) centers around the creation of key Bus Rapid Transit (BRT) routes.

Bus Rapid Transit is a bus-based mass transit system characterized by specialized design and infrastructure to improve transit quality and reduce delays. It is considered a cost-effective alternative mode for key corridors compared to metro, provides local accessibility to employment, or discourages car traffic in areas where pedestrians need to be prioritized. The main advantage of BRT is its relatively short planning and construction process, high transport capacity and cost-effectiveness [73]

These BRT routes provide an alternative (lower cost) mode of transportation for key corridors (such as Doha Expressway) compared to the metro, provide local accessibility to employment, and discourage car traffic in areas where pedestrians need to be prioritized (such as along the Corniche).

Other complementary bus schemes are proposed to address specific issues or improve geographical coverage in areas where demand can justify scheduled services. In total, there are 20 BRT and Bus Schemes, including nine infrastructure/facility schemes, eight new services/operations, and one each of regulatory, fleet and transportation planning schemes. The infrastructure/facility schemes focus on the construction and development of bus stops, depots, and terminals that support the bus services. The new services/operations schemes focus on the implementation of new bus routes, frequency of service, and other operational aspects of the bus services. The regulatory, fleet and transportation planning schemes focus on the policies, regulations, and guidelines that govern the bus services and the fleet management of the buses [72].

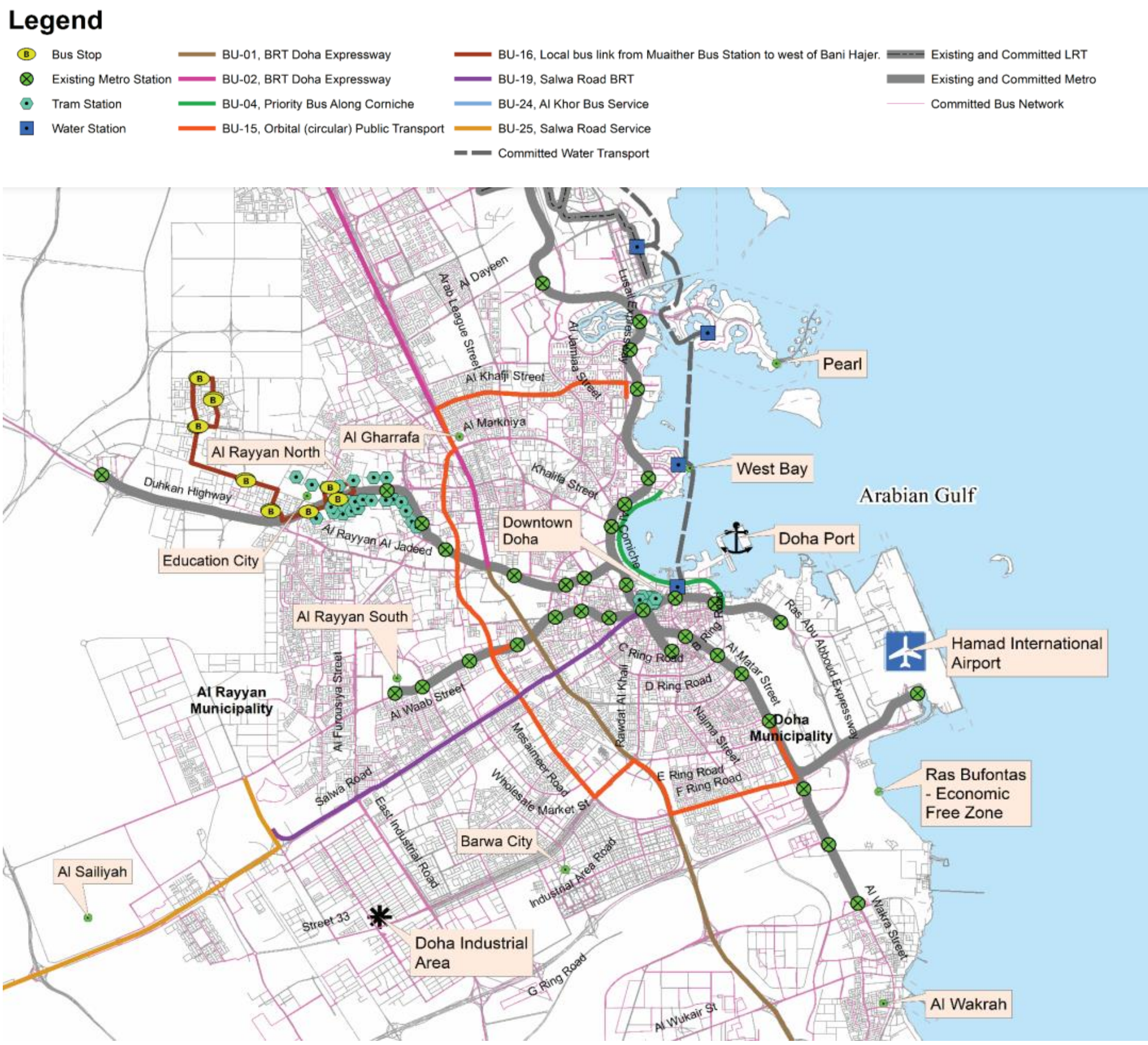

Figure 6.3: BRT and Bus Schemes in Doha
Source: Ministry of Transport, State of Qatar

6.1.4. Water Taxis

Water taxis are boats or watercraft that are used to transport passengers, like traditional land-based taxis. They may be used in coastal or riverine areas and can provide transportation services to individuals or groups. Water taxis are often faster and more efficient than traditional boats or ferries, and can be used for sightseeing, commuting, or transportation to and from islands or other areas not easily accessible by road. They can be powered by motors, sails, or a combination of both. Some water taxis are also used for transportation of goods as well.

The proposed ferry service would provide an alternative mode of transportation for residents, visitors, and tourists in areas along the coastal line, reducing the reliance on road transportation and helping to alleviate traffic congestion. The service would connect major residential, commercial, and leisure areas with easy access to Doha or the West Bay, providing convenient access to key destinations such as Hamad Port, Doha Port, HIA (Hamad International Airport), Al Wakrah, QEZ 3 and Al Khor. The extension of the service all the way to Al Khor would provide greater connectivity and accessibility to areas further north and support the development of these areas. Additionally, the ferry service would promote sustainable transportation and contribute to reducing the carbon footprint. The ferry service would also provide an opportunity for scenic views and enhance the tourist experience [72].

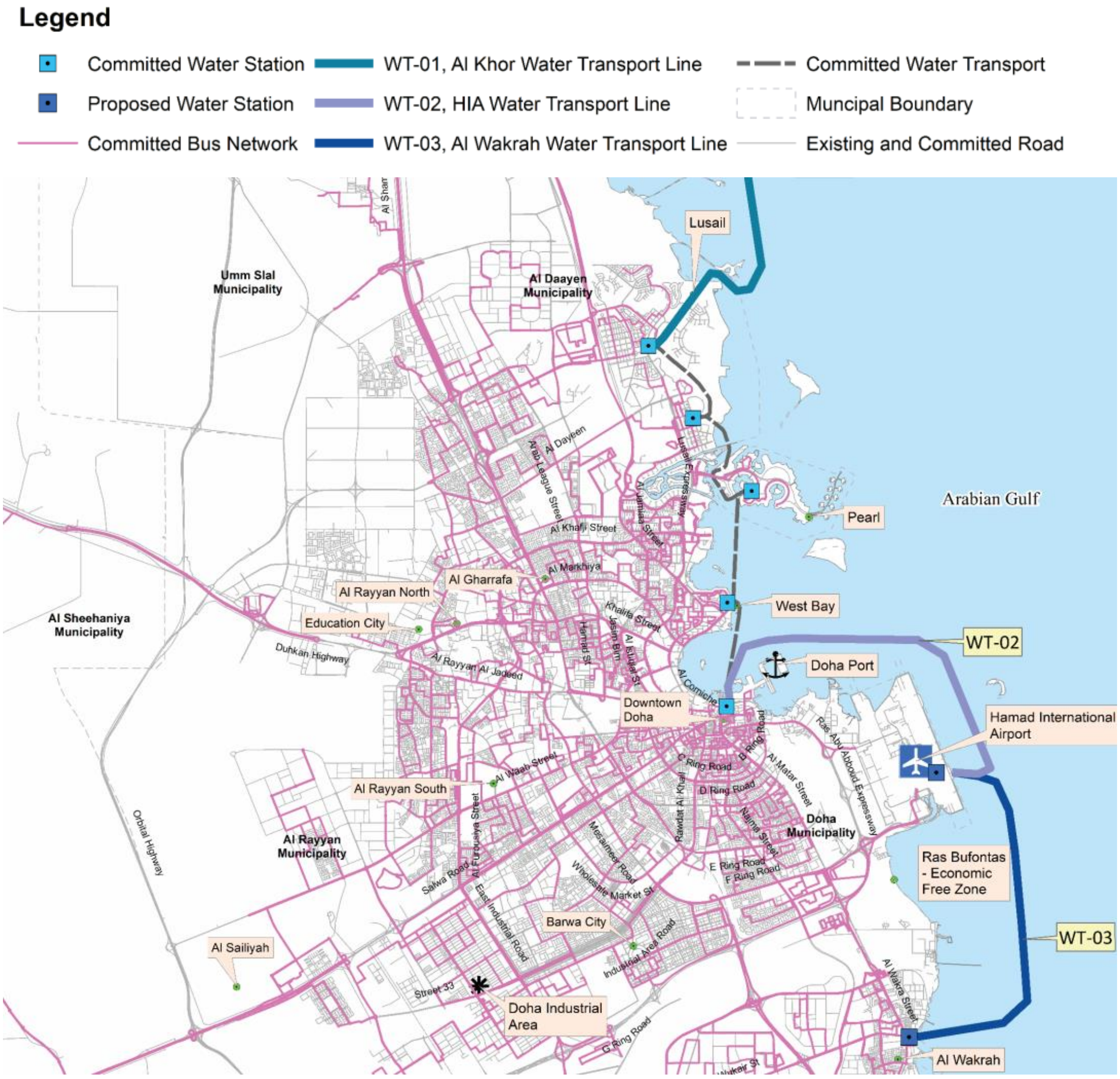

Figure 6.4: Proposed Water Route for Doha
Source: Ministry of Transport, State of Qatar

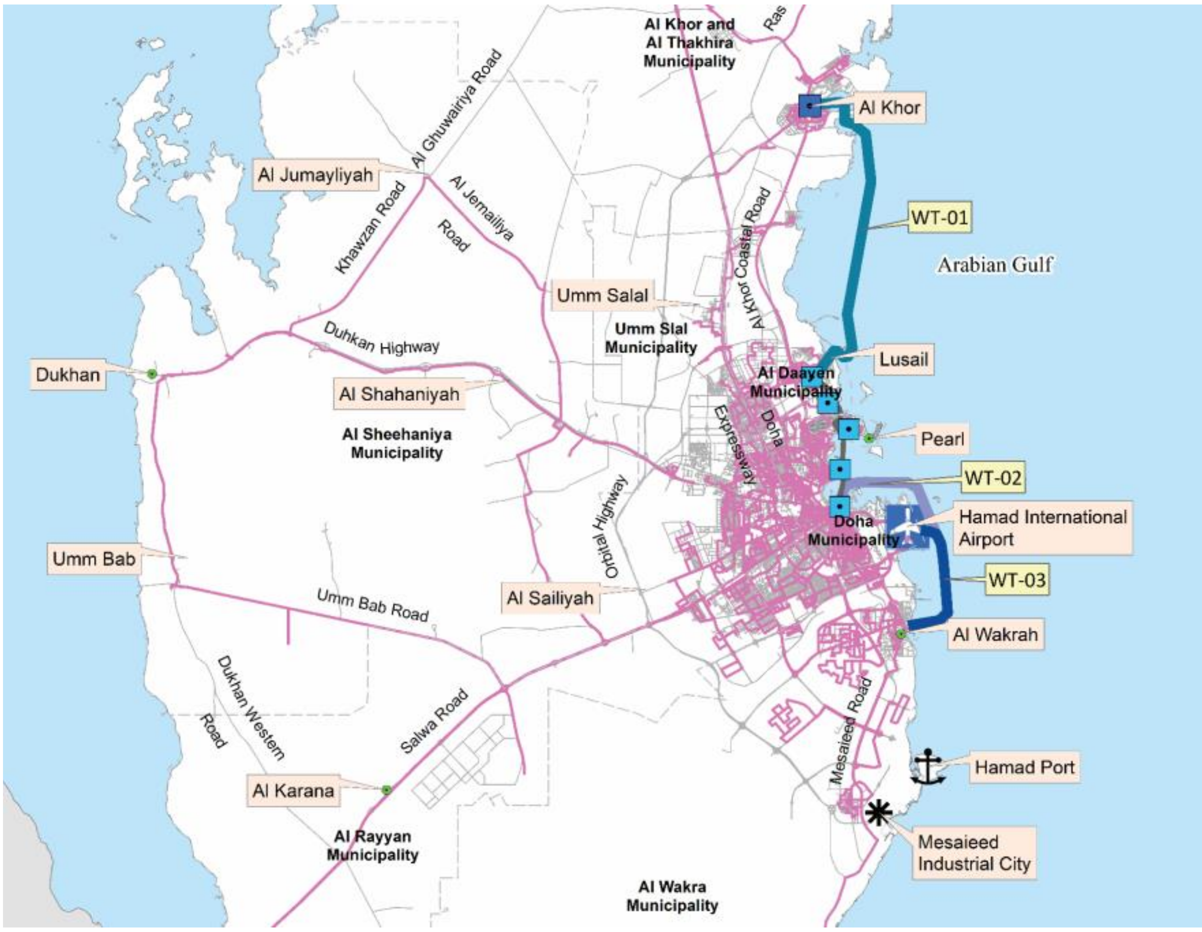

Figure 6.5: Propose Water transport Route in Qatar
Source: Ministry of Transport, State of Qatar

6.1.5. Cycling Network

Cycling is a non-motorized mode of transport that offers many of the same health benefits as walking, and potentially even greater benefits for longer distance journeys. However, the greater range and speed of cycling compared to walking requires a more extensive dedicated infrastructure. The proposed cycling schemes in the Updated TMPQ aim to address the identified issues related to cycling in Qatar and complement the planned cycling network.

The proposed schemes are divided into two main categories:

- Schemes that include infrastructure and facilities for the cycling network, such as interconnected segregated cycleways along main roads.
- Policy framework schemes related to cycling accessibility to public transport, such as bicycle docking facilities, integrated cycle lanes, shared-use with cars, and safe-route signage.

The proposed cycling schemes aim to improve the accessibility and safety of cycling, as well as encourage more people to use this mode of transport. This can be done by providing dedicated cycling infrastructure and implementing policies and regulations that promote cycling as a viable mode of transportation. The proposed schemes also aim to improve the integration of cycling with other forms of transportation, such as public transport, and to make cycling a more convenient and attractive option for people in Qatar.

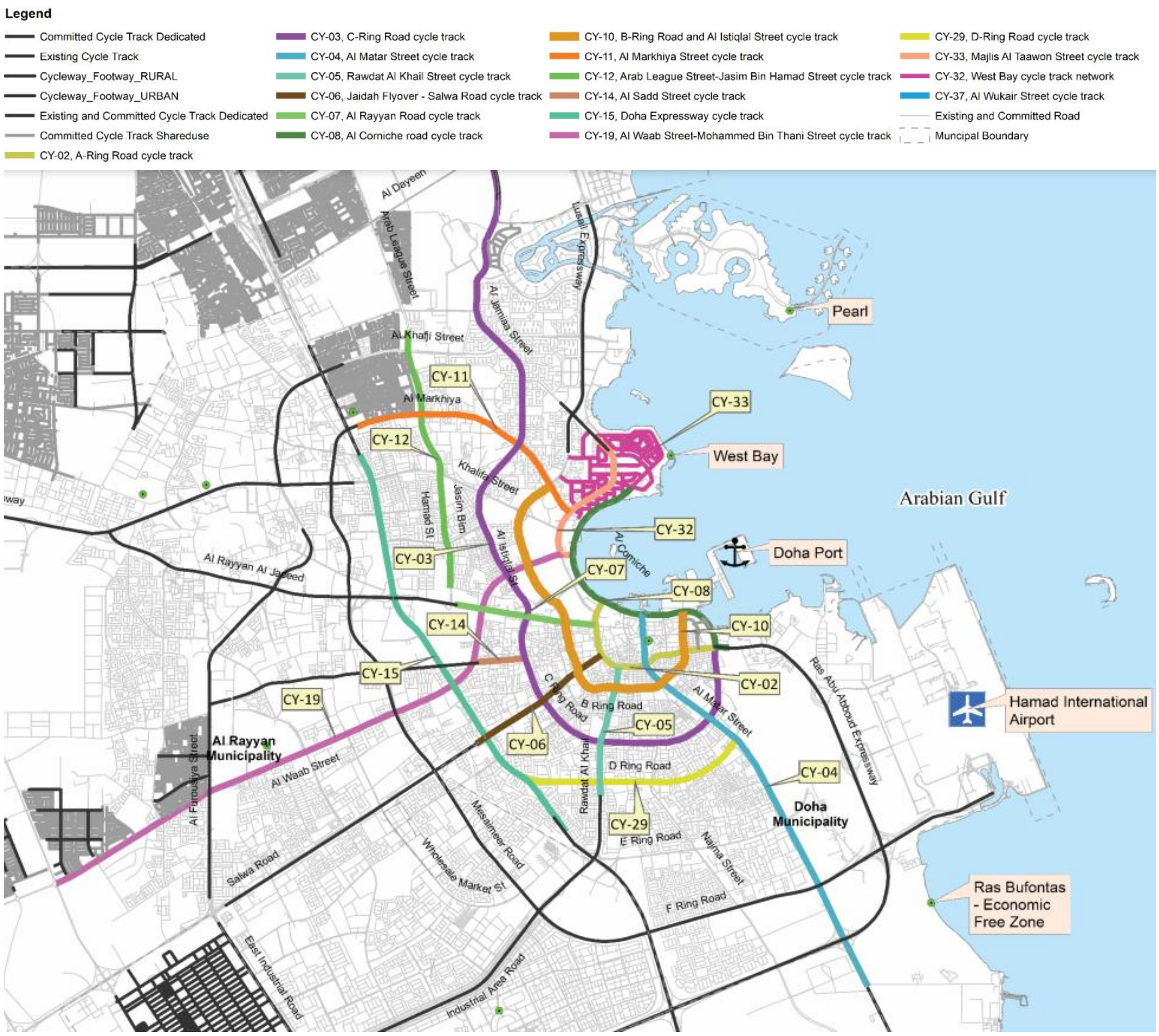

Figure 6.6: Cycling Tracks Proposed in Doha
Source: Ministry of Transport, State of Qatar

7 Qatar's Activity Based Model

QABM (Qatar Activity-Based Model) is a transportation model developed my Ministry of Transport, State of Qatar in collaboration with world-renowned Universities on Activity-based modeling: La Sapienza and Roma Tre Universities (Italy), Santa Barbara California, Texas, and Arizona in United States of America (USA). It uses the concept of an activity as the fundamental unit of travel, rather than the traditional trip-based models. This model considers the interdependence of trips and how decisions made about one trip can affect others. QABM is more advanced than traditional models as it accounts for the dynamic needs and journey patterns of people's everyday activities, forecasting transportation patterns across all modes of travel including private vehicles, public transport, cycling, and walking. It also provides a more sophisticated assessment of the impacts of different mobility policies such as congestion pricing and parking fares.

Type of Survey	Completed	Type of Survey	Completed
Automatic Traffic Counts	424	Household Interviews	10,082
Automatic Traffic Counts	76	Household Interviews	2,146
Turning Movement Counts	500	Laborer Interviews	1,044
Manual Classified Counts	100	Stated Preference Surveys	3,123
Travel Time Surveys	75	Roadside Interviews	18,599
Pedestrian and Cyclist Counts	25	Parking Interviews	1,148
Pedestrian and Cyclist Interviews	1,233	Hotel Visitors Surveys	1,067
Public transport Surveys	1,589	Air Passenger Interviews	1,174

Figure 7.1: Surveys carried out in the development of QABM
Source: Ministry of Transport, State of Qatar

It considers the mobility choices of each person, the interrelations that determine the daily mobility choices of each household member, the long-term mobility choices of each household member, the impacts of Park & Ride use and parking fares on the spatial distribution of activity opportunities, and the crowding effects on the level of public transport use. This model is useful for simulating how people may respond to policy alternatives, pricing mechanisms, as well as land-use and socioeconomic changes [74].

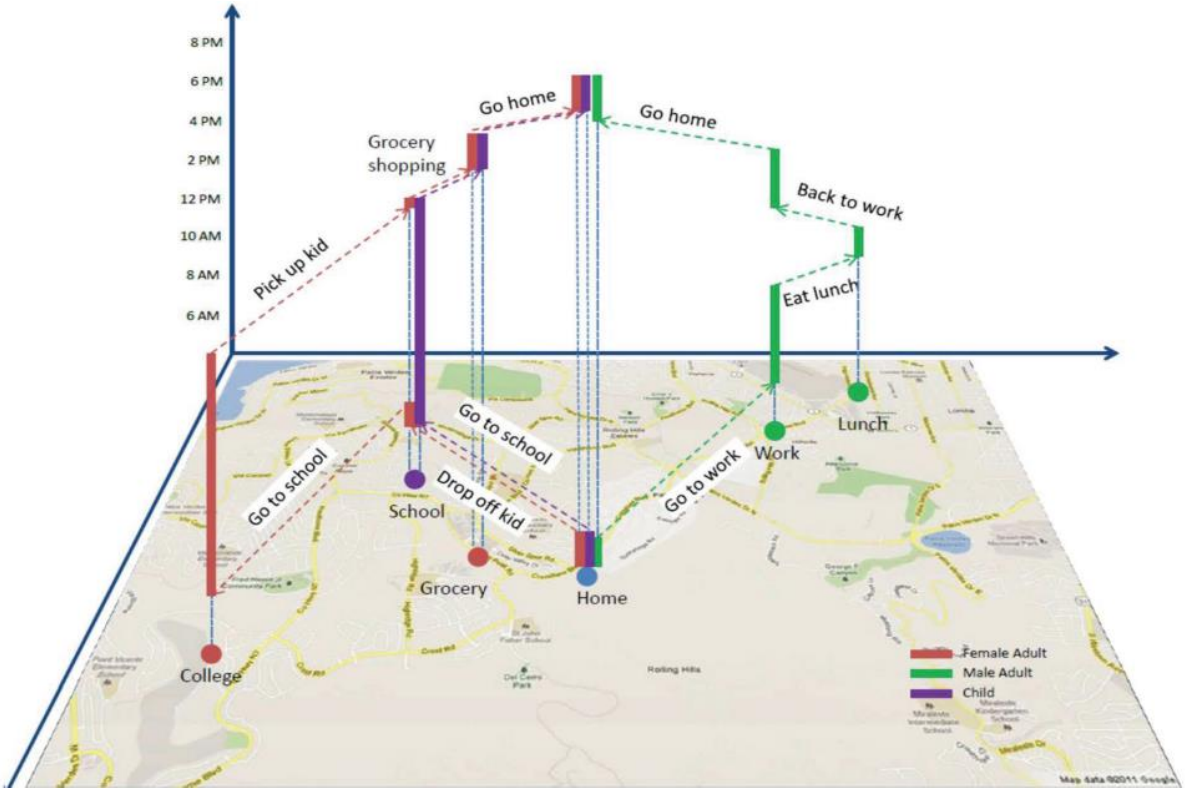

Figure 7.2: Activity Schedule Representation
Source: Ministry of Transport, State of Qatar

The Qatar Activity Based Model (QABM) is a sophisticated transportation model that considers the unique characteristics of the Qatar context. It is based on the Simulator of Activities, Greenhouse Emissions, Networks, and Travel (SimAGENT) developed for Southern California, with modifications from lessons learned in the New York Metropolitan Council (NYMTC). The QABM is designed to address a wide range of mobility policies and is customized to reflect the Qatar context. It is expected to be used as one of the main modeling tools for Qatar’s planning activities. The QABM is one of the 'state of the art' activity-based models and is one step ahead compared to other models. It includes integration with traffic assignment using automated feedback instead of manual iterations, a dynamic parking demand model, and an integrated interaction between private and public transport.

Location	Population	Models	Spatial Units	Software	Transport Plans
Qatar	2,169,000	ABM, Parking Park & Ride, Public Transport Crowding	Zones (1839)	VISUM	Master Plan
Abu Dhabi	2,800,000 (1,200,000)	Abu Dhabi Enhanced Model	Zones (1900)	CUBE	Master Plan
Auckland	1,400,000	Four-step demand model. MMA P&R, PT Fares, boarding and transfer attributes.	Zones (512)	EMME	Regional Land Transport Program 2015-2025, Integrated Transport Program (2012-2041), Regional Public Transport Plan 2013, Parking Strategy
Chicago	10,000,000 (2,800,000)	CT-RAMP1 ABM model, ABM-DTA integration approach	Zones - Microzones (1,944 internal + 17 external)	EMME / DYNA SMART	Traffic, Transit & Pedestrian
Philadelphia	6,000,000 (1,500,000)	ABM DAYSIM version: Household - Person	Microzone (3399)	VISUM	Master Plan
Rome	4,000,000 (2,875,000)	Land-Use and transport interactions demand model STIT. MMA. P&R	Zones (1331 internal + 8 external)	TransCAD	General Urban Traffic Plan, Air Quality Improvement Plan, Strategic Plan for Sustainable Mobility, Municipality Road Safety Plan, Rome Cycle Plan

Table 7.1: Comparison of Transportation Models
Source: Ministry of Transport, State of Qatar

Following the results of the best practices review, a Strength, Weakness, Opportunities and Threats (SWOT) analysis of QABM was carried out.

Strength	Opportunities
• **ABM** • **Park and Park&Ride models**	• **Detailed and realistic representation of PT (crowding model, fares, etc.)** • **Multimodal comprehensive policies**
Weaknesses	**Threats**
• **Requires a huge amount of data** • **Requires detailed information about population**	• **Rapid population expansion** • **Importance of avoiding excessive details**

Table 7.2: SWOT Analysis of Methodological approach of QABM
Source: Ministry of Transport, State of Qatar

7.1. Demand Model

The Qatar Activity Based Model (QABM) is a transportation model that has been modified to reflect the specific context of Qatar. The model is designed to address a wide range of mobility policies and is expected to be used as one of the main modeling tools for Qatar's planning activities. The overall model structure is presented in a cascading schematic form, with blocks on the left-hand side representing groups of models that are designed for the first year (baseline) of the simulation, which in this case is Year 2018. Each block represents a group of techniques and statistical models that are developed to replicate the population's activity and travel decision-making. The middle of the schematic includes the growth forecast and land-use regional economy components that produce changes over time and space. The right side of the schematic is a repetition of the daily activity and travel pattern models for the simulation of future years [74].

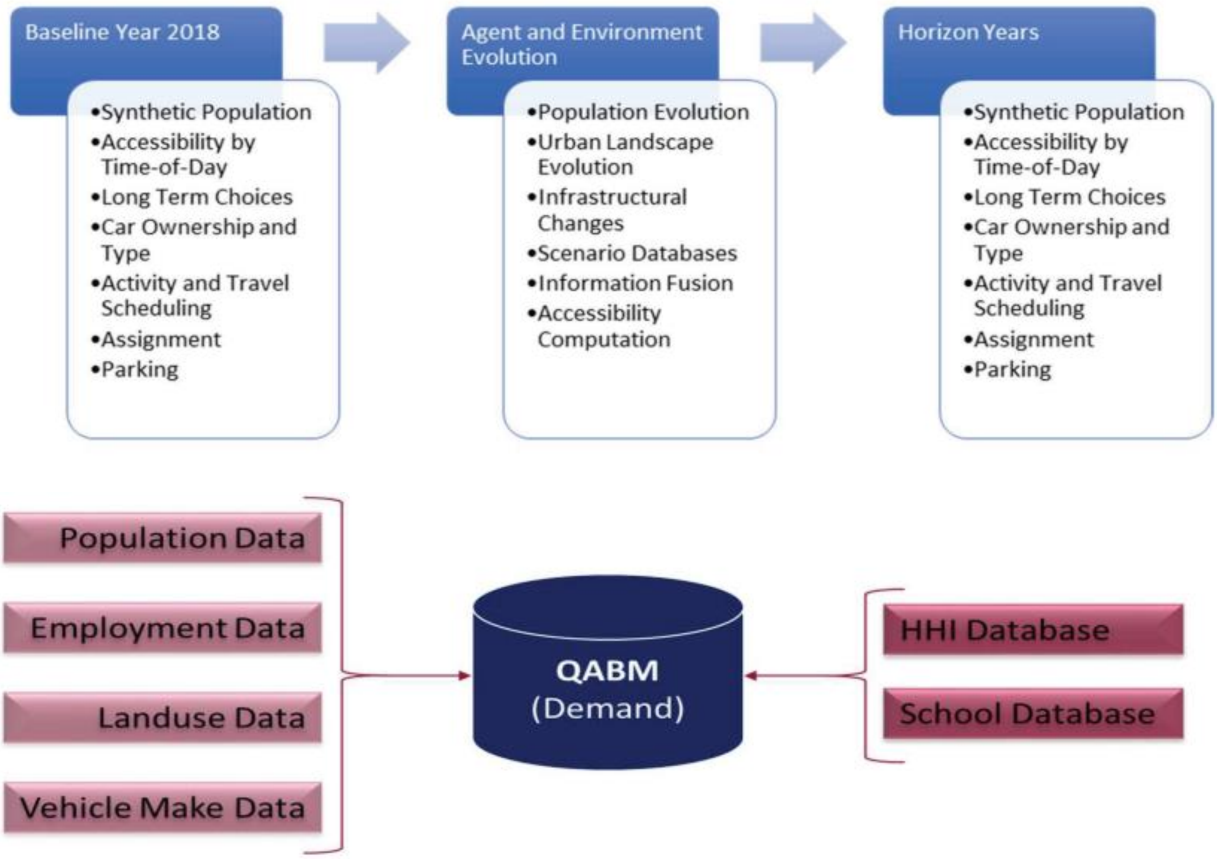

Figure 7.3: QABM Demand Model Representation
Source: Ministry of Transportation, State of Qatar

Each block of the figure represents a group of techniques and statistical models, many of which are developed to address policy actions aiming to replicate the resident population activity and travel decision making. In essence, the set of models on the left side.

- Recreates the resident population and the attributes for each person.
- Configure a daily schedule and
- Ultimately, assigns traffic to the network and computes parking.

This way, a variety of policies can be assessed at the microscopic level, tracking all decisions simulated by the model. For example, land-use policies of increasing density and land-use mix can be reflected in shifting of the spatial distribution of economic activity, location decisions, car ownership and use, activity participation, and destination choices. The model is designed to be dynamic and can consider the changes in socio-demographic factors over time and space and convert them into accessibility indicators that drive travel behavior.

7.1.1. Population Synthesis

In QABM the process starts with the use of a model called PopGen which generates/recreates the entire resident population of Qatar on a person-by-person and household-by-household basis. The input for this model is the spatial organization of the simulated area in the form of zone-specific univariate distributions of resident person and household characteristics provided by Qatar Census data. The model uses these distributions as control totals for each spatial unit of analysis (1,839 TAZs in this version of the model system) in an iterative algorithm that starts from a multivariate set of relationships among the person and household variables used as seed information. The seed information comes from a household and laborer survey in Qatar. For future years, these distributions are based on Qatar forecasts.

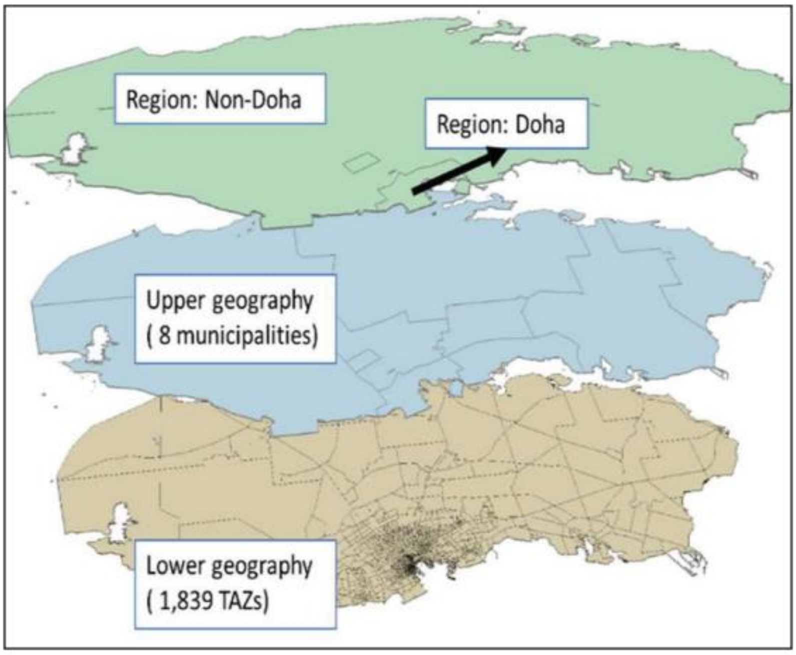

Figure 7.4: Spatial Analysis System Model
Source: Ministry of transport, State of Qatar

7.1.2. Accessibility by the Time of the Day

In QABM, the model represents the ease or difficulty of reaching different types of industries (representing the opportunities for activity participation) from each TAZ within different travel times and distances. It creates geographic "buffers" within which activities and opportunities that can be reached are counted. The types of industries include a wide range from construction to retail and government services. Different accessibility values are obtained for peak and off-peak periods which capture different roadway conditions. Procedures to capture patterns of opening and closing of businesses were also created by allowing different opening and closing hours for each industry type. The resident population with its detailed characteristics and accessibility indicators are the inputs for the next block. These indicators are used in many of the behavioral models of the baseline year, and for subsequent simulation years, they are modified when the spatial distribution of economic activities changes, and they are also modified based on travel times that may change based on network flow reflecting delays on road links and at junctions.

Figure 7.5 Traffic Analysis Zone - Accessibility Map for the AM, 20 Min- buffer for Services
Source: Ministry of Transport, State of Qatar

7.1.3. Estimating Long-Term Activities and Mobility Choices

In QABM, the synthetic population that is obtained from PopGen includes many demographic and socio-economic attributes for each household and persons within the household. However, many of the socio-economic choice phenomena are not explicitly modeled. The block of models called the Comprehensive Econometric Micro-simulator of Socioeconomics, Land Use and Transportation Systems (CEMSELTS) is used to estimate long-term activities and mobility choices. In CEMSELTS, each person and household created in PopGen and located in each zone of the study region is given additional characteristics. For example, college students are assigned a college TAZ, workers are identified using a labor force participation model, employed persons are assigned a type of industry, work location, weekly work duration, and work flexibility, and everyone is assigned a driver's license.

Using these characteristics, household income is computed, followed by a residential tenure model, and a housing type model. Car ownership, car type and make/model are modeled using the random utility Multiple Discrete-Continues Extreme Value (MDCEV) model, which is capable of modeling multiple vehicle holdings, body types, fuel types, age, and use simultaneously. The model system produces the spatial distribution of all the residents by different social and demographic levels, including ethnicity and employment and school locations assigned to each person. In addition, each household is assigned to a housing type, thus resembling a complete Census of the resident population, and can be done at any level of spatial aggregation. This is useful in testing different policy scenarios and focusing on specific subareas.

7.1.4. Estimating Daily Activities and Mobility Choices

In this block of models, daily activity and travel patterns are created for each synthetically generated household and person within each household. A modified version of the Comprehensive Econometric Micro-simulator of Daily Activity-travel Patterns (CEMDAP) is used to simulate activity-travel patterns of all individuals in the region for 24 hours along a continuous time axis. The model creates synthetic schedules in two steps: generation step in which work, and school activity participation and timing decisions are created, and the application of the scheduling of activities that produces the sequence of activities, with departure and arrival times, activity durations, mode for each trip and determination of the location of each activity. This creates a complete description of the locations and movements among locations over space and time for each person in a household.

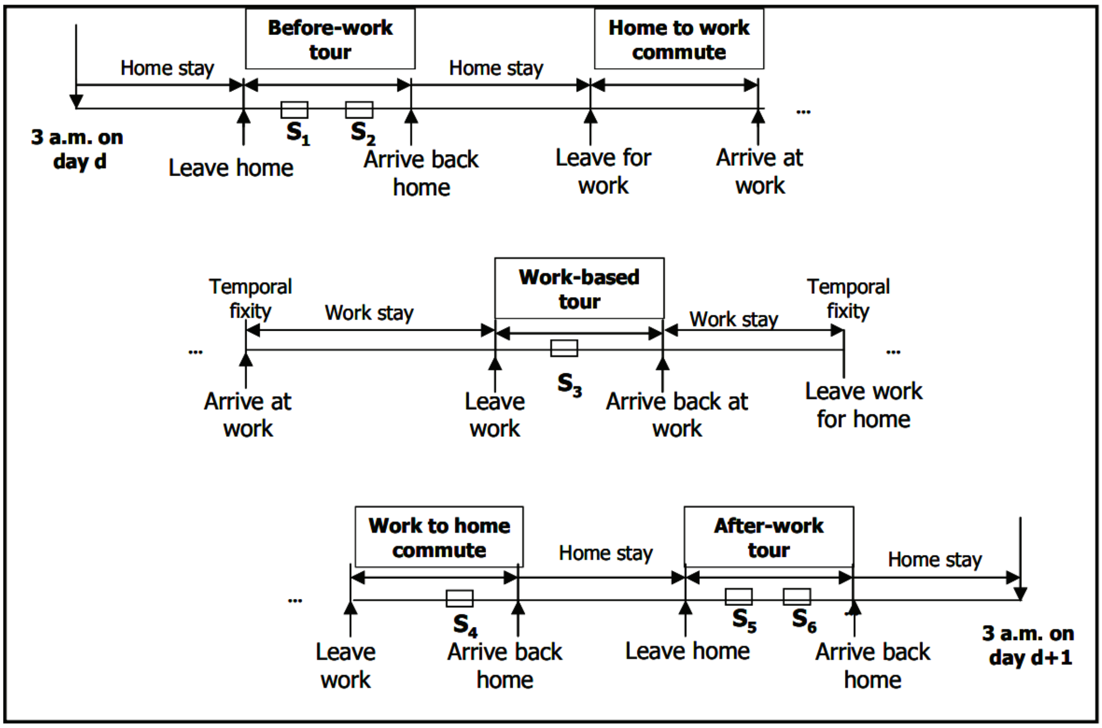

Figure 7.6: Daily Activity Model Depiction
Source: Ministry of Transport, State of Qatar

7.1.5. Data Input

The QABM (Qatar Activity-Based Model) uses survey data from household interviews (HHI) as its core data. This data includes information on household-level characteristics such as location, structure, income, vehicle and bicycle ownership, and housing characteristics. It also includes individual-level characteristics like age, gender, race, ethnicity, education, student status, employment, work hours, and driving license ownership. Additionally, the survey data includes information on the travel undertaken by individuals, including details such as how, why, when, and where they traveled. Time use and activity surveys also provide information on the specific activities participated in and their timing and duration. The model also uses land use and infrastructure data, including information on the spatial characteristics of households and employment, school, and activity opportunity locations. Transportation network data, including information on the highway and transit networks, is also used in the model.

7.2. Supply Model

The transport network supply model that uses a formal structure to accurately represent the transportation system in Qatar. The model includes a detailed representation of all the roads, bus lines, and metro services that have been built or are planned. The ability of the model to reproduce real-world phenomena is enhanced through detailed modeling and the use of data from extensive surveys.

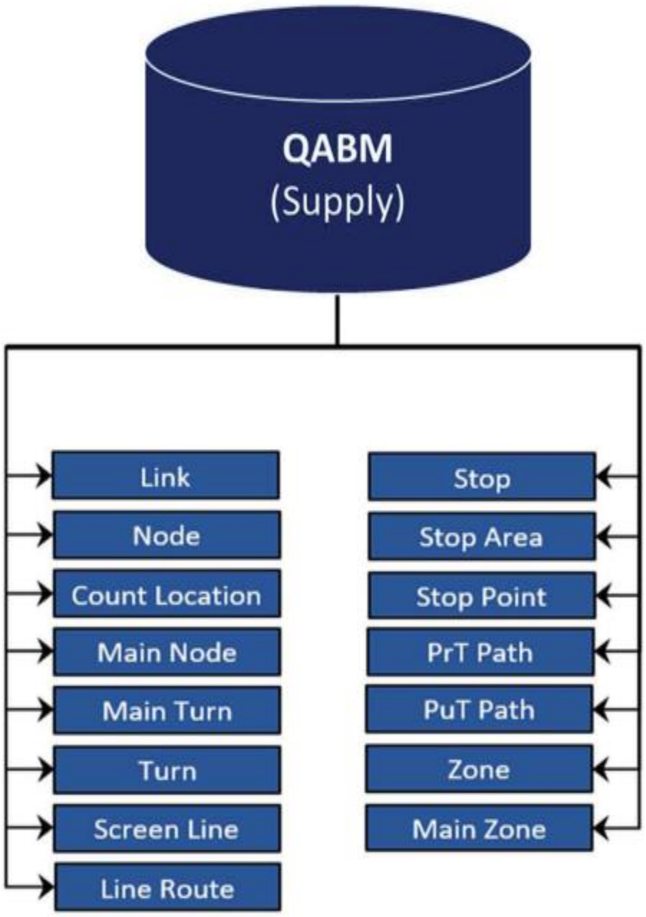

Figure 7.7: Supply Model Data structure
Source: Ministry of Transport, State of Qatar

The network coding in QABM is highly detailed and specifically designed to represent the road junctions in Qatar. It includes all available turning maneuvers in a unique form, which allows for the simulation of different traffic scenarios. Each traffic light is also coded with signal settings, providing a more realistic representation of the transportation system. The Supply Models Configuration and Modelling Report provides more detailed information on the supply models configuration and modeling.

Feature	Numbers
Links	182,502
Nodes	64,769
Turns	553,328
Main Nodes	1,344
Main Turns	76,694
Count Locations	1,242

Table 7.3: Summary of supply features in QABM
Source: Ministry of Transport, State of Qatar

In addition to the detailed representation of road junctions, QABM also includes models for intermodal connections. New parking and park-and-ride models have been implemented to represent the various transportation options available in Qatar, as well as a new crowding model to consider possible congestion effects that may occur in future scenarios when the metro network is completed, and demand has increased. This enables the model to simulate the impact of new transportation projects on the transportation system, and to evaluate the effectiveness of different policies and planning decisions.

7.2.1. Zoning System

The QABM uses a Transportation Analysis Zone (TAZ) system to ensure consistency with administrative boundaries, new mega projects, future primary road network, and metro transit lines. The TAZ system is compliant with huge datasets collected from different sources such as population composition and socioeconomic characteristics. Different authorities in Qatar use various administrative zoning systems, such as Municipalities, Planning Zones, Districts, and Census Blocks. These zones have been subject to modifications due to new developments and projects. The new TAZ system is developed as an aggregation of Census Blocks and includes 1,839 TAZs in total. Below figures show the changes made to the zone boundaries for compatibility with Census Blocks and planning zones.

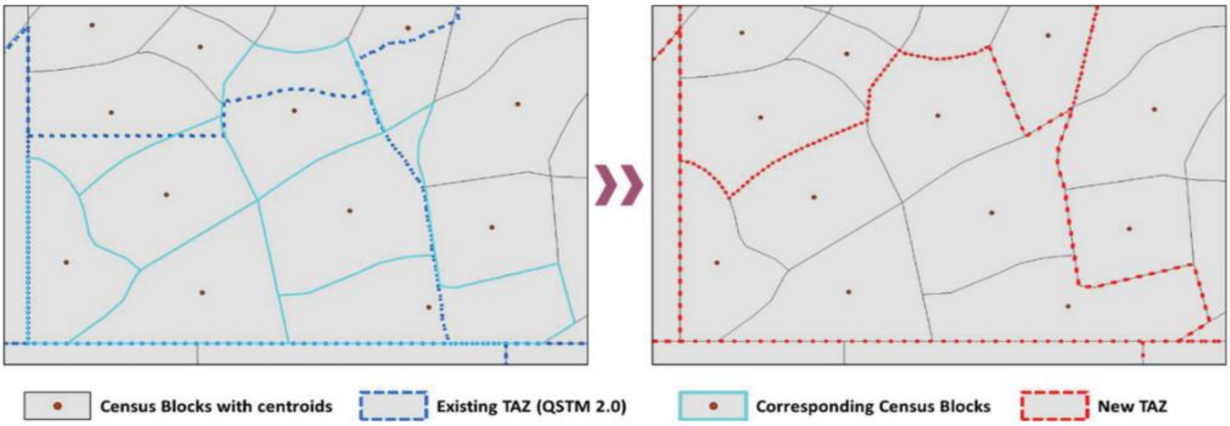

Figure 7.8: Adjusting the TAZ Boundary to be Compatible with the Census Block
Source: Ministry of Transport, State of Qatar

7.2.2. Road Network Model

The road network model development process in QABM involves several steps to ensure accuracy and consistency with the collected data. This includes topology validation and updating the road hierarchy, which required site visits and analysis of various sources of information such as GIS data and Google Earth. This process is outlined in a schematic flowchart in the figure below. The first step is to validate the topology of the road network data, which means checking for errors and inconsistencies in the data. This includes checking for missing links, missing intersections, and other errors that may affect the accuracy of the model.

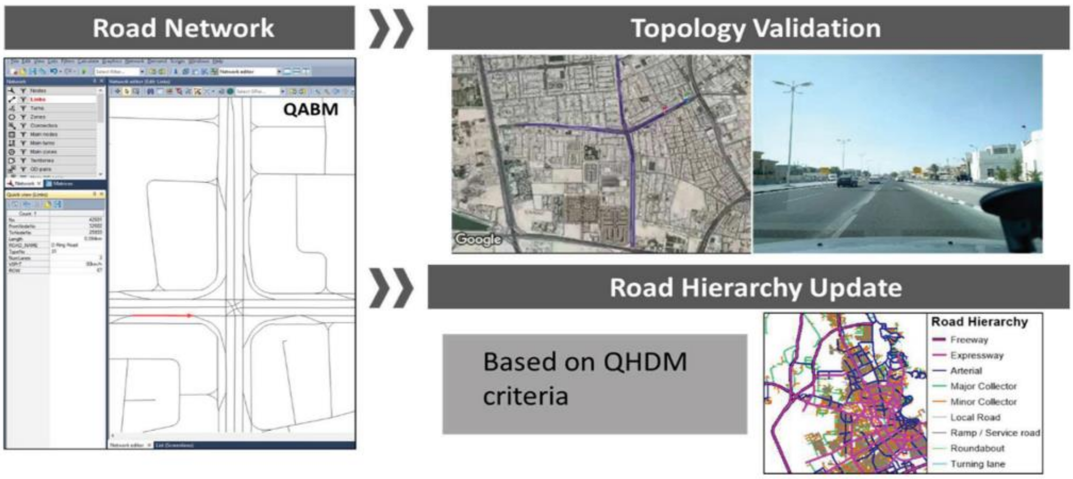

Figure 7.9: Topology validation and Hierarchy Update
Source: Ministry of Transport, State of Qatar

Once the topology is validated, the road hierarchy is updated to ensure that it reflects the actual road network and traffic flow. This includes determining the functional class of each road and updating the road hierarchy accordingly. For example, major arterial roads would have a higher hierarchy than local streets. This step also involves updating the road attributes such as the number of lanes, posted speed limit, and other characteristics that affect traffic flow.

7.2.3. Road Network Coding

The road network model for the State of Qatar includes the existing road network (base year) and several future road network models (horizon year) that consider all improvements that are planned or committed for that specific horizon year, creating a realistic scenario. The road network has been coded in detail to capture even the smallest interactions between conflicting movements at junctions and between different modes of transportation. The road hierarchy has been updated to match the criteria defined in the Qatar Highway Design Manual, ensuring a closer correspondence between the physical characteristics of the roads and modeling requirements. The process of updating the road hierarchy was carried out in two steps, including an audit of the existing road hierarchy, and a more analytical approach of categorizing road corridor sections based on homogeneity and corresponding information.

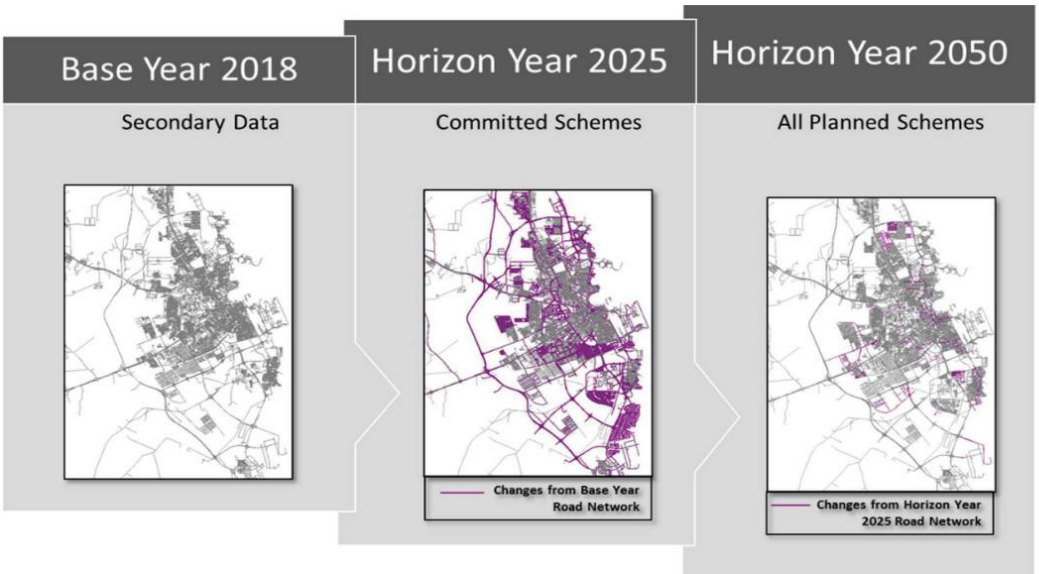

Figure 7.10: Road Network Model Evolution
Source: Ministry of Transport, State of Qatar

7.2.4. Public Transport Network Model

The public transport (PT) model implemented in QABM has several features to make the transportation model more realistic and efficient.

1. Public Transport Network Coding and Implementation: This feature includes the implementation of all current and planned PT services in Qatar, as well as the connectors and transfer links between the various PT services. The model also displays the evolution of the public transport network from the base year of 2018 to the projected horizon year of 2050.

2. Public Transport Network Assignment: For the public transport assignment, both the timetable-based and headway-based assignment methods are used. The timetable-based assignment is used for the base year model due to the low frequency of services, while the headway-based assignment is used for the horizon years when metro, LRT, and bus services become more frequent.

3. Transit Crowding Modeling: To account for the various elements of a PT trip, such as discomfort and delays caused by crowding, a crowding model has been implemented in QABM.

4. Fare System Representation: The fare system implemented in QABM reflects the existing card-payment system in the base year, which is distance-based. In the horizon year models, the fare system has been developed according to the information available in the Qatar Bus Routes Operation Study (QBROS) fare system. This includes a multi-modal ticket that allows for free transfers among bus, metro, and LRT lines within the Greater Doha area, a single-mode ticket for LRT with a flat fare, a distance-based ticket for trips where only bus is used, and a zone-based ticket for water trips with free transfers between bus and water services.

5. Interaction between Private and Public Transport Supply: It is essential that bus travel times are representative of the travel times on the road network where they share a common space. Accordingly, public transport bus services have been built into the road network layer in QABM so that bus travel speeds can be kept synchronized with the speed of other vehicles (cars, heavy goods vehicles, etc.). To fully account for this, a special procedure which updates the bus travel times in the PT model, based on the travel times experienced in the road network, has been implemented in QABM.

UPDATES	UPGRADES
Existing bus network updated to February – March 2018	Crowding Model
Detailed Timetables	Interaction between Private and Public Transport Supply
Qatar Bus Route Optimization Study included in the Model implementation	Fare System
Existing and future Rail Network input data updated to April – May 2018	
Education City and Msheireb Tram System coded as built	

Table 7.3: Public Transport Model Update and Upgrades
Source: Ministry of Transport, State of Qatar

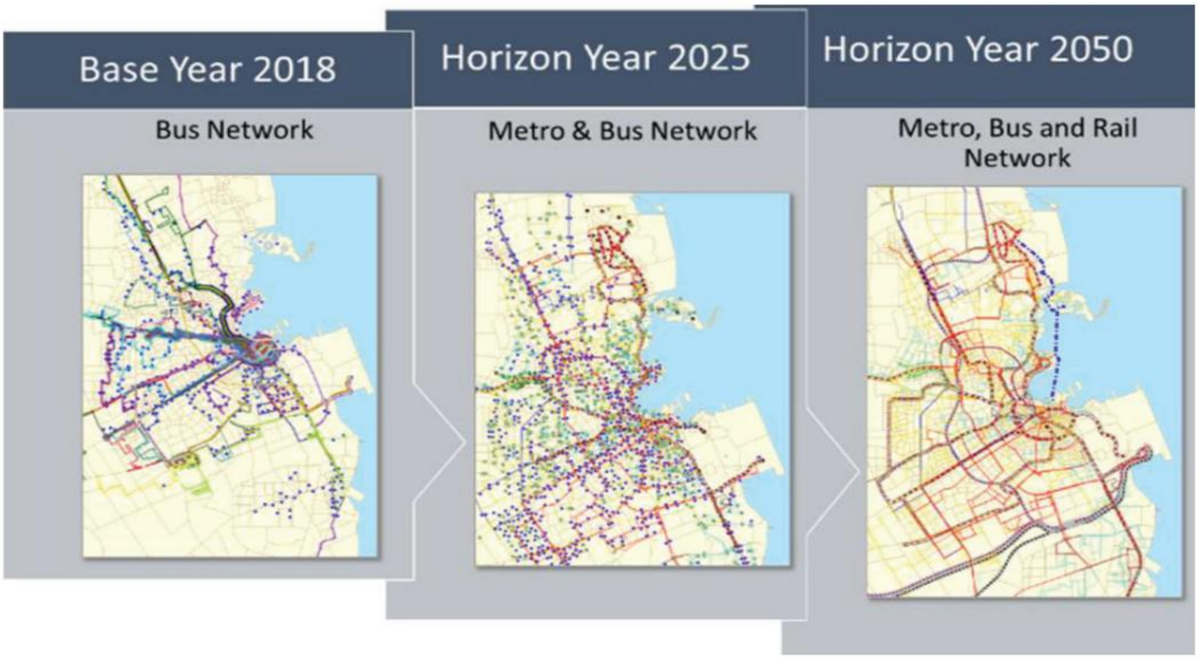

Figure 7.11 Public Transport Network Model Evolution
Source: Ministry of Transport, State of Qatar

7.2.5. Parking Model

The parking model in QABM is designed to provide a comprehensive and accurate representation of parking behavior. The model has a two-level approach, which includes:

1. Disaggregated parking model: This is built within QABM, and it explicitly emulates parking behavior.
2. Network-based parking model: This is the second level of the model, and its role is to distribute the parking demand among the different available alternatives based on the cost utility (or cost dis-utility) describing the parking choice of each user class for each parking type.

The network-based parking model considers different parking types, user classes (Qatari/Non-Qatari) and income segmentation (low, medium, and high-income) that are implicitly included in the model by adopting the Value of Time (VOT), which allows the possibility of examining alternative charging strategies in future scenarios. The model works at the zone level (TAZ) and for each destination zone, a set of alternative TAZs for parking are selected, thus generating what is described as the Catchment Area (CA) related to that specific destination. The cost utility for determining the choice of parking location includes, for each time interval, the available parking alternatives in the Catchment Area related to the parking destination.

The parking search time in each zone and parking type is a function of the parking occupancy level. This function yields higher values for the search time for more capacitated car parks. The VOT adopted for the cost utility computation reflects the opportunity cost of time spent traveling versus time that could otherwise be spent performing other activities. This is customarily expressed as a fraction of the household income.

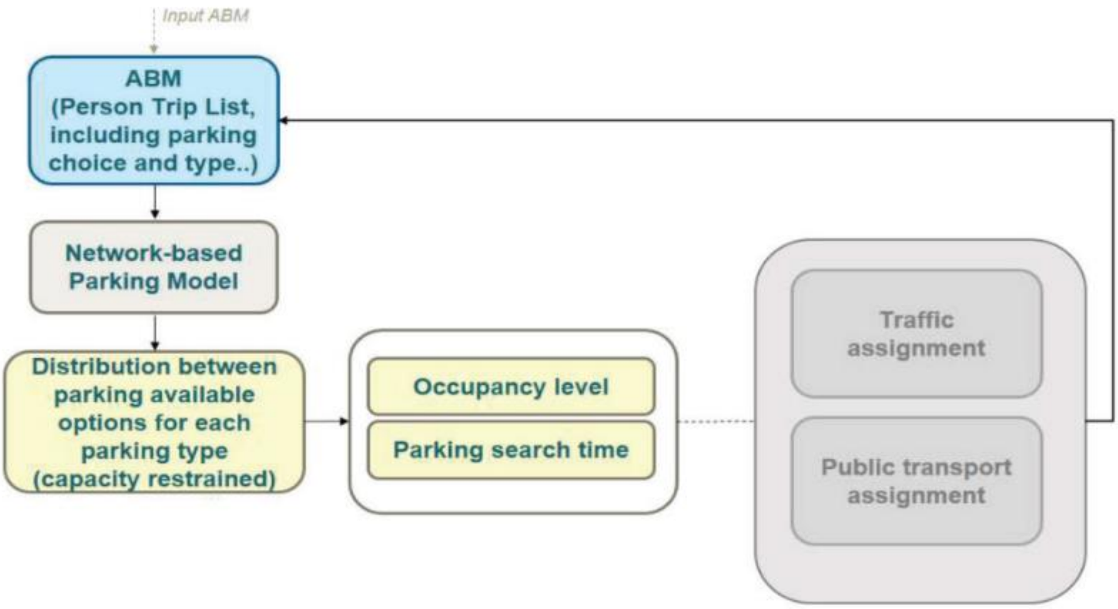

Figure 7.12: Output of Parking Model and QABM Road Network Model Integration
Source: Ministry of Transport, State of Qatar

7.2.6. Park and Ride Model

The Park and Ride model in QABM allows the simulation of individual trips that combine the private mode for the first component of their journey, parking at the Park and Ride site, and subsequently using public transport for the second component of their journey. This feature enables the assessment of the benefits of introducing Park and Ride services, such as reducing car trips and congestion, as well as the evaluation of alternative scenarios in terms of location, dimension and fare systems of the Park and Ride sites. The Park and Ride model is fed by demand from the higher tier model and simulates the loading process of the Park and Ride sites and modifies the Park and Ride site selection when the parking occupancy is close to capacity. The output of the model includes parking occupancy levels, updated private and transit demand matrices, and is calculated based on factors such as VOT car travel time, parking search time, waiting time, onboard travel time, parking cost, and PT fare.

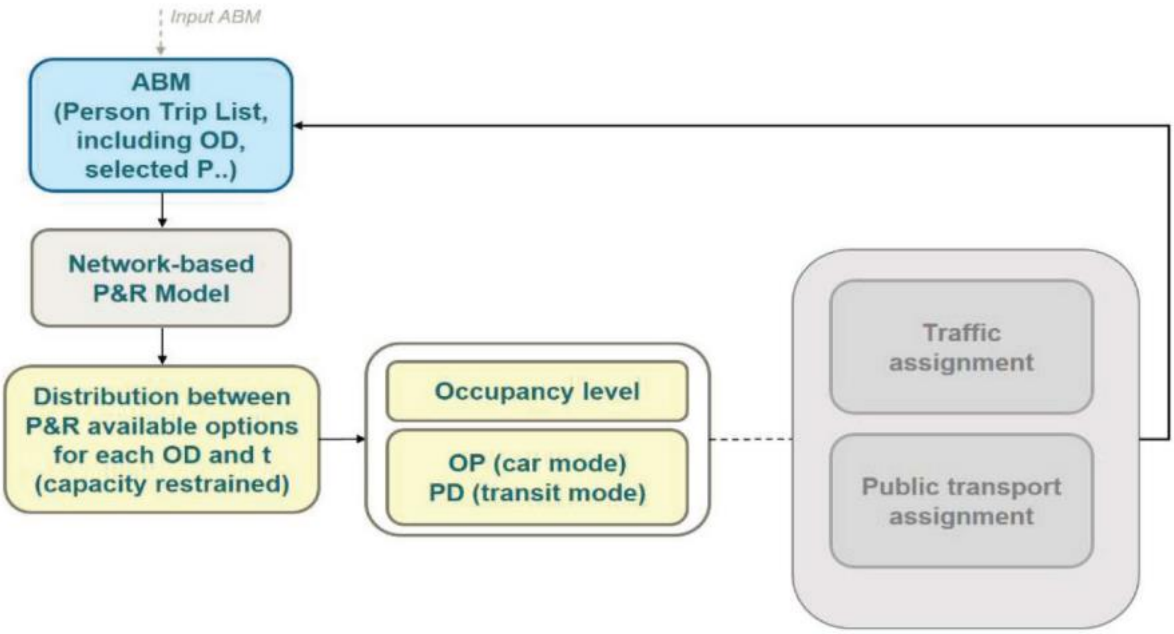

Figure 7.13: Output of Park & Ride model and QABM-Supply Model Integration
Source: Ministry of Transport, State of Qatar

Site No.	Location / Site Name
1	Al Wakra
2	Matar Al Qadeem
3	Sports City
4	Al Messila
5	Al Riffa
6	Education City
7	Katara
8	Legtaifiya
9	Lusail
10	Al Qassar
11	Equestrian Club

Table 7.4: List of Park and Ride Sites Represented in QABM
Source: Ministry of Transport, State of Qatar

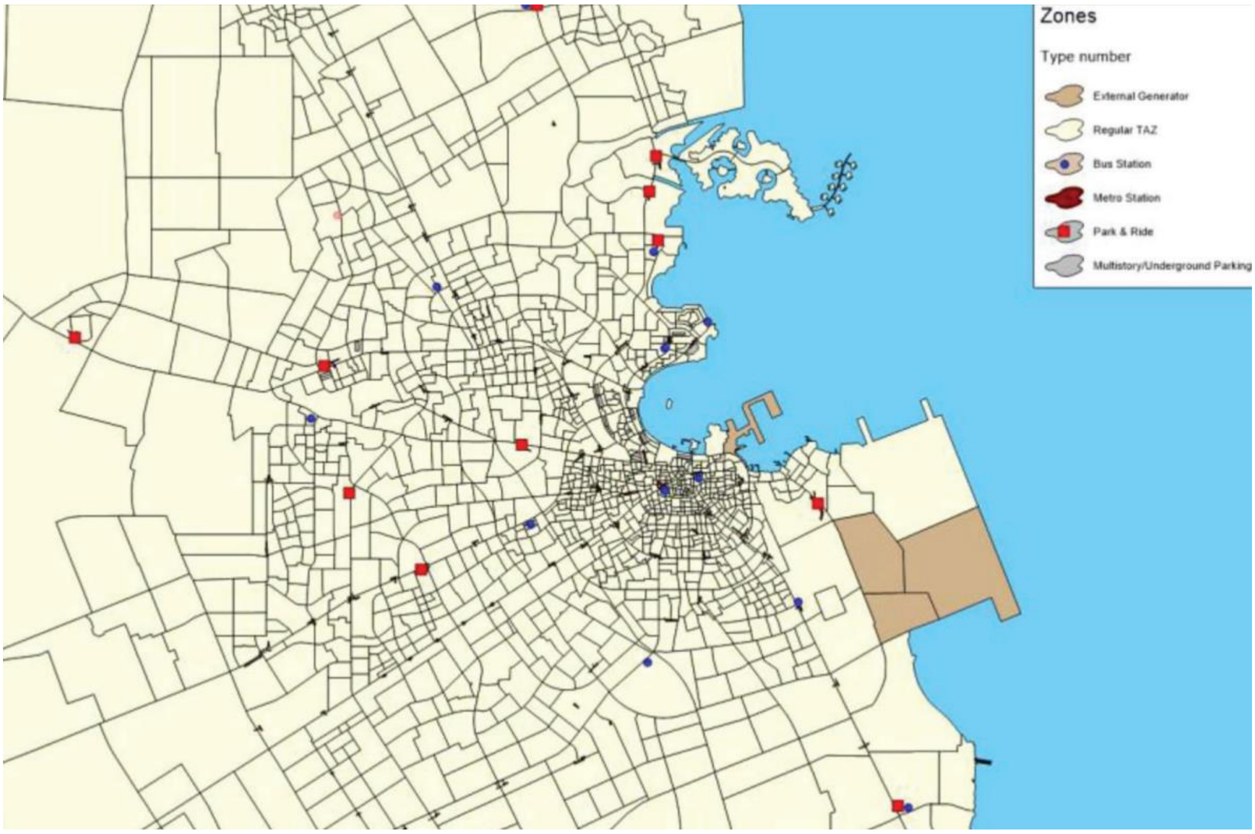

Figure 7.14: Location of Park and Ride Sites incorporated into QABM
Source: Ministry of Transport, State of Qatar

7.3. Overall QABM Procedure

The Qatar Activity Based Model (QABM) is a comprehensive transportation model that utilizes various data inputs and modules to simulate and analyze transportation patterns and accessibility in the State of Qatar. The overall QABM procedure is represented in a flowchart, with dark blue boxes representing the various modules that make up the overall process, grey boxes representing input data, and green boxes representing output data. The modules that make up the overall QABM procedure include PopGen and CEMSELT, which fall outside the integrated loop, the Accessibility Tool, the CEMDAP full-day choice model, the Parking Model, the Park & Ride Model, the Matrix Aggregator, which converts person whole day travel into peak hour flows, and VISUM, which is a traffic assignment tool that implements, runs and controls the integration loop, based on instructions set out by the GUI.

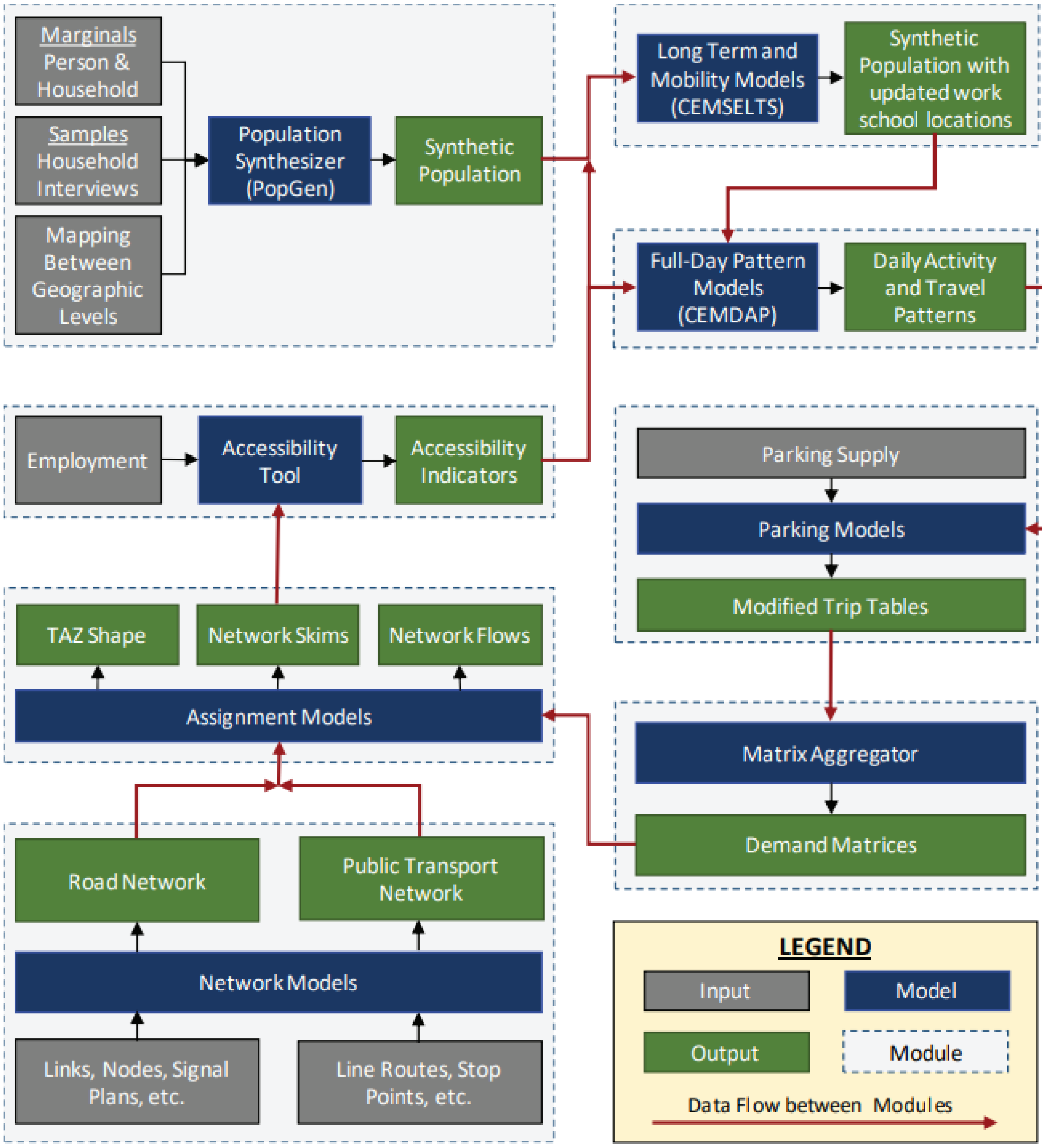

Figure 7.15: Overall QABM Procedure Flowchart
Source: Ministry of Transport, State of Qatar

7.4. Forecasts

The QABM model uses data from different sources to predict the transport system in future years. The horizon years considered for analysis and simulation are 2025, 2030, 2035, and 2050. The planning data required as input into QABM include population totals, household population, labor population, and employment marginals, which are collected at the TAZ level. The data used in the model includes total households, households by size, households by residence type, total population, persons by gender, persons age by categories, and persons by Qatari and non-Qatari categories, total employment, and employment by sectors.

7.4.1. Population

The QABM model uses population forecasts provided by TMPQ, based on the future land use plan (QNMP). The total population forecasted for 2035 and 2050 are 3,570,000 and 4,210,000, respectively. The population is split into household and laborer populations using base year proportions. The population projections are adapted from the existing transport model (QSTM 2.0) and adjusted to match the TAZ system used in QABM. The population forecasts are shown in Figure 7.1 for the horizon years 2025, 2030, 2035, and 2050, split into households and laborers, as well as by employment category.

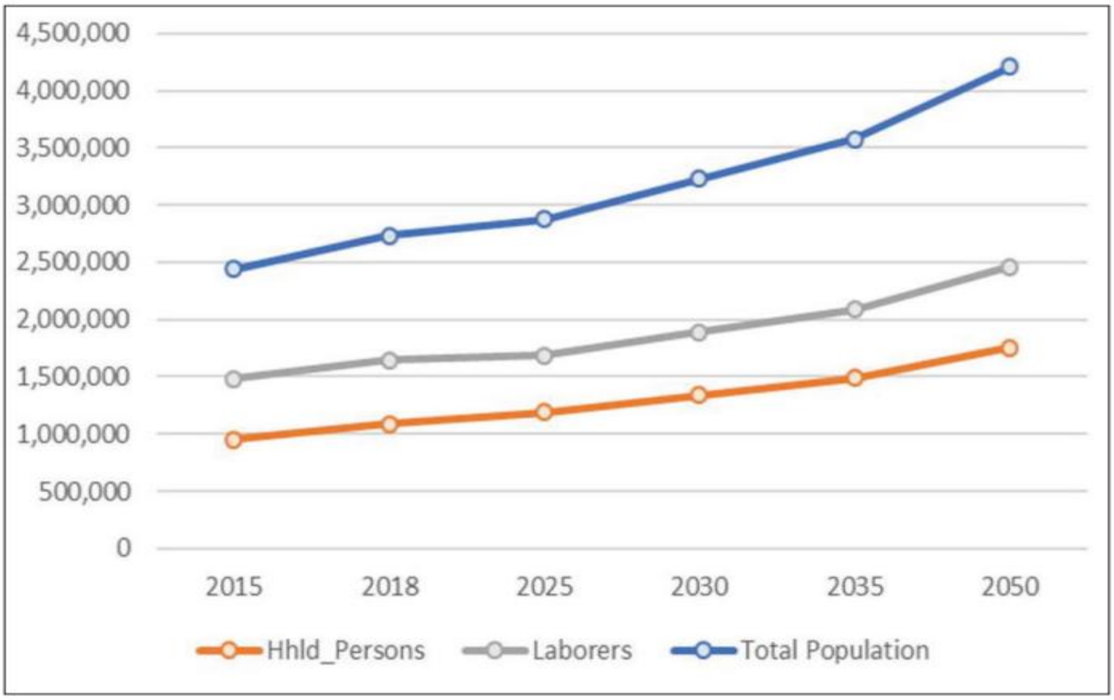

Figure 7.16: Trend of Population in Future Horizon Years
Source: Ministry of Transport, Qatar

7.4.2. Demand Forecasts

In the baseline horizon year models, the demand for transport is forecasted for the years 2025, 2030, 2035, and 2050. The demand is measured in terms of the number of trips taken during the AM peak, MD peak, and PM peak periods. The demand is expected to increase by 12%, 15%, and 14% respectively in the AM, MD, and PM peak periods in 2025 compared to the base year scenario. The modal share of public transport (PT) is expected to be 11% in the AM peak, 9% in the MD peak, and 9% in the PM peak in 2025. As the years progress, the demand for transport is expected to continue to grow, with an increase of nearly 13%, 15%, and 13% over those of the horizon year 2025 in 2030. The modal share of PT is expected to remain similar in 2030. In 2035, the modal share of public transport is predicted to rise to about 14% in the AM, 10% in the MD peak, and 12% in the PM peak, mainly due to the introduction of more metro lines by 2035. In the ultimate year, 2050, the demand for transport is expected to reach about 1,300,000 trips in the AM peak, 1,000,000 trips in the MD peak, and almost 1,245,000 in the PM peak. The increase of private transport is expected to be higher than that of public transport in 2050, with modal shares of PT forecasted to be approximately 12% in the AM peak, 9% in the MD peak, and 10% in the PM peak.

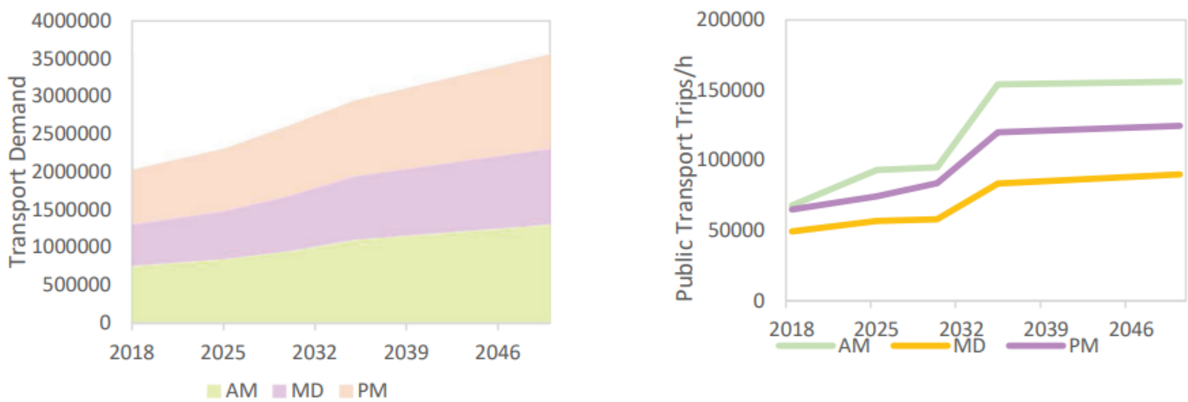

Figure 7.17: Trend of Predicted Demand - Total Transport (Left) and public transport (Right)
Source: Ministry of Transport, State of Qatar

7.4.3. Supply Forecasts

Ashghal, an organization in charge of transportation infrastructure in a certain region, has proposed 48 expressway projects and a Local Roads and Drainage Program (LRDP). 30 of the expressway projects are planned to be completed by 2022 and will be considered in the Horizon Year 2025. A quantitative assessment procedure was applied to select the most effective projects to relief traffic congestion from the remaining 18 uncommitted schemes. Seven expressway projects have been identified for implementation as part of the baseline scenario for Horizon Year 2035. LRDP projects have been selected based on the quantitative assessment approach for Horizon Year 2025 and 2035. For Horizon Year 2050, all remaining projects from Ashghal and LRDP will be included in the model. The road network is expected to increase from 27,000 km in 2018 to 32,000 km in 2025, 34,000 km in 2035, and 35,000 km in 2050. The Public Transport Network Models of the Horizon Year 2025 and 2030 include the 3-Line Metro network, 4 Lines of the Lusail LRT network and Tram Lines.

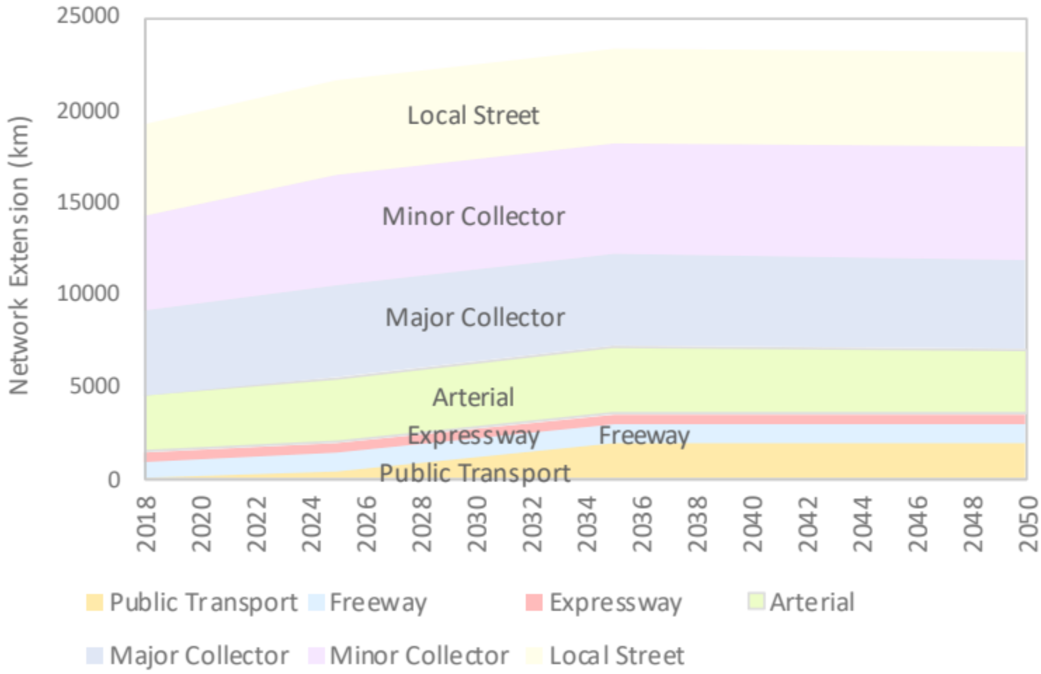

Figure 7.18 Evolution of Road Network from Base to Horizon Years
Source: Ministry of Transport, State of Qatar

7.4.4. Transport System Performance Forecasts

The model produces a wide range of results, including the type of activities by persons, number of stops, performance of the transport system in terms of travel times, distance travelled, and congestion levels. Results for the horizon years 2025, 2030, 2035 and 2050 are summarized as follows:

- Private Transport Network: The total traveled distance by car in the AM peak is expected to decrease from 3.9 million vehicle-km in the base year to about 3.3 million in 2025 (-15%), then increase slightly to 3.7 million in the years 2030 and 2035 (-4%). For the ultimate year 2050, when the transport system is supposed to be unchanged and the population is still on a rising trend, the total travel distance will grow to 4.7 million vehicle-km, exceeding the current value by 18%.

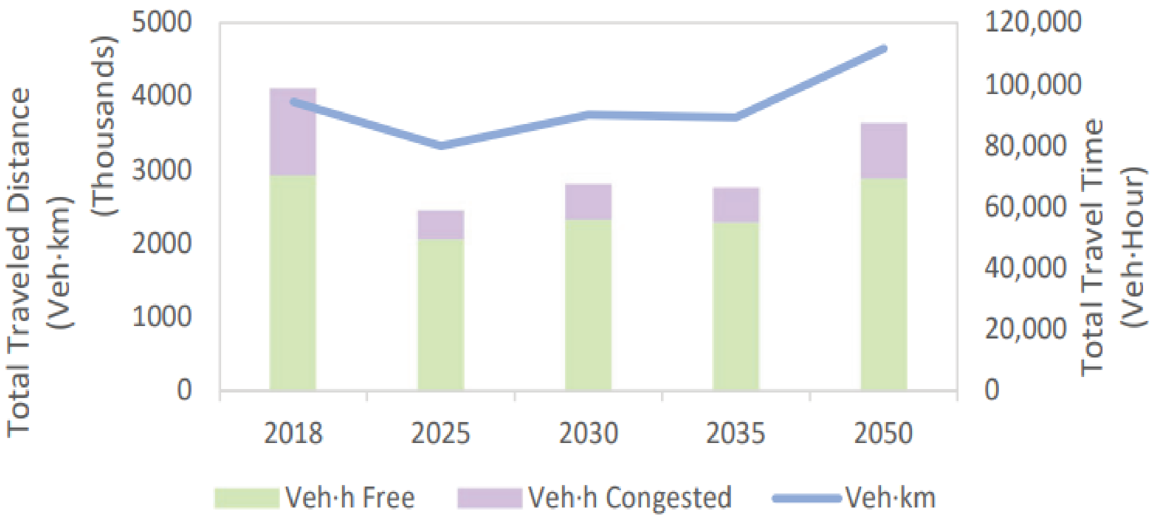

Figure 7.19: Total car traveled distance and Total time in the AM Peak
Source: Ministry of Transport, State of Qatar

- Public Transport Network: The Qatar Public Transport Network will be more extensive in 2025, when the three Metro lines, the Lusail LRT and tram network will be operating. The patronage is expected to increase by about 25 times compared with the Base Year. In the morning peak hour, about 53,000 passengers will access the public transport network and will travel for a total of about 30,000 hours, covering 830,000 km, with 96,000 total transfers from one line to another.

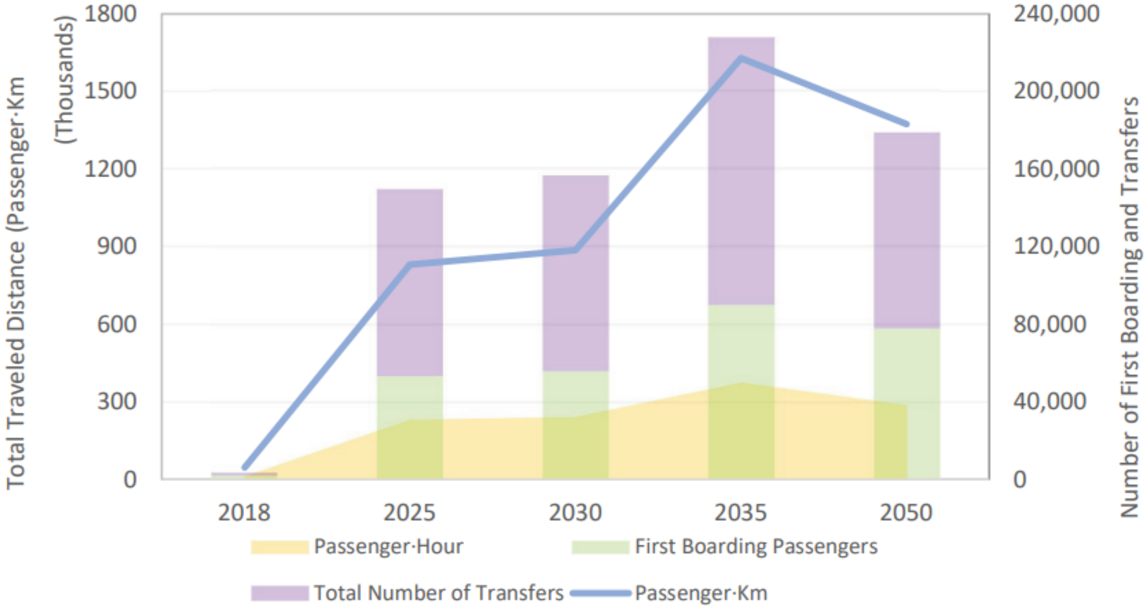

Figure 7.20: Passengers Traveled Distance, Total Boardings and Transfers on Public Transport - AM Period
Source: Ministry of Transport, State of Qatar

7.4.5. Sensitivity to Transport Policies

The goal of the policy option analysis in the strategic transport planning process is to investigate potential alternatives to the ongoing or planned projects in the Baseline Scenarios. The level of detail in the policy option testing is preliminary and has two goals: to assess the ability of the model to reproduce the effects of changes in transport supply and to gain a preliminary estimate of possible impacts. Policy options such as changes in fuel cost, congestion pricing, public transport tariffs, and parking fares have been studied using best practices from other countries and by using a preliminary analysis to confirm the sensitivity of the model to these changes. Additionally, a Stress Test Scenario has been implemented to identify the most critical elements of the transport network and potential measures to reduce congestion. More information can be found in the QABM Sensitivity Tests Report.

Strategy	Enabling Mechanisms
Trip Reduction	Substituting trips: • Physical to virtual (tele-activity) • Physical to physical (e.g. passenger to freight in home delivery) • Linking trips (trip chaining and multi-purpose trips)
Distance Reduction	• Switching destination
Modal Transfer	• Reducing car use and switching mode towards collective and non-motorized modes
Load Factor Increase	• Increasing load factor for individual, collective and goods vehicles
Better Vehicle Flows	• Re-distributing flows on network links by switching travel time or travel route • Increasing capacity of links and junctions
Better Vehicles	• Introducing and spreading technological innovation • Improving maintenance

Table 7.5: Strategies and Mechanisms for Transport Policy Options Implementation
Source: Ministry of Transport, State of Qatar

7.5. Sensitivity Analysis

The Sensitivity analysis aims to demonstrate that the structure of QABM (Qatar Activity-Based Model) can react sensibly to changes in travel time and transport costs. Specifically, the model outputs change if travel time or transport costs change. The analysis was conducted by testing the sensitivity of the model to different policy options such as fuel cost, congestion pricing, public transport tariffs, and parking fares.

- Fuel Cost: Increasing the cost of gasoline from 1.55 QAR/liter (base year gasoline cost) up to 2.325 QAR/liter resulted in a reduction of 3.3% of car traffic and a negligible effect on public transport patronage.
- Congestion Pricing: The introduction of road tolls was simulated in two selected areas within the C-Ring and around the West Bay, for two different levels of charge, based on international best practice review. These levels were 10 QAR/entry and 43 QAR/entry. The results of the test confirmed that the model is sensitive to the introduction of tolls, although only limited reductions of road use and slight increase in public transport patronage were estimated.
- Parking Fare: For evaluating the sensitivity of the parking model, two different pricing policies were tested, a parking fare of 11 QAR/h and another fare of 43 QAR/h in all the parking lots (both on-street and off-street) existing in the two selected areas within C-Ring and around the West Bay. The results showed that the lower parking fare produced a reduction of cars attraction of nearly 5.6% and a decrease in car park occupancy of about 3.6%. This was mainly due to relocation of parking to nearby places and to modal shifts when possible. The

higher parking fare reduced car attractions by 14.3%, while car park occupancy reduced by only 1.4%, due to the increasing cumulative effects of parking choices in the previous hours in the AM Peak. These variations were amplified in the PM peak, with greater reductions with both the lower fare scenario and the higher fare scenario.

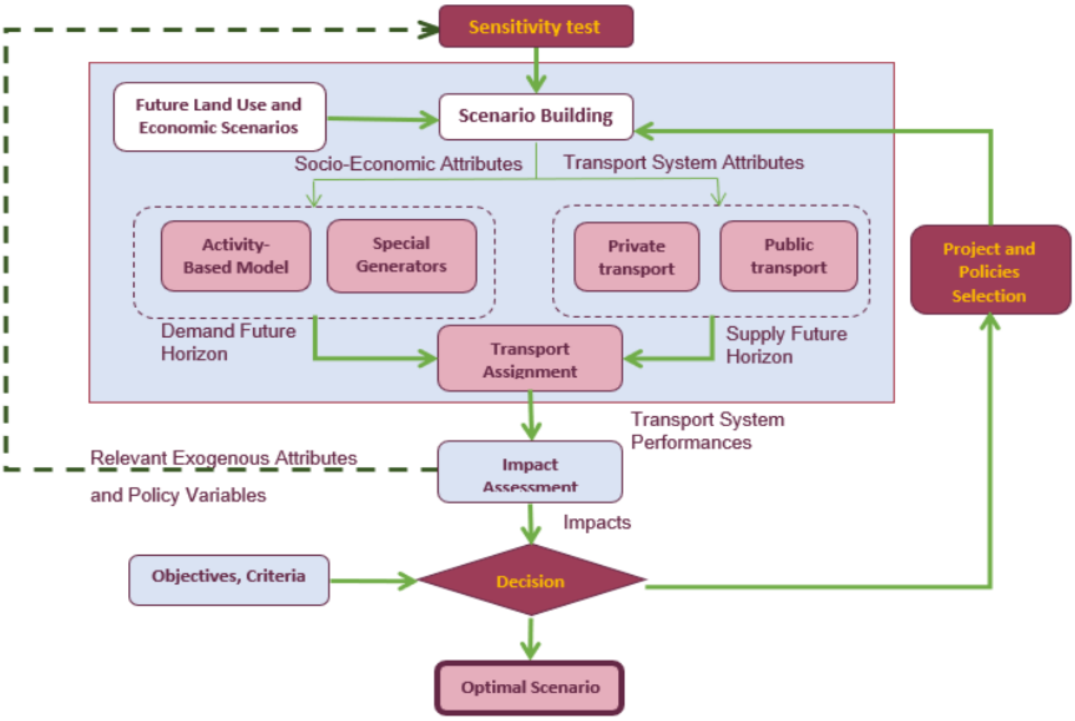

Figure 7.21: Policy Selection Framework
Source: Ministry of Transport, State of Qatar

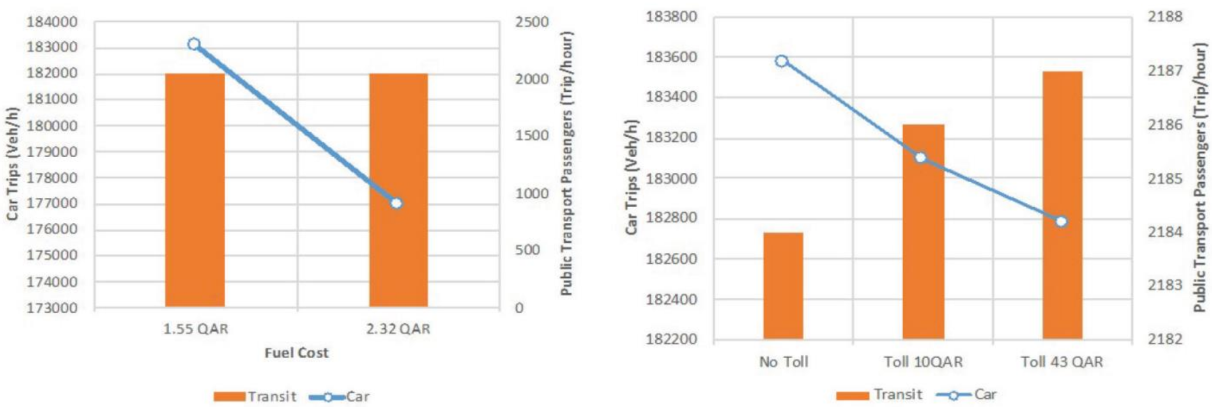

Figure 7.22: Sensitivity Analysis forecasts
Source: Ministry of Transport, State of Qatar

8 Discussion and Recommendations

This chapter summarizes the study’s accomplishments made in accordance with the research aims. Recommendations highlight additional pertinent studies and topics that should be considered in future decision-making and policy formulation.

8.1. Generalization of Findings

The study of Qatar's public transportation plans highlights the country's efforts to create a seamless transportation system that is accessible and efficient for its growing population and tourists. The previous chapters (5 & 6) of the study delve into the details of the country's efforts to integrate multiple transportation modes and prioritize public transit infrastructure. The long-distance railway project underway in Qatar is expected to boost Inter-GCC tourism and business trips, which in turn will further emphasize the importance of public transportation investment.

The Activity Based Model for Qatar (Chapter 7) serves as an innovative solution to balance demand and supply in the transportation network, reducing network stress and improving its resilience. In addition, the government's focus on promoting green mobility is in line with its commitment to sustainability and reducing carbon emissions. With various strategies in place, Qatar is well on its way to becoming a city with sustainable transportation modes, reducing the need for private transportation, and promoting a more environmentally friendly lifestyle.

The study provides a comprehensive overview of Qatar's public transportation plans and models, highlighting the importance of public transportation in the country's growth and development. The focus on sustainable transportation modes and the implementation of innovative solutions to address the demands of a growing population and tourist industry, shows the country's commitment to creating a seamless and efficient transportation system.

8.2. Recommendations

The goal of Mobility Management (MM) is to change the demand for a specific mode of travel by implementing policies and strategies. MM can be done in two ways: "push measures" which control and regulate people's actions by imposing fines and penalties to discourage car use, and "pull measures" which encourage people to choose public transport through incentives and information campaigns. These measures can be "hard" or "soft". Hard measures are costly and time-consuming, such as building a new metro line, while soft measures are non-physical and less costly and time-consuming, such as fuel pricing, driving restrictions, and parking charges [75].

Though the State of Qatar with its Ministry of Transport have well established a plan in action to improve the overall public transport network, there might still be implications that the people of Qatar who were not yet exposed to the economic and environmental benefits that public transportation brings in terms of sustainability, still prefer to use their private modes of transport simply out of habit. The focus of this section is on soft-pull policy measures that increase public transport ridership, which fall into three categories: internally motivating strategies, satisfaction-increasing strategies, and stimulating PT-use and car-habit disrupting strategies, and possible hard-push methods that include temporary / permanent development / change of road infrastructure or land use.

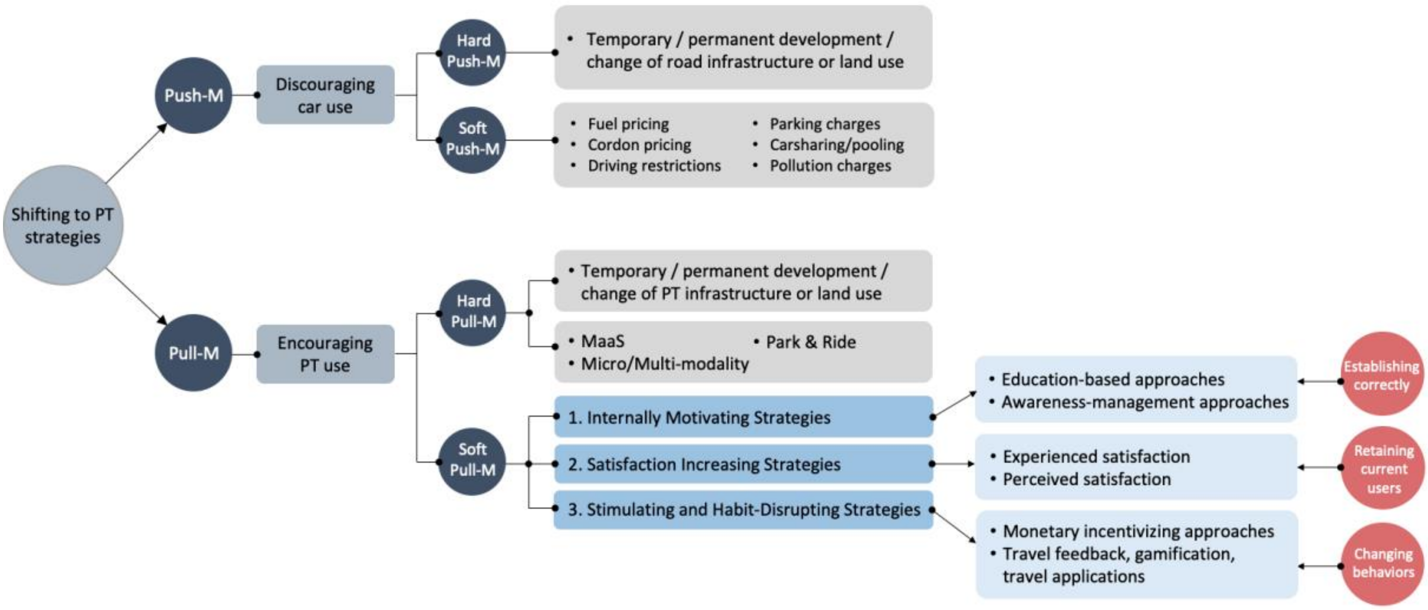

Figure 8.1: Classification of strategies to increase the use of public transport
Source: [75]

8.2.1. Pull Method

Various options are available to transport decision-makers and planners to promote the use of public transport with soft pull measures, which are non-physical interventions that aim to change people's behavior towards public transport.

Figure 8.2: Hierarchy of public transport encouraging strategies
Source: [75]

Three main categories of policy interventions that can be leveraged to increase the effectiveness of traditional measures: internally motivating strategies, satisfaction increasing strategies, and stimulating PT-use and car-habit disrupting strategies. These categories and their related approaches are discussed in detail below:

1. Internally motivating strategies: This category focuses on techniques that intrinsically motivate people to choose public transport over car by gradually and firmly adjusting the fundamental constructs of their behavior (i.e., attitudes, norms, and perceived control). Education, especially from early childhood, and awareness management approaches (AMA) lie within this category. Policy makers should shift their attention from merely awareness-raising to awareness-management, by fine-tuning the information's format, style, sender, etc. according to the characteristics of the target individuals.

2. Satisfaction increasing strategies: This category concentrates on increasing user's experienced and perceived satisfaction. Improving satisfaction with public transport will be essential to help retain current users which is as important as attracting new ones. Electronic ticketing systems and real-time information (RTI) are some examples of low-cost measures that can improve users' satisfaction by modifying their inaccurate perception of the existing service factors.

3. Stimulating PT-use and car-habit disrupting strategies: This category of interventions can best target individuals who drive their car out of habit. Monetary incentives, specifically free PT tickets, have shown success in behavior shift and motivation to change. However, pricing approaches bear the risk of losing their effectiveness with the disappearance of the reward. A reasonably priced method to increase PT use is therefore the implementation of monetary incentives with one or more additional strategies such as awareness campaigns, gamification, etc. [75]

8.2.2. Push Method

Push strategies for public transport use are measures that aim to discourage the use of private cars and encourage the use of public transport by imposing fines, fees, restrictions, and other penalties on car use. These are often referred to as "sticks" as they aim to make private car use less attractive or more difficult, thus pushing people towards using public transport. Some examples of push strategies include:

1. Signaling Priority for Buses:

   Studies on Japanese signaling priority [76], found that the implementation of bus priority systems led to improvements in traffic flow and schedule adherence for buses. There was a reduction in travel time for all vehicles, excluding buses and two-wheeled vehicles, on the peak-direction lanes at major intersections, with reductions associated with two of the nine intersections being significant. Additionally, feedback from questionnaires indicated a net 2% modal shift from other modes to bus transit and a net 0.5% modal shift from car to other modes, resulting in a net 2% reduction in the use of cars and a net 7% increase in the use of buses. Hence priority systems were an effective countermeasure for traffic congestion and modal shifting.

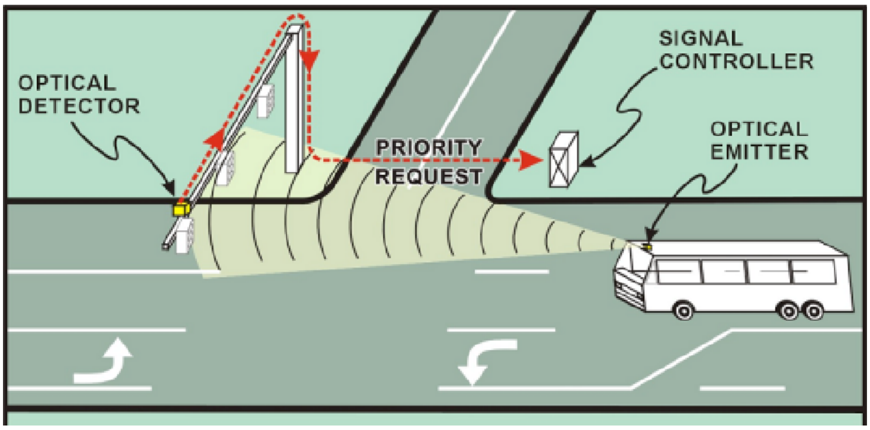

Figure 8.3: Illustration of Bus Priority Signaling

2. Strict City speed limits / Traffic Calming:

   Zurich introduced 30km/h speed limits on parts of its streets to reduce noise and improve the quality of life of residents [44]. This led to prioritizing the public transport network, making it difficult for private modes of transport to travel quickly or even find adequate parking through the city center. Similar policies have been followed by the city of Copenhagen, reducing the number vehicular driving and parking spaces with the phenomenon of traffic calming, improving the infrastructure for bicycles, and encouraging multi modal usage of public transportation [77]. In the Netherlands, Denmark and Germany, traffic calming is usually areawide and not for isolated streets. That ensures that through-traffic gets displaced to arterial roads designed to handle it and not simply shifted from one residential street to another.

Figure 8.4: This contra-flow lane in Copenhagen enables cyclists to ride in both directions, while cars are restricted to one direction. The roadway has been deliberately narrowed through the provision of bike parking. In effect, these modifications have turned it into a bicycling street, where cyclists outnumber motorists.
Source: [77]

3. Traffic Limit Zones:

   Traffic restrictions are an unpopular tool to mitigate urban air pollution, and a measurable improvement in air quality is needed to demonstrate the effectiveness of this measure. Italy is the leading example of the imposition of

Traffic Limit Zones or ZLT (Zona Traffico Limitato) in mostly historic city centers and specific areas where vehicular access in these special zones is regulated and limited to either residents living in the zone or allowing only specific type of emission vehicles for environmental concerns. This encourages the public living outside these zones to use public transportation to avoid hefty traffic violation penalties in the country.

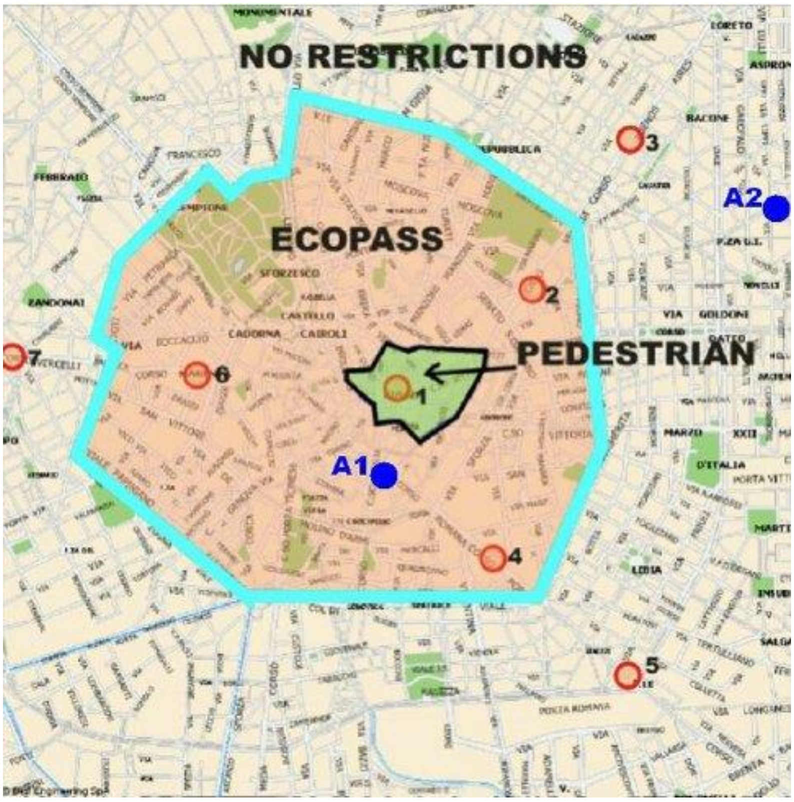

Figure 8.5: Traffic Zone Map of Milan
Source: [78]

4. Infrastructural changes:

Reducing car parks with physical barriers and implementing strict policies can be an effective way to reduce car use in cities. This is particularly important since parking is generally free on streets and only charged in commercial spaces like shopping malls in Doha, while very few get penalized for parking on pedestrian pathways Figure 8.6.

By limiting the number of available parking spaces and making it more difficult for cars to access certain areas, people may be more inclined to use alternative modes of transportation such as public transit, biking, or walking. Additionally, reducing the number of car lanes and creating separate bike and pedestrian lanes can make these modes of transportation safer and more accessible for people. By providing dedicated lanes for public transit and bikes, cities can encourage people to use these modes of transportation as well, as they will be able to travel more quickly and efficiently than they would be able to in a car.

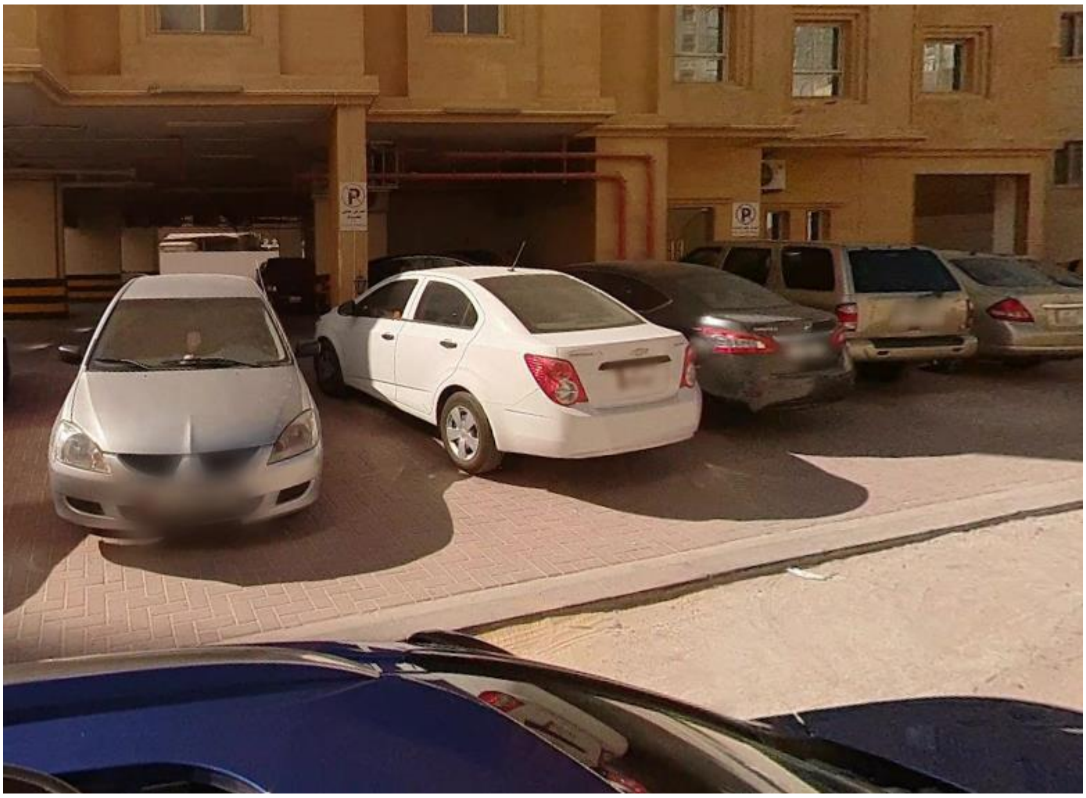

Figure 8.6: Car Parking in no Parking Zone, Al Saad, Doha
Source: Google Street View, 2021. Courtesy: Mahmoud Alhashem

Implementing shared car and pedestrian roads in city zones with reduced speed limits for cars can also make cities more pedestrian-friendly and reduce the number of cars on the road Figure 8.7. This can be particularly effective in areas where traffic is slow-moving or congested, as people may be more willing to walk or bike rather than drive. Although implementing these changes may be difficult at first, a hard push method to reduce car use and improve other modes of transportation can be essential to creating sustainable, livable cities.

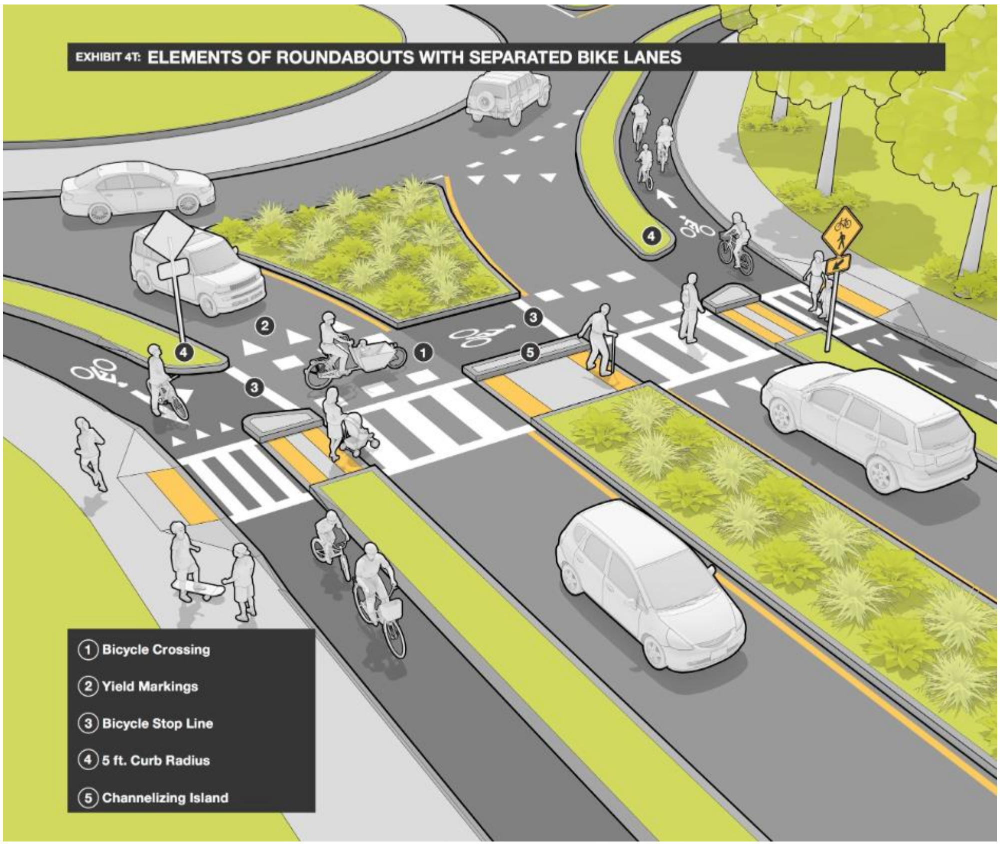

Figure 8.7: Multimodal Street Design
Source: [79]

In deduction, Mobility Management (MM) plays a vital role in promoting sustainable transport by encouraging people to shift from private modes of transportation to public transport. Soft-pull measures such as internally motivating, satisfaction-increasing, and stimulating PT-use and car-habit disrupting strategies can be effective in changing people's behavior towards public transport. At the same time, hard-push methods such as priority signaling for buses, strict city speed limits, and traffic limit zones can discourage private car use and encourage the use of public transport. By combining both soft-pull and hard-push methods, transport decision-makers and planners can create an efficient and sustainable transport system that promotes economic, social, and environmental benefits for the community.

9 Conclusion

The advancements made in the state-of-the-art transportation system have led to significant improvements in Qatar’s mobility, connecting various areas of the country with its transportation modes seamlessly. The sensitivity analysis tested the Qatar Activity-Based Model's reaction to changes in travel time and transport costs, specifically examining policy options like fuel cost, congestion pricing, public transport tariffs, and parking fares. Increasing the cost of gasoline resulted in a reduction of car traffic, while congestion pricing showed limited reductions in road use and slight increases in public transport patronage. Parking fare testing showed that a lower fare produced a reduction of cars attraction and a decrease in car park occupancy, while a higher fare reduced car attractions by a greater percentage but had a smaller effect on car park occupancy. The analysis confirmed the model's sensitivity to these policy options.

The future transportation masterplan shows great promise for further improving mobility through the extension of railways, highways, waterways, and cycling network schemes, enabling people to travel more efficiently and comfortably and promote intermodal trips. However, the safety and comfort of all users, especially cyclists and their behavior, are of utmost importance while using these transportation systems. The criticism on cycling safety in Doha, specifically regarding the hot weather conditions, highlights the need for more policies that ensure safer cycling mobility. The absence of road policies, the lack of priority given to public transport and pedestrian infrastructure, and the presence of wider roads generally contribute to the promotion of car use.

Transforming hot cities into bike cities requires a holistic approach that accounts for the unique challenges presented by extreme heat. One approach is to implement policies that improve cycling safety, such as building natural barriers along cycling paths to provide shade and mitigate the effects of heat. Another key consideration is creating infrastructure that is designed to promote cycling, such as bike lanes and bike parking facilities. Additionally, providing education and resources to the public on the benefits of cycling and how to cycle safely in hot weather can also be effective in increasing cycling rates. City planners and policymakers must also consider the unique needs of their communities and develop strategies that encourage cycling while considering local factors such as topography, distance, and cultural norms. Ultimately, successfully promoting cycling in hot cities requires a comprehensive, multi-faceted approach that addresses the challenges posed by heat while leveraging the many benefits of cycling.

Additionally, governments must work towards creating a culture that encourages cycling as a primary mode of transportation, with the necessary infrastructure and policies in place. Encouraging the use of more sustainable modes of transportation such as cycling, not only reduces traffic congestion and air pollution but also promotes physical activity, leading to a healthier lifestyle. Because the negligence of primary education on this mode of transportation could prove to have pitfall in where significant population cannot use such infrastructure.

In conclusion, while the state-of-the-art transportation systems and the future transportation masterplan show great promise for improving alternate modes of mobility, there is still a need for more policies that prioritize the safety and comfort of all users. Governments must take the necessary steps to create a sustainable transportation system that meets the needs of all users, while also promoting the use of more sustainable modes of transportation. By working towards a greener and healthier future, we can create a more efficient and sustainable transportation system that benefits everyone.

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