Sustainable transportation in Dubai: Evaluating the Effectiveness and Efficiency of Dubai Metro System

النقل المستدام في دبي: تقييم فعالية وكفاءة نظام مترو دبي

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Abstract

Dubai is a fast developing city which in the past few years has taken major steps towards having a more sustainable urban development. Furthermore, this city is home to one the most innovative urban rail networks in the region which provides mobility to millions of commuters per year. In 2013, Dubai was elected as the host to 2020World Expo. This opportunity has created a new wave on urban development and expansion in Dubai. Based on the theme of Dubai Expo 2020 which is Sustainability, Mobility and Opportunity, there is major attention paid to sustainable developments and sustainable transportation. This has been one of the main derivers of this research.

A transportation system is considered sustainable that would be able to provide mobility and accessibility to people and goods while having minimum harmful environmental, social and economic impacts on cities and the societies.

By focusing on the impacts of urban development, population growth, increased mobility and integration of various transportation modes on the ridership of Dubai metro in years 2015 to 2025, this research evaluates Dubai metro system in terms of effective and efficient transportation provision. Moreover, through generating numerous sets of predictive ridership patterns for Dubai metro during the mentioned years, this research identifies and discusses the parameters that have a direct and indirect impact on the metro ridership fluctuation. Identifying these parameters would be beneficial in developing future transportation development schemes and plans.

ملخص

دبي مدينة سريعة النمو اتخذت في السنوات القليلة الماضية خطوات كبيرة نحو وجود تنمية حضرية أكثر استدامة. وعلاوة على ذلك، هذه المدينة هي موطن لأحد شبكات السكك الحديدية في المناطق الحضرية الأكثر ابتكارا في المنطقة الذي يوفر التنقل إلى الملايين من الركاب سنويا. في عام 2013، انتخب دبي بوصفها البلد المضيف لمعرض اكسبو2020 العالمي. وقد خلقت هذه الفرصة موجة جديدة حول التنمية الحضرية والتوسع في دبي. على أساس موضوع دبي إكسبو 2020 وهي الاستدامة والتنقل والفرص، وهناك اهتمام كبير يدفع للتطورات المستدامة والنقل المستدام. وقد كان هذا واحدا من الاسباب الرئيسية لهذا البحث.

يعتبر نظم النقل المستدامة التي من شأنها أن تكون قادرة على توفير التنقل والوصول إلى الناس والبضائع في حين هناك الآثار ضارة كحد ادني بيئية واجتماعية واقتصادية في المدن والمجتمعات.

من خلال التركيز على آثار التنمية الحضرية والنمو السكاني، وزيادة الحركة والتكامل بين مختلف وسائط النقل على الركاب من مترو دبي في السنوات 2015-2025، هذا البحث بتقييم نظام مترو دبي من حيث فعالية وكفاءة توفير النقل. وعلاوة على ذلك، من خلال توليد مجموعات عديدة من أنماط الركاب التنبؤية لمترو دبي خلال السنوات المذكورة، وهذا يحدد البحوث ويناقش المعلمات التي لها تأثير مباشر وغير مباشر على تذبذب الركاب المترو. كما أن التعرف على هذه المعايير تكون مفيدة في تطوير مخططات وخطط التنمية النقل في المستقبل .

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Chapter 1: Introduction

1.1. Overview

Transportation, accessibility and mobility are key elements to all urban developments. Moreover, sustainable transportation plays a major role in sustainable and liveable urban developments in small or large communities and cities. Sustainable transit would enhance economic growth through providing better integration of economy, provide trade prospects, respect the environment while providing efficient movement of people and goods within local and global markets, provide a safe and reliable transit system to the commuters, enhance social equity and in general enhance the living quality of residents of any urban settlement (SD, 2014).

Design, development and implementation of any transportation system on any scale are of high importance. As stated by Tumlin (2012), a well-designed, well-planned and well-executed transportation system would help greatly in achieving a well-integrated and practical transportation network. While this can contribute significantly to the success of an urban development, lack of enough investment on the mentioned factors can result in development of a transport system that is poorly responsive to the local, provincial or even global needs of an urban settlement. In this path, continuous assessment and analysis of the designed transit systems plays an important role in understanding the functionality level of different transportation systems as well as their efficiency and viability.

In the Middle East, the transportation sector is challenged in many ways. On one hand, its underdeveloped and inefficient networks continue to hinder economic development. On the other hand, the transportation sector represents a major consumer of energy in the region and a primary contributor to carbon emissions (Elgendy & Yassine 2012).

The United Arab Emirates as a Middle Eastern country and as a result, Dubai, has been rapidly witnessing a substantial growth of population and urbanization and an unprecedented stride in the constructional developments; along with the boom and economic developments, elements of importance that placed pressures on the

transportation systems of all types as well as the economy and environment (RTA 2012).

Despite this pressure, undoubtedly, Dubai has been successful in developing a unique urban infrastructure and creating an integration of various public and private transportation modes over a rather short period of time. In addition to the already existing urban development plans and schemes of Dubai, in the year 2013, this city was selected as the host of the World Expo 2020. This election created a new wave of urban development in this city with development plans and schemes that are in conjunction with the theme of Dubai Expo 2020 which is: Sustainability, Mobility and Opportunity.

1.2. Research Objectives

Dubai Expo 2020 and its theme (Sustainability, Mobility and Opportunity) have been one of the main deriver of the current research which focuses on the evaluation of effectiveness and functionality of public transportation in Dubai.

Among different available types of public transport modes, the main focus of the research in hand is drawn to the urban railway systems and in particular Dubai metro; a public transportation mode that has become an urban icon in the region, if not the world. Dubai metro has one of the most innovative operational technologies and over its operational period it has provided mobility to millions of commuters. Furthermore it is believed that Dubai metro has had significant impacts on increasing the quality of public transportation; hence the sustainability of transport in this city.

The main ambition of the present research is to investigate and evaluate sustainability of Dubai Metro. For this purpose, the study has been divided into 2 main phases. In the first phase it is aimed to set up a clear definition and understanding of a sustainable transportation system, its characteristics and performance. Furthermore, it will be discussed how public transportation can help

in improving overall sustainability of the transportation system. This will be achieved through extensive research of the available literature on this topic.

The second phase of the study mainly focuses on an in-depth analysis and evaluation of the effectiveness and efficiency of Dubai metro system. In this phase, provided mobility and accessibility to the commuters using this transportation system will be evaluated. This evaluation will be carried out in 3 stages:

In the first stage, through a general simulation of Dubai metro operation in years 2015 to 2025, the overall metro ridership in these years will be obtained and analysed. The results generated in this stage would help with understanding the ridership patterns and transportation mode share in the stated period of time.

In the second stage, the impact of parameters such as further urban development, population growth, increased tourism rate, as well as hosting World Expo 2020 on Dubai metro ridership will be studied. The impact of the mentioned criteria will be evaluated through analysing the ridership of strategically selected metro stations. These stations would each be considered as a case study of at least one of the mentioned parameters.

In the third stage, further study will be conducted on how transportation integration can enhance the ridership, accessibility and sustainability of the public transportation in Dubai. For this purpose, integration of Dubai Metro, Dubai Tram and Dubai Bus services will be studied and analysed.

Results obtained from this study would be evaluated in order to investigate

Results obtained from the second phase of this research would help in evaluation of Dubai public transportation. These evaluations would clarify Dubai Metro's role in providing and enhancing a sustainable public transportation for the city at the present time and in the future.

Furthermore, the result of these evaluations will point out the strengths and weaknesses of Dubai Metro system in respect to public mobility and accessibility provision. Doing so will open new perspectives of the topic for urban designers and

transport planners as well as sustainability researchers and advocates who wish to conduct more research in this area of study.

1.3. Research Outline

The present document is divided into five chapters where each chapter elaborates to the research on different levels. This chapter was an introduction to the topic in hand; presenting the main ambition of the project.

In the following chapter, a thorough literature review of sustainable transportation and its parameters and the key concepts that play an important role in creation and provision of a sustainable transportation system will be presented. Reviewing the literature related to these concepts is widely essential and beneficial since these measures can be used for evaluation purposes in later staged of the project. Additionally, a number of case studies will be selected and reviewed in order to investigate their approach towards sustainable transportation, how it has been achieved and what the pros and cons of these approaches are.

Chapter three will focus on the methodology of the research. Through evaluation of different possible methods to conduct similar researches, the most suitable method will be selected to be used in this project. In this chapter the employed tools and resources for completion of this research will be stated.

Chapter four will present the generated results and findings of the research based on the body of exploration and on the basis of the methodology that has been set in chapter three. The presented results will then be explained, analysed and discussed thoroughly.

The final chapter, chapter five will be dedicated to concluding the project, where a summary of the achievements of the project will be given. Also the challenges and limitations of this research will be discussed and the chapter will be ended by mentioning the possible recommendations for further work and research.

Chapter 2: Literature Review

2.1. Overview

In this chapter, a detailed literature review on the topics of transportation, sustainable transportation and public transportation will be presented.

In the first part of this chapter, a detailed literature review will be presented, providing a thorough background study on the subject of transportation over the time, its impacts on the urban development, history of sustainability movement and sustainability development. This section will then be followed by a thorough research and investigation on the topic of sustainable transportation and its various indicators and parameters.

A profound understanding of the above topics has been achieved through reviewing earlier available literature and researchers' works. The articles used in this section have been selected from a wide range of papers focusing on sustainable transportation, public transportation, policies affecting sustainable public transportation and guidelines for improvement of sustainable transportation. Papers studied and discussed in this chapter are chosen based on their relevance to the research topic.

Literature presented in this section will then be followed by the researched precedents of cities and countries that have planned, invested in and developed a more sustainable transportation system.

2.2. Transport and Transportation

Taken from Latin and old French roots (Fig. 2.1), Webster (2011) defines the words "transport" and "transportation" as bellow:

"Transport (verb):

- Take or carry (people or goods) from one place to another by means of a vehicle, aircraft, or ship.

Transportation (noun):

- A system or means of conveying people or goods from place to place.
- The action of transporting something or the state of being transported."

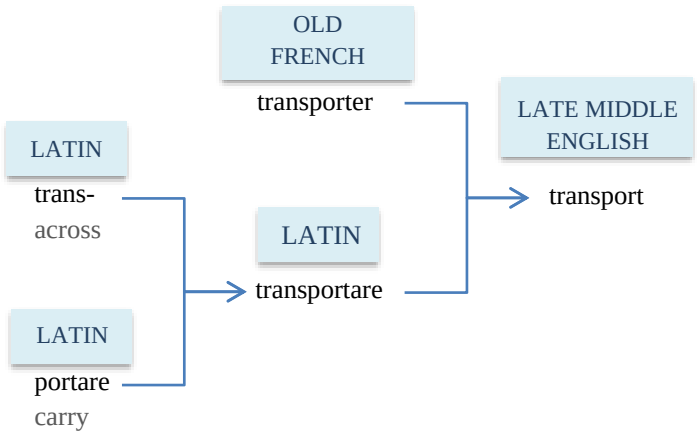

Figure 2.1: Origin of the word "Transport"
Source: Webster, 2011

The history of transportation, of course, goes back to the Palaeolithic ages when the early human used nothing but their feet as means of movement and transportation. Although the cave painting of animals such as horses appeared as early as 30,000 BCE, there is no clear evidence of when and how domestication of horses and other animals started for transportation purposes. As for water transport, log boats and dugouts are believed to be the oldest types of boats used by human between 8000 and 5000 BC (Wonning, 2012).

For centuries, these modes of transportation were the only options for the early human. While water transportation improved on many levels, land transportation remained limited to pedestrian travels or direct use of animals. In the late Neolithic and early Bronze Age, about 3,500 BC, discovery of the wheel added a new dimension to the land transportation system. This initiated the invention of early carts and carriages which made long distance travelling easier and later on helped in developing the very first railway system (Wei, 2010).

The earliest evidences of railways (wagon ways) are found about 600 BC in Greece. The more advanced rail systems, mainly used for transportation of goods, were developed during 16th to 18th century (Wonning, 2012).

Transportation was greatly improved during the 18th century. In addition to developments of railways, early automobiles were invented in 1768 (Gregersen, 2011). Moreover, air transportation was introduced through invention of hot air balloons by Montgolfier brothers (Wonning, 2012). However it was invention of the steam engine in 1781 that revolutionised transportation and technologies related to it. This invention was the starting point of significant changes in transportation technology and infrastructure (THF, 2013).

In the 19th century, following the invention of steam engine, land and water transportation were greatly improved. Invention of locomotive revolutionised rail transport making it faster and easier. This was also a starting point for underground rail service that was first developed in mid-19th century using steam trains which later on gave place to electric trains (Wonning, 2012).

Automobile fabrication and performance was further improved by using new generation of steam engines and were later on advanced by introduction of diesel engine (Gregersen, 2011).

Also the accessibility and efficiency of water transportation was greatly increased by introduction of steam ships that could travel much further distances and were able to carry much more loads of goods and cargo. Improvement and use of these transportation modes rapidly increased during the 19th and 20th century (Wonning, 2012).

The 20th century started off with major progress in air transportation system. In 1905 the first aeroplane was made and put to test. Although airplanes were vastly used during World War I and II, it wasn't before 1945 that commercial use of airplanes became popular and has grown ever since (THF, 2013). Other modes of transportation, land and water transportation, also were further developed: Electric trams were introduces in early 20th century and later on they gave way to motor busses and electric busses, use of cars became more common in 1960s and new water transportation systems such as hovercrafts were invented in mid-20th century. Towards the end of the 20th century, most transportation modes reached their most innovative stage (Wonning, 2012).

The evolution of transportation technology and infrastructure still continues. Today, the main ambition is to increase the efficiency, functionality and sustainability of different transportation means by altering their technology and design. Inventions of hybrid vehicles, electric vehicles and fuel cell vehicles are examples of attempts to achieve this goal (THF, 2013).

2.3. Public Transportation

2.3.1. A Brief History

Public transportation, also referred to as mass transit is a shared passenger transport mode which is available for general public use.

Ferries and boats are known as the earliest vehicles designed and used for public hire, therefore water transportation is considered as the first mode of public transportation in history. On land, travelling fixed routes using coaches and carriages to carry paying passengers was the main mode of public transport for several centuries (THF, 2013).

The first known organized public transport mode in cities is the omnibus transportation system originated in Paris, France during the 17th century. This new mode of public transport soon became common in other European countries such as United Kingdom, however gave its place to the fast developing railway system in the 18th century (Vuchic, 2010).

Rapid advancements in transportation technology after the 18th century, especially improvements of railways, made public transportation a much more desirable mode of transportation. Compared to available private modes of transportation, public transportation was faster, easier, safer and cheaper. This resulted in significant increase in usage of public transportation during 19th. Although public transportation usage rate faced several ups and downs in the 19th century, it reached its peak toward the end of World War II (THF, 2013).

In years after World II, due to mass production of automobiles, public transportation usage rate experienced a drastic drop. While using private cars became more common, public transportation lost its significance in everyday life of citizens. This drop reached its turning point when the oil crisis happened in 1973 (THF, 2013).

As an example, Figure (2.2) illustrates the fluctuation of public transportation ridership in the United States between years 1917 and 2011. Beutler (2012) explains that the fluxes of the graph are due to national and international and global change; incidents such as economic boom or crisis, oil crisis, population growth, urbanization and socio-cultural evolution.

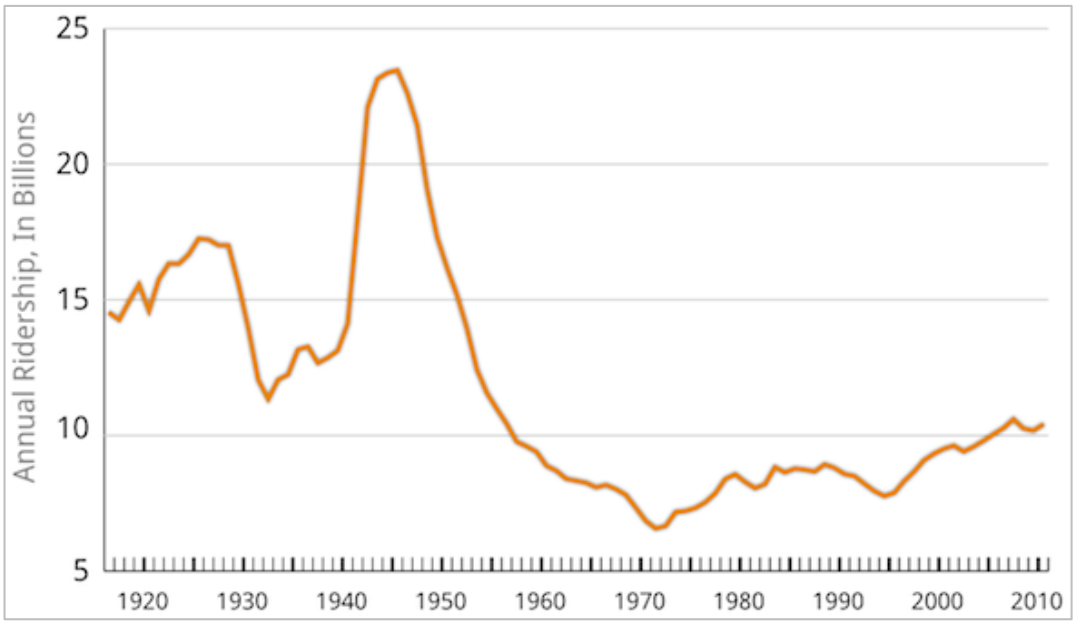

Figure 2.2: Annual public transportation ridership in United States in years 1917-2011. Source: APTA, 2012

Since 1973 there has been more awareness regarding the importance of fossil fuel resources and environmental preservations. In transportation sector, new initiatives aim to facilitate public transport and discourage use of private transportation modes. This has resulted in the gradual increasing rate of public transportation usage over the past four decades.

2.3.2. Today's Public Transit

Public transit systems around the world have distinct differences in terms of operation. While in Asia public transportation sectors are mostly run by privately owned and publicly traded mass transit corporations, in North America, municipal

transit authorities are in charge of public transportation operations and in Europe, these operations are run by state-owned companies (Calimente, 2012).

Mass transit services can be profit-driven where the user would be charged based on the travelled distance or it can be funded by government subsidies where flat rate fares are charged to each passenger; although fully subsidized (zero-fare) are provided in some towns and cities (Calimente, 2012).

Today, mass transportation has been divided into three main hierarchical sectors (Vuchic, 2010):

- Urban public transport:

This sector is responsible for providing public transportation within a city and local suburban areas. The main transportation mode used in this sector are: City busses, trolley busses, trams (or light rail), passenger trains, rapid transit (metro, subway, underground), water taxies, water buses and ferries.

- Inter-urban (or national) public transport:

National transportation systems provide services for travelling from one city to another within a country. Dominating public transportation modes between cities are: Airlines, intercity railways, coaches and water carriers.

- International public transport:

Providing transportation facilities for travelling between countries, international public transportation modes are similar to inter-urban public transportation modes whoever, the vehicle used in this sector can be of higher durability due to longer travelling distance.

Transportation modes mentioned above are the most popular public transportation modes around the world. As for uncommon modes of urban public transportation the following two systems can be mentioned:

- Personal rapid transit (PRT):

This system is an automated cab service that operates on a guided rail network. This service offers the convenience of personal automobiles while having the efficiency of public transportation (Jain et al., 2015). PRT systems have recently been implemented in few urban communities around the world, Morgantown in West Virginia, USA (Gibson, 2014) and Masdar city in Abu Dhabi, UAE (Dilworth, 2007) are examples of these communities.

- Cable-propelled transit (CPT):

CPTs are engine-less vehicles that are propelled by a steel cable and commonly move people between two destinations with varying topography. Although this system is generally linked with usage in ski resorts, use of CPTs in many urban areas has increased in past few years. Examples include Metrocable of Medellin, Colombia and Caracas (Dale, 2010), Venezuela, Portland Aerial Tram (Richardson, 2006), Roosevelt Island Tramway in New York City (Cohen, 2008) and London's Emirates Air Line (BBC News, 2012). Full integration of this system within existing public transportation networks has positively impacted mass transit in these cities (Dale, 2010).

2.4. Transportation and Urbanisation

Kennedy, Pincetl and Bunje (2011) compare cities and urban settlements to living organisms. In a living organism, food and information are being transferred through vein and nervous system networks. It is through these transmissions that growth of any living organism is achieved. As an organism grows, these networks develop further and become more complex in order to adapt to the emerging needs of that particular organism. It is due to this adaptation that survival of different organisms is guaranteed. Similarly, in cities, transportation networks are means of transference of food, goods, material, information and technology within and without the city. These transmissions help cities to grow over the time and enhance the civilians living quality.

Transportation, whether public or private, has influenced and been influenced by the process of urbanization throughout the time; urban growth and expansion has always been followed by transportation network development in order to provide access to the new boundaries and where there has been an expansion in transportation network, new urban settlements have emerged.

Urbanization is defined as the urban process of environmental, infrastructural and social adaptation to gradual increase in urban population due to population shift from rural to urban areas. This phenomenon is responsible for formation of cities and urban settlements and their growth over the period of time; as more people move to urban areas to live and work in the central parts (Demographic Partitions, 2014).

Predictions of United Nations indicate that by 2050 around 64% of the developing world and 86% of the developed world will be urbanized. This amount which approximately equals to 3 billion urbanites by the year 2050, will mainly be distributed in Africa and Asia (The Economist, 2012).

Urbanization which is one of the many outcomes of industrial revolution in 1820, made cities a more attractive place to live, as they could offer more job opportunities, higher living quality and better facilities. This, coupled with ever increasing population growth rate, resulted in rapid economic inflation, hence rising real estate values (Chakwizira, Bikam and Adeboyeho, 2014).

At the same time, technological evolution of transportation modes made traveling between distant destinations within a city much easier, faster and cheaper. Such developments on one hand and rapid increase of urban living costs on the other hand, encouraged urbanites to choose farther locations to reside. Moreover, introduction of private cars in daily lifestyle of civilians, made it possible for them to live in the suburbs, where the living cost could be much less, while working in the central parts of the city. Using this new and cheap technology then became a part of everyday life of people, providing easy access to different destinations inside and outside the urban area. Therefore new developments formed on the outer borders of cities to provide facilities to the new residents of those areas.

This development process which is referred to as “urban sprawl” is one of the most important results of urbanization and transport in formation of today’s metropolitans and megacities (Chin, 2013).

Over the time, urbanization has had many negative environmental, social and economic impacts on the planet and human life. Today, the effects of urban sprawl on transportation in growing megacities have become a rising concern in many different contexts.

Physical and functional aspects of urban sprawl are characterized by low density and isolated developments, followed by a low degree of local mixed land use. These factors have not only had damaging impacts on both economic growth and social demeanour of urban community, but also they have had undesirable effects on the environment.

Increased rate of frequent, long distance travels by vehicles has greatly contributed to the rising domestic greenhouse emission, resulting in global climate change and endangering habitats due to global warming. Moreover, high rates of automobile dependency in urban areas have accelerated consumption and depletion of fossil fuel resources worldwide (Lemonsu et al., 2015).

In the late 20th century, all the mentioned factors triggered the sustainable environmental movement; aiming to attain a sustainable urban growth through stablishing stronger metropolitan development management system.

2.5. Urbanization and Sustainability Movement

The technological improvements over centuries gave human the opportunity to control the environment the way he saw fit. The domination of man over the time had negatively changed the environment; however, it was not until the Western industrial revolution that the harmful impacts of these changes were tangible.

As a result of the industrial revolution in the 19th century, the ever increasing pace and extent of changes forced by humans endangered the environment on many different levels (Goudie, 2013).

Modern sanitation systems as well as advances in medicine protected greater populations from fatal diseases, leading into population explosion and therefore accelerated urbanization rate. Immense use of fossil fuels to power factories as well as to produce electricity resulted in over-exploitation of non-renewable resources and substantially increasing air and water pollution. These mentioned points are only a few of many factors that had (and still have) amplified the destructive effects on the environment (Turner, 2008).

It was after the industrial revolution that arising concerns about the environmental and social effects of industry were expressed by few political economists and scientists, leading to the Environmental Movement of the 19th century.

It was during this movement that topics such as interrelated effects of over-population on the environment and economics were brought to attention; forming the basis of the modern discipline of ecological economics. Moreover, physiological impacts of environment on plants were studied for the first time, heralding the scientific discipline of ecology (Roosa, 2010).

By the 20th century, ecology had reached a general recognition as a scientific field, and various fundamental concepts of sustainability were being studied and explored. These concepts included: the interrelatedness of natural living systems coexisting in a single living interconnectedness of all living systems in a single living global system, the biosphere; significance of protecting natural cycles such as water, material and waste cycles; and the provided energy by trophic levels of living organisms (Roosa, 2010).

In parallel further technological advancements led to considerable increase in health, wealth and population. Although this was perceived as a desirable result of global progress, their impact on exponential increase in the human consumption of resources was undeniable. In 1930s, this factor was the main trigger for a group of economists to develop models of non-renewable resource management and the

sustainability of welfare in an economy which relies in non-renewable resources (Roosa, 2010).

After World War II the developed world entered a new era. As Robin (2008) describes it:

"The Great Acceleration - the phenomenal post-1950s surge in the human enterprise that has emphatically stamped humanity as a global geophysical force."

Environmentalists and sustainability researchers pointed out that there were major environmental costs associated with many technological progression benefits. Moreover, harmful side effects of innovative technologies and materials such as plastics, synthetic chemicals, nuclear energy and industrialized agriculture in addition to increasing use of fossil fuels were jeopardizing human life and transforming societies. Additionally, the energy crisis of 1973 and 1979 exposed the extent to which the developed world had become dependent on non-renewable resources (Blewitt, 2012).

It was through these acknowledgements that it was realised environmental problems were not regional issues anymore and they had become major global problems. Subsequently, committees were formed to improve the public knowledge of the environmental issues and to promote energy conservation and waste elimination. This was the start of the modern sustainability movement; a movement that aimed to stablish a guideline to a more sustainable future ((Blewitt, 2012).

In 1987, in the report published by the United Nation's World Commission on Environment and Development (WCED), "Our Common Future", stated that achieving a sustainable and reliable future is only possible through a "sustainable development"; a development that would meet the needs of populations while not increasing harmful environmental impacts. It was also advised that developments in all sectors were acceptable as long as they followed the principals of the sustainable development (Baker, 2011).

This manifesto encouraged the movement towards sustainable living in all sectors, resulting in (Baker, 2011):

- Development of large-scale and small-scale sustainability policies;
- Development of renewable energy resources
- Increasing sustainability awareness of public

2.6. Sustainable Development

The World Commission on Environment and Development (WCED) (1987) defines the concept sustainable development as:

"Sustainable development is development which meets the needs of the present without compromising the ability of future generations to meet their own needs."

In the pervasive discussion and use of this concept, there has generally been recognition of three major factors (Harris, 2010 and Baker, 2011):

- Economic sustainability: A system is economically sustainable if it is able to produce merchandises and services on an enduring basis, sustain controllable levels of government and external responsibility, and elude severe regional imbalances which would lead to damaged production in different economic sectors such as agricultural or industrial.
- Environmental sustainability: A system is environmentally sustainable if it would be able to hold a reliable resource base, evade over-exploitation of renewable resource systems and environmental sink functions and limit the consumption of non-renewable resources to the level that investment is made in adequate substitutes. This includes maintenance of biodiversity, atmospheric stability, and other ecosystem functions not ordinarily classed as economic resources.
- Social sustainability: A system is socially sustainable if it is able to provide social equity on various levels, provide acceptable level of social services such

as health and education, offer political liability and provide contribution opportunities to the public.

As it can be understood, the concept of sustainability is based on the grounds that communities are composed of social, economic and environmental systems that are in constant evolutionary interactions with each other. In order to ensure that the community would, in present and future, continue to operate to the welfare of its inhabitants, maintaining and enhancing the harmony and balance between these systems is crucial. A society is considered healthy, balanced and sustainable if it would be able to endure into the future, providing an acceptable level of life quality for all its members. Today, for any community and society that is aiming for a successful future, sustainability is a goal toward which they should strive and against which they should weigh proposed strategies, plans, outlays, and resolutions. Sustainable development is looking at the context of society or community from a wider perspective in both time and space (Blewitt, 2012).

Building on the above mentioned factors, a series of guidelines has been developed in order to break down the aspects that contribute to each of these principals. Using such guidelines would enable countries, governments and communities have developed a series of guidelines based on their requirements and state of development.

2.7. Sustainable Urbanization

Sustainable urbanization aims to improve and maintain livability; improve economic endurance; provide social, multigenerational and racial equity; improve environmental quality; incorporate disaster resilience and mitigation and promote consensus-building, participatory decision making process (Monday, 2013).

Pursuit of sustainability is profoundly a local undertaking since social, economic and environmental needs and concerns of each nation varies while continuously developing and changing. Therefore the quality, quantity, importance, and balance

of those needs and concerns are unique. For that matter sustainability approaches and mitigation efforts are tend to be tackled on local basis (Monday, 2013).

The mentioned locality has a hierarchical characteristic. When the subject of attention is sustainable urbanization on a larger or global scale, locality would refer to each country; while on smaller scales, locality can refer to a city or even smaller area such as an urban block. This bottom-up approach would help planners to address the issues associated with each sector of an urban development more thoroughly. However, in order not to lose the greater perspective which is a global sustainable urbanization and development, following a well-planned agenda in necessary. This top down approach would give the planners a comprehensive outlook of the development (Nash, 2013).

The first step on the path to sustainable urbanization is to compose, develop and refine the related policies. These policies based on the three main principals of sustainability would impact various layers of the community on different levels. Different layers of a community can be categorised as (Baker, 2011):

- Natural environment
- Built environment
- Economics and industries
- Inhabitants

These layers although categorised separately, correlate simultaneously. Therefore it is important to understand: First, how and to what extends, each category (and their subcategories) can contribute to the sustainable urbanization and second, how and to what extends, their interactions would affect this process (Baker, 2011).

As discussed earlier, transportation – a subcategory of the built environment- plays a significant role in the process of urbanization. While a well-planned and sustainable transport system would positively contribute to different factors of the community such as the environment and economics, an unsustainable transportation can take a toll on communities.

Therefore, to develop, enhance and promote sustainable transportation, it is of high importance to understand what is a sustainable transportation system, how can it be achieved and in this process, what factors would affect and be affected by changes in this system.

2.8. Sustainable Transportation

Occupying the second highest place for consumption of fossil fuels worldwide, transportation has substantial effects on the environment. This sector is responsible for up to 25% of world energy consumption and CO2 emission; out of which, almost 97% of it is produced thorough burning of fossil fuels. Greenhouse gas emissions from transport are increasing at a faster rate than any other energy using sector. Road transport is also a major contributor to local air pollution and smog (IEA, 2015).

Sustainable transport refers to the vast subject of transport that has lesser harmful impacts on the social, environmental and economic aspects of a community and on the broader scope, is able to run on renewable sources of energy.

During the past years many organisations have tried to stablish a clear and complete definition of a Sustainable Transportation System:

Organization of Economic Co-operation and Development (OCED, 2002) defines Environmentally Sustainable Transportation (EST) as:

"Transportation that does not endanger public health or ecosystems and meets needs for access consistent with

a) Use of renewable resources at below their rates of regeneration, and
b) Use of non-renewable resources at below the rates of development of renewable substitutes."

ECMT (2004) defines sustainable transportation as follow:

"A sustainable transport system is one that is accessible, safe, environmentally-friendly, and affordable."

Centre for Sustainable Transportation (CSTC, 2005) states that:

"Sustainable transportation system is one that:

- Allows the basic access needs of individuals and societies to be met safely and in a manner consistent with human and ecosystem health, and with equity within and between generations.
- Is affordable, operates efficiently, offers choice of transport mode, and supports a vibrant economy.
- Limits emissions and waste within the planet's ability to absorb them, minimizes consumption of non-renewable resources, limits consumption of renewable resources to the sustainable yield level, reuses and recycles its components, and minimizes the use of land and the production of noise."

The above mentioned definitions are just a few of the many that have tried to explain the aim and ambition of a sustainable transportation system development. However, for researchers, planners and designer, in order to be able to plan and design a sustainable transportation system and further more analyse and evaluate the proposed system in terms of its sustainability, it is crucial to know and understand different parameters and indicators of a sustainable transportation system.

Transportation systems are one of the most important means of providing social and economic connections as they exist to provide new opportunities offered by increased mobility to people. However, the benefits of the increased mobility should be evaluated against the negative social, economic and environmental

impacts of that transportation system. Therefore it can be claimed that, sustainable transportation systems contribute positively to the environmental, social and economic sustainability of the communities they operate in (Rodrigue, Comtois and Slack, 2013).

Fundamentally, provision of access to work, education, goods and services is the main purpose of any transportation system. Traditional methods of transport planning intend to enhance mobility through means that lead to automobile dependency. However, following the guidelines of sustainable transport planning and initiatives would enhance access to all mentioned nodes while simultaneously decreasing environmental and social impacts of transportation, as well as managing traffic congestion. Sustainable transportation initiatives can be implemented based on short-term milestones that would focus on improvement in fuel efficiency and vehicle emission control while long-term goals would include replacing fossil-based energy systems with other alternatives such as renewable energy resources (VTPI, 2013). Although it should be mentioned that successfully implementing sustainable transportation initiatives would only be achievable through stablishing a sustainable community (RITA, 2010).

There are various indicators that the sustainability of different transportation systems would be defined by and evaluated against them. Having knowledge about all these role playing parameters, how they contribute to sustainability of a transport system, what is the basis of their evaluation and how they can be enhanced can be an asset to any group or system that aims to promote and enhance transportation sustainability.

In the following sections these indicators will be introduced and their contribution to sustainable transportation and methods by which they can be evaluated and improved will be discussed.

2.8.1. Affordability

Transportation affordability addresses the financial pressure households endure in paying for transportation services, specially households that are struggling to afford for basic goods and activities such as shopping, healthcare, school, work and other social activities.

Surveys indicate that transport system users consider affordability one of the most important factors in choosing of transport system. However, conventional transport planning tends to give little attention to the aspect of affordability and contemplates a narrow set of transportation costs and cost saving approaches (VTPI, 2015).

There are a number of elements that can influence affordability of a transport system (VTPI, 2015):

- Income or wealth
- People's travel choices and demands
- Quality and variety of transportation modes
- Price of transportation
- Ease of access to different zones and hubs within the city
- Housing affordability

According to The World Bank (2014), a transportation system can be considered affordable if all the users of the system, including the 20% of the population at the bottom of the income pyramid, would not spend more than one fifth of their income on transportation or 45% of their income on transportation and housing combined; since households usually make trade-offs between housing and transport costs. Therefore a cheaper home cannot be considered affordable if it significantly increases transport costs. However, this being said, in many developing countries, even public transportation often remains unaffordable for the poor.

Major challenges of planning transportation systems in a developing country are first, to assess the percentage of income spent on transportation by weaker households; and second, to understand transport sequence and arrangements in respect to residential localities, distance of the journey and travel mode. In such countries, low-income households often tend to choose farther areas out in the periphery of the cities to reside due to high real estate rates in the central urban

zones. Consequently, this process effects the development of suburban clusters with subsequent impacts on the levels of transportation dependency, congestion, air and noise pollution, decrease in physical activity levels and growth of urban poverty(Babinard, 2015).

Transportation affordability is an issue even in developed countries. A large percentage of homeowners and home seekers these days are dealing with high transportation cost when looking for and affordable residence, mainly because they are forced to live in distant areas with often very few public transportation choices. In many cities, housing cost in the outlays can be considerably lower. However, transportation costs on the other hand can end up much higher (Babinard, 2015).

A study in the United States shows that the sum of housing and transport charges averages about 57% of working families' income in metropolitan areas of this country. This is mainly because numerous homeowners and renters have chosen to migrate from the city to the outskirts in order to finding more affordable housing and therefore lower their housing expenses. However, the cost of living is not only the amount of money paid for the rent or the mortgage; transport related costs – for reaching work, school, shopping and healthcare centres- also should be considered as well. Moreover, estimating transport costs are usually more difficult than that of housing because of the unpredictable need of transportation facilities. As a result, many households who relocate to the suburbs end up exchanging high housing costs for high transportation costs, often spending more on transport compare to the amount they spend on rent or mortgage. Furthermore, as suburban residents' income rises they incline towards choosing automobiles as their main transport mean, in order to have a more convenient transportation facility (SCI, 2015). The two mentioned point greatly contribute to increasing urban sprawl as well as economic, social and environmental damages.

Therefore, in order to reverse such trends and to make public transportation an effective, poverty-fighting mean as well as an attractive and affordable alternative to the private transportation, addressing the issue of affordability and behavioural change go hand in hand (Litman, 2013).

Providing affordable transportation for the public is possible but requires comprehensive planning. Few factors that can improve transport affordability are (Litman, 2013):

- Non-motorized transportation improvement (such as walking, cycling, hand carts, etc.) by improving their infrastructure.
- Encouraging ridesharing
- Improving transit services for the benefit of lower income class and to reduce vehicle ownership and associated costs.
- Motorizes and non-motorized transportation integration
- Improving land use accessibility to reduce the necessary physical travel for reaching goods and services.
- Location efficient development through integration of residential and commercial developments to increase accessibility
- Etc.

2.8.2. Accessibility

The topic of transportation accessibility focuses on people's general ability to reach services, activities, destinations and goods, which as a whole; they can be referred to as opportunities. Furthermore, it evaluates the time, money and effort that users have to devote to transportation. In other words, it evaluates the efficiency of transportation services from the users' point of view. Transportation accessibility can create potentials for connections and interactions within a community and therefore create a more sustainable transport network. Transportation and land use development choices usually include trade-offs among different types of accessibility. For instance, road design structures that exploit traffic speeds can decrease active modes of transport and transit accessibility such as walking and cycling (VTPI, 2015).

The ultimate aim of any transportation system is to provide direct and indirect accessibility opportunities. However, in the conventional transport planning practices, there is more focus on providing “mobility” rather than “accessibility”. Moreover, in such planning systems, transportation and land use development choices usually include trade-offs among different types of accessibility (Tumlin, 2012).

For instance, road design structures that exploit traffic speeds can decrease active modes of transport and transit accessibility such as walking and cycling. Therefore in the conventional planning system, the evaluation of transport system performance, including access provision, is based primarily on motorized vehicles travel modes. These evaluations are mainly based on indicators such as roadway services, traffic speeds and vehicle operational expenses and other indicators are often ignored and unrecognized. Taking such evaluation procedures tend to give more importance to mobility over accessibility and automobile transportation over other transport systems (VTPI, 2015).

In recent years, new planning strategies and standards pay more attention to access quality and accessibility analysis. Today, the ability to evaluate accessibility has improved since land use and transportation planners are able to stablish more useful measures and tools for evaluating accessibility impacts such as level-of-service index for multi-modal transportation system, as well as measuring and estimating the travel distance, cost and time through developing design models that would represent various users requirements, their demands in terms of activity and services and their choice of transportation mode. However, it has to be mentioned that techniques that focus on accessibility planning are still new and practitioners face challenges when applying them to particular decisions. Therefor creativity and judgmental abilities are a must in order to perform a comprehensive accessibility study and integrate new accessibility elements (VTPI, 2015).

Generally there are several direct and indirect factors and parameters that affect the quality of accessibility in an urban settlement:

1. **Activity and transport demand:** While transport demand refers to the extent of mobility and access that is required by people in different situations, transport activity indicated the amount of mobility and access which people have essentially experienced. On average people usually make between 2 and 4 trips per day out of which those who travel to several destinations such as school and work or have higher income, tend to have higher levels of demand (Mattson 2012).

Transportation activity and demand can be categorised based on a number of ways (VTPI, 2015):

- The demographics of the users such as: age, gender, earnings, employment situation, etc.
- The purpose of the travel.
- The final destination such as: school, job, store, friends and family, parks, etc.
- Time of travel in a day or season.
- Selection of different transportation modes
- Transportation distance.

These parameters indicate that improvement in transport accessibility such as quality, price and variety can lead to a rise in transportation demand and activity.

2. **Mobility:** Physical movement of people, whether as pedestrians or vehicle passengers is called mobility and it is measured based on number of trips, distance by trips, length of distance and amount of speed. All these parameters are in direct relations to one another and all of them directly impact accessibility. Meaning that by facilitating faster travel options for more number of people, more destinations can be accessed, which will result in higher accessibility (VTPI, 2015).

   However it has to be considered that enhancing these parameters through conventional transport planning schemes, such as increasing vehicles traffic speed limits and volumes of vehicles, can decrease the accessibility of other

modes of transportation through limiting pedestrian commutation and encourage singular, automobile dependent development configurations. Therefore enhancing high occupant vehicle transportation system through public transportation can increase personal mobility while avoiding high congestion rates and vehicle mobility rates (VTPI, 2015).

3. **Transportation Options:** Transportation diversity or transport option is a criterion that focuses on the quality, quantity and variety of the available transportation modes on a specific rout between origin and destination nodes. In general, destinations that are served by more modes of transportation and better service quality often have better access. Therefore improvements in transportation options can result in improved accessibility (Schiller, Bruun and Kenworthy, 2010).

   Different transportation modes often vary in their capabilities, thus they can serve people with different demands and in various situations. For instance, while active transport modes such as walking and cycling are very suitable for short distance trips, for travelling longer distances within main urban corridors public transportation can be the most suitable transport mode and to reach more discrete places automobiles are considered to be the best travel mode (Schiller, Bruun and Kenworthy, 2010).

   In traditional and modern transport planning system, the quality of various modes is evaluated by means of different Level of Service (LOS) rating systems which rank the quality of services from A, being the best to F being the worst quality. Such ranking systems will inform the decision makers about the areas that should be attended to in order to enhance transportation options and increase the comfort level of the users (VTPI,2015).

   Sometime, a particular factor significantly affects accessibility. For example, inadequate information or poor security around transit stations can constrain transit use (potential riders don’t know how to use it or have exaggerated fears of discomfort and risk).

4. **User Information:** Often a specific issue can considerably affect the accessibility of different transportation systems. For instance, insufficient information about the available transport modes and the facilities they offer to the users can make the riders to avoid or limit the use of a particular mode. Therefore it can be claimed that the quality of information can highly impact the practical accessibility and expedience of different mobility options.

   To further explain on the issue, if we take public transport users as an example, in order to plan their journey accurately and the way they see fit, they would need precise and suitable information on travel routes, roads situations such as traffic delays and diversions due to accidents, road construction or congestion. Furthermore information on the available transport services on the route of their travel, as well as their price and schedule can help them to select the appropriate mode of transit. The need for such information applies to all transit users even pedestrians and cyclers. In many cases, improving user information can be a very cost effective method for improving transportation accessibility (VTPI, 2015).

   Today, in addition to the maps and brochures that offer transportation information, there are many new and innovative platforms such as websites, social media, telephones and GPS devices that have made these information available to the commuters. However, potency of the information provided via the mentioned tools relies on the awareness and capability of the user to access and use the provided information.

5. **Integration:** The quality of various transportation systems integration can greatly impact the quality of accessibility. Parameters such as ease of transference between different transit modes, the condition and accessibility of stations and terminals and convenient parking spaces are a number of parameters that can enhance or weaken transport integration (VTPI, 2015).

Generally automobile transportation is well integrated and most destinations provide ample and usually inexpensive or free of charge parking spaces. Moreover most transit terminals such as airports, train and bus stations can conveniently be reached through roads and highways.

However, insufficient and unsuitable integration can sometimes be the main obstacle in non-automobile access. For instance, using public transportation for reaching airports can sometimes be a challenge. Moreover, train and bus station sometimes happen to be out of reach specially for people with disabilities or those carrying heavy loads. Therefore enhancing integration of different transit modes can positively impact the usage of these systems, hence improve accessibility (Schiller, Bruun and Kenworthy, 2010).

6. **Affordability:** The topic of transportation affordability and its major impacts on providing a more sustainable transport service has been previously discussed. But it has to be added that this factor can have considerable indirect effects on accessibility of transport system.

   Affordable transportation provides transit with significantly high social values. This means that the users and therefore the society would not need to endure extreme and unwanted financial pressure to meet the charges of different transportation modes. This fact, contributes greatly to increasing transportation accessibility, in particular for the lower-income group of people (VTPI, 2015).

7. **Mobility Replacements:** Mobility replacements initiatives (also called mobility substitutes) aim to offer alternative methods that would increase accessibility while minimizing mobility rates by providing services at the user's location. These services are mainly driven by telecommunication and delivery services and offer accessibility to a variety of goods and activities to users.

   Mobility substitutes can be an effective method to reduce the number of vehicle travels. Mass delivery systems can distribute goods and services to a large

number of people while requiring considerably less mobility. Furthermore mobility replacements can complement other modes which can result in reducing vehicle transit. As an example, by receiving delivery service for major shopping loads or required services, people can choose other transportation modes such as walking, cycling or even public transit for running minor errands (Litman, 2013).

However, mobility substitutes can have limitations. One of the major limitations of this system is that mobility replacements are often less productive and adequate than the physical access. For instance, although it might be easy and appealing to buy goods online, they can be often less satisfying than visiting stores where goods can be tested prior to purchase. Moreover, in some circumstances, mobility alternatives create added mobility since it can encourage discrete and scattered development and longer travel distances (VTPI, 2015).

Therefore, this initiative can be mostly effective at decreasing vehicle travel if applied as part of an all-inclusive mobility management system that enhances travel opportunities and disfavour driving.

8. **Land Use Factors:** Several parameters related to urban form and urban land use such as the mixture of different land uses, density, connectivity and walkability can have impacts on accessibility.

   Modern urban development initiatives such as Urban Smart Growth, tries to address these parameters by having new planning approaches towards them. These approaches aim to help the designers and planners in reaching a more comprehensive and sustained urban development. On the topic of land use impacts on accessibility, smart growth initiatives explain that planning for an accessible land use pattern means that there would be less mobility needed for people to reach different activities and their destination (VTPI, 2015).

   In this planning system accessibility of a normal household would be imagined as a triangular connectivity between home, services and work (different land

uses). Therefore the general accessibility is affected by the distances that are travelled and the opportunities that are located in between these destinations.

Moreover, accessibility can be affected by different patterns of land use connectivity.

In a linear connection pattern, if the starting point of the travel is located one of the ends of that path (Figure 2.3) the commuter would travel a much longer distance to reach the services or activities present at the other end of the route.

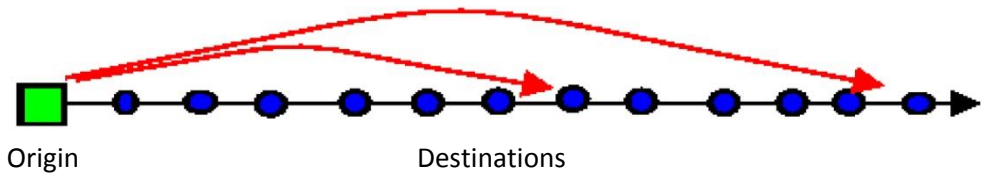

Figure 2.3: Access from one end of a road.
Source: VTPI, 2015

While if the origin point has a higher centrality value (Figure 2.4), the commuter would require much less mobility to access the other destinations on the route and therefore such connectivity patterns would increase accessibility.

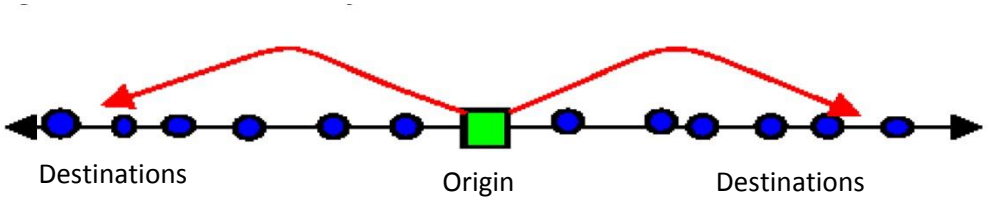

Figure 2.4: Access from central part of a road.
Source: VTPI, 2015

Also accessibility can improve if the two ends of a path or road would reach each other to create non-linear path (Figure 2.5). Since such patterns would allow the commuters to travel in a loop road and avoid backtracking for sever of their trips.

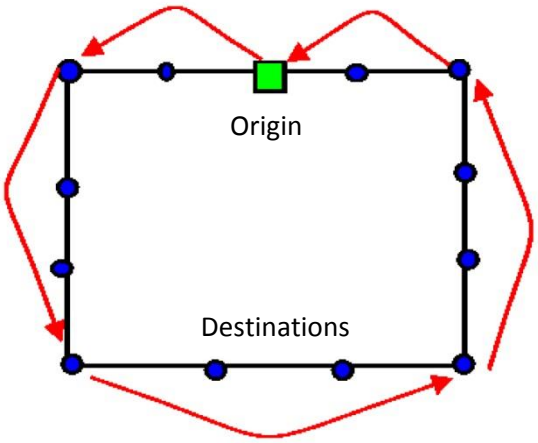

Figure 2.5: Access from an origin on a loop road. Source: VTPI, 2015

Furthermore, crossroad connection patterns would be helpful in increasing accessibility since firstly, they allow access in various directions in relation to an origin point (Figure 2.6) and secondly the side roads that connect each wing of a crossroad to the other one, increaseconnectivity and therefore accessibility (Figure 2.7).

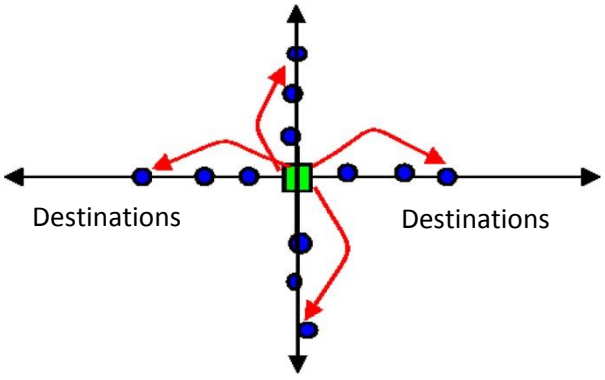

Figure 2.6: Access from a point on a crossroad. Source: VTPI, 2015

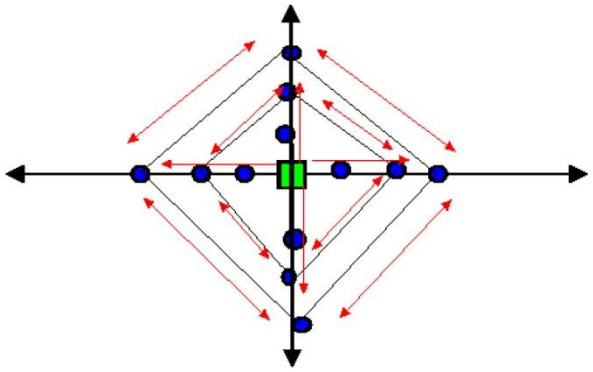

Figure 2.7: Side roads connecting destinations on a crossroad. Source: VTPI, 2015

The other factor that contributes to a better connected urban development is the density distribution (people density and/or jobs density) and clustering of people and activities. The concept of clusterization can be implemented in various systems. In some urban developments the idea of clustering is employed to locate different land uses in separate colonies.

However, when aiming to increase accessibility and connectivity, the urban clusterization focuses on allocation of various different land uses in a single cluster. In other words, smart growth developments try to create a relatively homogeneous land use distribution in urban settlements. Therefore, by increasing land use density and mix, smart growth developments can provide shorter travel distances. Moreover, higher proximity and accessibility can greatly impact the choice of transportation mode by increasing walkability. Since more commuters tend to choose walking and cycling when travelling shorter distances (Gayah 2012).

9. **Transport Networks Connectivity:** Continuing from the topic of land use connectivity; transportation network connectivity focuses on the concentration and linkages in and between different transportation modes' networks.

   In an urban settlement, road networks are either planned based on hierarchical design approach or based on density distribution. Taking the former approach would create wide arterial roads and sparse streets which usually have higher average speed range. However they tend to have less accessibility due to longer distances that should be ravelled to reach a destination as well as high congestion and low walkability and bikability. On the other hand, taking the latter approach would result in a development that can provide good accessibility due to dense roads and paths networks, shorter and direct travel routes between destinations, multiple routes connection, streets with lower speed limit that would better allow for walking and cycling (Gayah 2012).

   A well connected city would require both long, high speed arteries as well as shorter walkable paths. However it is of high importance to plan the transportation networks based on the centrality and connectivity needs of each cluster and neighbourhood in a city. The highest accessibility in a development can be achieved when the connectivity requirements of the urbanists is met while providing access to different modes of transportation, public and private (Gayah 2012).

   The above explained criteria represent some of the most important parameters that can impact the accessibility of a transportation system. As it can be understood, these complex parameters are in close and continuous correlation with each other.

   Therefore comprehensive planning policies and guidelines are required for directing the planners and designers towards a wider perspective in their practices that would help achieving higher accessibility rates and eventually more sustainable transportation systems.

2.8.3. Equity

In a sustainable transportation system, transportation equity addresses fairness and equality of the transport modes on various levels. This factor evaluates the distribution of impacts of many previously discussed factors and their social and economic costs and benefits in terms of their fairness and propriety (Quamie, 2011).

Transportation planning choices and decisions can have various major effects on the equity of a transportation system:

- Quality of the available transportation choices impacts people's social and economic opportunities.
- Transportation services enforce many indirect, unexpected and external charges on the users such as, traffic delays, road accident risks, infrastructure costs that are funded through users' fees, pollution and unwanted land use effects.
- Transportation expenses make a major portion of most households, businesses and government expenses.
- Transportation services necessitate considerable public resources such as tax funding, road rights of way and even accessibility. Allocation of these resources can support some people over the others.
- Transportation planning resolutions can impact different developments in terms of location and type, thus they can influence their accessibility, land costs and regional economic activities.

- Transportation planning choices can highly impact employment and economic growth, which have direct impact on urban development distribution.

However important and unavoidable, analysing transportation equity can be a complex job since there are several factors and types of equity to evaluate. Also, each factor has its own socio- economic impacts which should be measured and

evaluate through different means and methods while considering people participation in these procedures. Therefore there are chances that a specific decision might pass as equitable when evaluated from one perspective but inequitable if evaluated from other perspectives (Policylink, 2014).

Equity principles mainly affect transportation policies and planning choices and resolutions and in general they can be classified into three main groups:

Horizontal Equity: This class of transport equity which is also referred to as fairness and democracy in transportation, addresses the dispersal of transportation system influences among individuals and groups that equally have the same abilities and needs. Based on this classification, equal entities and groups should receive equal shares of resources, be charged for equal costs and in general be treated in the same manner. This indicates that public regulations and policies should avoid favouring one person or group over the others. Furthermore, regarding fees and taxes, all consumers should receive the service they are paying for and pay for the service they are receiving equally, unless a certain funding system is precisely defined and justified (VTPI, 2015).

Vertical Equity; Income and Social Class: This sub-category of vertical equity, also mentioned as social and environmental justice as well as social inclusion, discusses the dispersal of transportation services impact among entities and groups that can be classified in different groups based on their abilities, needs, and in this topic, based on their income and social class. In this class, transport policies, regulations and services are equitable if they favour the group of people that are socially and economically in a disadvantage, thus reimbursing for overall inequities. These kinds of principles that are made to benefit the disadvantaged group in the community are called progressive policies, whereas policies that put extreme pressure on this group of people are called regressive. Having in mind this definition, this category of equity is dedicated to supporting affordable

transportation modes as well as providing allowances, discounts and special services for the group of people who do not have the economic and social advantages as others. Moreover, it aims to ensure that these groups would not need to tolerate the pressure of external costs of different transportation systems such as pollution, financial costs, accidents, etc (VTPI, 2015).

Vertical Equity; Mobility Need and Ability: The second sub category of vertical equity focuses on the distribution of transportation systems effects among individuals and groups that are different in terms of their mobility ability and requirements. In this class the main emphasis is on the extent to which the transportation services are successful to satisfy the needs of travellers with mobility disabilities. These sets of policies are mainly used to sustain transportation designs based on universal, accessible and inclusive standards in order to provide services and facilities to accommodate all transport users' needs, inclusive of the groups with special needs (VTPI, 2015).

In today's transport design and planning industry, most practitioners, designers and decision-makers tend to address equity related issues and concerns. But there is not enough guidance for conducting complete and thorough transportation equity assessment. The tools and guidelines that are currently being used to evaluate transport equity usually focus on limited set of impacts associated with a specific group of people. Although these analyses are ad hoc based, they should also address equity issues from a wider and more general perspective in order to enable responsible bodies to improve transport equity on a larger scale (VTPI, 2015). For that matter, there are numerous parameters that can be taken into consideration, whether for policy-making purposes or stablishing design guidelines, out of which few are listed here(VTPI, 2015; Schiller, Bruun and Kenworthy, 2010; Toronto Public Health, 2013; Blumenberg and Pierce, 2012):

- Improve data on additional and unplanned costs of transportation
- Improve transportation data on travel demands as well as quality of different modes of transportation such as walking, cycling and public transportation.

- Implement transport polices that support affordable modes of transportation such as walking, cycling, public transit and carsharing.
- Improve transportation infrastructure of affordable transit modes.
- Assure lower-income travellers of the affordability of public transit system.
- Insure public transit affordability to the group of people that are economically, socially and physically underprivileged.
- Promote carsharing (car rental services that are designed to offer an affordable substitute to private car ownership), pay-as-you-drive insurance (an insurance system that would charge the car owners directly based on how much a car is driven), and other alternative services that would provide a more affordable option for occasional car use.
- Increase transportation affordability through transportation demand management, cost management and promoting the use of cheaper transportation modes.
- Promote and fund development of reasonably priced and reachable housing and multi-modal urban communities.

2.8.4. Safety

Transportation safety addresses issues related to unexpected and unwanted incidents such as road accidents, plane crashes and cargo damages, associated with all modes of transportation. A sustainable transportation would aim for protection of lives and properties of its users. This ambition can be achieved through implementation of the related policies, precise management and technological development and improvement in all modes of transportation (BP, 2014).

Apart from fatalities caused by air and water transportation, road transportation is known responsible for a large number of accidents and fatalities worldwide. According to WHO (2013) in the year 2010, road traffic accidents and injuries has cause over 1.24 million deaths worldwide. This number is just a little less than 1.26

million deaths in the year 2000. Therefore, addressing transportation safety issues is among the priorities of transportation authorities around the world. Out of this number, eighty per cent of the deaths in the road traffic take place in developing countries which counts for almost seventy two percent of the world population.

This shows that the developing countries endure an extremely high pressure of deaths in road transportation sector compare to the level of motorization in these countries.

Although there are no methods that could help in avoiding or stopping the unwanted accidents of any transportation mode; there are actions that can be done in order to reduce and minimize such incidents. This goal can be achieved through (BP, 2014):

- Technological improvements of the vehicles in order to enhance the reliability of the vehicles.
- Regular maintenance of all public transportation vehicles in order to reduce the possibility accidents due to faulty parts.
- Mandating yearly vehicle monitoring of all private transportation vehicles in order to reduce risks
- Improving driving and transportation knowledge and education in the society.
- Implementing policies and regulations to reduce road congestion, since congestions tend to increase the probability of road accidents.
- Encourage using mass transit modes since they help reducing individual car accidents.
- Reduce the speed limits where applicable.
- Install speed cameras that would mandate drivers not to exceed a certain driving speed
- Increase traffic fines for inappropriate driving that would cause road accidents.
- Employing professional supervision of road and transport planning, design and execution.

2.8.5. Fuel Efficiency

The major operational cost associated with different transportation systems is the amount of money spent on producing and/ or importing petroleum that could be used for operating vehicles. Moreover, transportation sector is known as the second highest consumer of fossil resources after the industrial sector, with the private transportation sector being a major fossil fuel consumer among other modes of transportation. This has put a significant pressure on these resources and has increased their depletion rate (IEA, 2010).

The two mentioned facts have made the governments and authorities to pay additional attention to increasing the energy efficiency of different transportation systems whether public or private through developing various policies. The ambition of fuel efficiency policies is to reduce the amount of consumed fuel (oil or any other type of fuel) in transportation sector that would firstly, reduce the pressure on fossil fuel resources and secondly, it would reduce the amount of funding needed for producing or importing petroleum. To do so, the main focus of these policies is on (VEIC, 2015):

- Promoting the use of public transportation instead of private automobiles. This would help in moving more number of people for the same amount of consumed fuel.
- Reducing road congestion in order to reduce the idle hours spent by different vehicles which would increase fuel consumption while having zero mobility.
- Investing in producing or importing vehicles that would operate on alternative fuel resources that petroleum such as hybrid vehicles that can run on both petroleum and CNG gas or vehicles that use renewable energy resources to operate such as electric vehicles and fuel cell vehicles.
- Increasing taxes of vehicles that are high fuel consumers.
- Encouraging the use of transportation modes that have zero fuel consumption such as walking and cycling.

- Using urban and transport planning schemes and strategies that would reduce vehicle dependency of mobility within urban communities and clusters.
- Reducing or removing fuel subsidises in order to encourage the commuters to use alternative modes of transportation than private transport system.
- Maintaining speed limits since vehicles use less fuel when running on lower speed.

Implementing these policies would not only increase the fuel efficiency of transport modes, reduce fuel consumption and lower fuel provision costs; it would also positively affect the sustainability of overall transportation systems on numerous different levels.

2.8.6. Environmental Stability and Pollution Prevention

Over the time, transportation industry has impacted the natural environment and its habitats in many different negative ways. As it has been mentioned before, transportation sector is a major contributor to the increasing rate of global warming through production of greenhouse gasses such as CO_2, CFC_s, CH4, etc. However in addition to that, different modes of transportation have had their share in damaging the natural environment.

Road transportation has endangered the life of many species by destroying their habitats such as forests and green belts in order to construct road networks. Marine life has been affected by water transportation modes through their discharges, petrol leaks and wastes that are emptied into the water. Also the air transportation system is responsible for endangering birds' wildlife specially during their migration season (VTPI, 2014).

In addition to air and water pollution and endangering the wild life of many species, in urban areas, transportation is counted responsible for the major amount of noise pollution in the cities.

Based on the currently available transportation technologies and practices, it is not possible to completely avoid the harmful impact of different transportation modes on the environment. Although addressing all these issues in the best way possible is not an easy task, there are actions that can be taken in order to reduce these impacts. One of the most important ambitions of any sustainable transportation system is to implement design techniques, methods and policies that would help in stabilizing the environment through wildlife preservation, pollution reduction and reducing CO_2 emission. These ambitions can be achieved by:

Promoting the use of public transportation systems: Using public transportation can reduce pollution by reducing the number of vehicles on the roads and reducing the number of travels made by them. This can help in reducing noise pollution, air pollution and lowering the CO_2 emission. Furthermore, increasing in the usage of public transportation modes will reduce the need of road construction due to lower flows of traffic. This will enhance the natural environment, save forests and green belts (which have very important role in air filtration and purification) and protect wildlife (Golińska and Hajdul, 2012).

Investing in creating knowledge and a suitable infrastructure for the use of electric and fuel cell cars: Although electric vehicles might be considered as a new technology, they have been around since 1980s. Electric vehicles obtain their fuel from a variety of batteries which are commonly made of lead, nickel-metal hydrides and lithium concoctions. They store the provided energy from electrical outlets that can be introduces as electric recharging stations in different locations of the city (Baxter, 2011).

Like electric vehicles, fuel cell vehicles can be a great alternative for normal vehicles. The best known fuel cells rely on using hydrogen gas to produce electricity as fuel. The only discharge from these vehicles is water which is claimed to clean enough to drink (Baxter, 2011).

Although these vehicles are not able to use renewable energy resources and still rely on fossil fuels for operation, the amount of used fuel is considerable less.

Moreover, low (and sometimes zero) emission of the vehicles with these technologies are far more desirable than the produced hydrocarbons, CO_2 and different types of Nitrogen oxides that would not only rise the air pollution levels, they will also increase the amount of discharged greenhouse gasses which are the main contributors to increased rate of global warming (Baxter, 2011).

Reduce congestion: Reducing congestion in the cities will reduce the time different vehicles spend in idle mode. This will reduce fuel consumption which will result in less discharges of pollutant into the air. Moreover, reduced congestion will decrease the lees of noise pollution in the urban areas (Baxter, 2011).

Reducing the time spent on the road: This ambition can be achieved through employing smart transport planning schemes and techniques that would reduce the distances between different attractions, activities, services and destinations by intelligent distribution and clustering of different land uses. This will reduce the vehicle dependency of the commuters and use of greener modes of transportation such as walking and cycling would become more feasible. This would greatly reduce the amount of discharged toxic gasses into the air and hence reduce air pollution, reduce noise pollution and increase accessibility (Baxter, 2011).

Monitoring the location of different types of developments in regard to the road and transportation networks: To reduce the local noise and air pollution, it is important to strategically distribute different land uses and developments based on their closeness to the main urban arteries and corridors (Baxter, 2011).

Locating residential, educational and healthcare zones in the proximity of main roads and streets of the city can increase the unwanted noise and air pollution in the local area.

Mandating regular maintenance of the vehicles: Irrespective of the modes of transportation (whether air transportation, water transportation or road

transportation), regular maintenance of vehicles can greatly contribute to reduce the amount of discharged pollutants in the environment (Baxter, 2011).

Replacing old vehicles with new and more efficient vehicles: No matter how well a vehicle is maintained, older vehicles produce more pollutants in comparison to the new vehicles. Moreover, the technological developments in vehicle designing and manufacturing would not only increase the safety and reliability of that vehicles, it will also reduce the toxic substances discharged from them (Golińska and Hajdul, 2012).

Forests and green belts preservation: Forests are often referred to as the lungs of the planet since trees, plants and vegetation are the main organisms that filter and purify the air through photosynthesis and conversion of CO_2 to O_2. Moreover, they are home to many different kind of species that their existence relies on the existence of the forests. Therefore, avoiding the destruction of forests and green belts would not only save the habitat of these species, it would also help in better filtration of the air pollutants and increase the overall air quality (Baxter, 2011).

2.8.7. Cultural and Heritage Preservation

A sustainable transportation system would encourage and enhance cultural activities by providing different kinds of access to them and respecting the formation of open communal spaces that would increase social interactions and therefore increasing socio-cultural quality of urban communities.

Moreover, a sustainable transportation planning scheme would aim to preserve the cultural heritage of the nation trough employing thoughtful planning and construction methods. There are many reported incidents that transportation development has caused the destruction of historic buildings over the world. The partial collapse of a 113 year old heritage building in Kashmere Gate in Dehli, India,

due to underground excavation work for the construction of the Central Secretariat-Kashmere Gate metro line (Verma, 2015); and the extreme case of metro line developments in Vietnam that has resulted in destruction of over two hundred historical building in order to accommodate metro transportation system (Thanh Nien Daily, 2014), are two examples of malpractice in transportation development.

Therefore, it is of high importance to design and implement policies and regulations that would reduce such cultural damaged in urban and suburban areas.

2.8.8. Economic Development, Productivity and efficiency

Through linking people to businesses, services and resources, a sustainable transportation empowers economic activity. Therefore, transportation advancements and improvements are mostly encouraged in order to enhance economic improvements. Usually there are discussions over the transportation policies that would best support economic development and productivity objectives.

Decisions made in transportation planning sectors can greatly impact economic growth and development is numerous ways (VTPI, 2015):

- Through contribution to economic activities such as freight and shipments, national and international business related journeys, distribution and transfer of services. This influences manufacturing and supply costs.
- Through industries that are associated with transportation and their productivity, recruitment and revenues.
- Through users expenses and their fiscal impacts.
- Through enabling people to reach destinations, activities and services that would impact their engagement in economic productivity, opportunities and development; such as schools, business hubs and shopping places.
- Through the additional expenses enforced on various activities, people and localities.

- Through influencing land use expansion patterns, location and clustering.

A number of these impacts are extensively taken into consideration during transportation planning, policy making and project evaluations. However some others are often disregarded or underrated.

On the other hand, the impact of transportation on economic development is sometimes considered as a main transport planning ambition but in many other times it is ignored. Both of these extreme scenarios may result in poor planning and policy decisions: Strategies that would enhance transportation economic development would oppose other design and planning aims, resolutions that address social and environmental ambitions could oppose economic productivity and development of the transportation systems. Therefore, having a progressive economic development in the transportation sector relies on a comprehensive consideration of all social, environmental and economic objectives in order to create optimum policies and regulations and to reach the possible solutions (Weisbrod et al., 2014).

Nevertheless, it should be mentioned that although transportation plays an important role in economic productivity, it also forces considerable economic outlays. Therefore unnecessary mobility provision can have the same economic damage as providing too little mobility for the users. As an example, obligating people to to carry heavy loads in their hands as a replacement of using vehicles would be as economically inefficient as if they are obliged to drive every short trip to destinations that can be simply reached by walking or biking (Weisbrod et al., 2014).

This is where the efficiency factor of a transportation system should be considered. Transportation efficiency addresses the balance (or imbalance) between the costs and charges to operate a transportation mode and the provided mobility and accessibility by that particular transport system and its effectiveness (Golińska and Hajdul, 2012).

Running a transportation system, whether public or private, puts many hidden and obvious economic stresses on the governments and authorities. These costs include (Golińska and Hajdul, 2012):

- Transport planning and design cost.
- Construction charges
- Operation costs; which includes fuel charges.
- Maintenance charges.

In transportation systems, accessibility efficiency and economic efficiency have a very close correlation to one another. A poorly thought accessibility and mobility plan can negatively influence the economic efficiency of the transport system. Therefore, in order to be able to develop an efficient transportation system or enhance the efficiency of current transportation systems, it is important to have a clear and smart accessibility and mobility plan and policy in order to avoid or stop unnecessary investment and development.

Moreover, in order to evaluate and monitor the economic efficiency of the system, it is important to have cost control and management systems that would control and analyse the costs and charges of the transport system provision, the running fuel costs and its maintenance charges, in order to take the first step towards a more economically efficient transportation mode. Furthermore, economic efficiency rises if the cost of parameters related to transportation such as time, energy, safety and land is lowered or if the value contributed by transport operations surges. As an example, the efficiency of transport system can be enhanced if trips that have higher values (economical or non-economical) are given more importance over lower-value travels. This method can escalate transport system efficiency although it may reduce the overall vehicle flow and traffic. The second step for achieving an economically efficient transport system would be to analyse and evaluate how the provided transportation can increase financial and economical interaction within the society through providing access to business hubs, retail centres, educational clusters, etc. (VTPI, 2015) .

Transport policies that encourage and advocate efficient transportation, help in achieving optimal mobility system; in which mobility and access provision is not extensive nor is limited and each transportation mode is used for the purpose it serves best. This increases productivity and consequently economic growth and development (Gudmundsson et al., 2015).

Optimizing transport system efficiency, even if it is a very modest gain, delivers productivity benefits and improvements that impact the economy on many different levels. For instance, lowering shipping charges can escalate business revenues, lower retail expenses and enhance service condition and quality and quantity or an amalgamation of these (Gudmundsson et al., 2015).

In order to be able to evaluate transportation economic development in terms of the necessity, functionality and efficiency, considering and finding an answer to the following questions can be beneficial:

Is investing in transportation developments and improvements the best possible way to enhance and boost economic development? Or could implementing other policies and investing in alternative sectors be a better and more cost effective answer to economic development?

Do the transport planning proposals really enhance overall productivity? Are the predicted and professed benefits really contributing to economic productivity and economic transfers? Does achieving benefits in one region, industry or business result in economic losses to other businesses or industries? To what degree are the benefits affected by inflated costs, inclusive of hidden and additional costs?

Do the proposed plans offer the best possible method to enhance transportation, mobility and access? Or would it be possible to meet the transportation and access demand through better management of the currently existing and functioning transportation modes, which would be at a much lower costs that investing in new transportation developments?

Is subsidising transportation, specially its running costs such as tickets, tolls and petrol costs, reasonable? Or would it be more efficient, beneficial and reasonable if the users themselves were directly counted responsible for covering these charges?

2.8.9. Community Development

A transportation system that is considered sustainable would enable the authorities to improve the development of urban communities as well as enhancing the living quality of their users.

The state of life quality is the key element that would define the success of any urban community. Transportation and its infrastructure are considered the backbone of cities and one of the main derivers of the communal and urban development. Expanding and improving vehicle transit system as well as green transportation methods such as pedestrian and bike system would anchor development of more accessible, walkable, amenity-rich and liveable communities. Providing more accessibility and reducing the proximity of different land uses would lower vehicle dependency of the commuters which would result in reduction of transportation charges associated with each household. Moreover, by reducing the number of road construction, more free spaces would be available that could be dedicated to creating public social hubs and construction of green parks and urban forests, or it can be used to make more space for providing more residential, commercial and retail opportunities (CNT, 2014).

Functionality and existence of a diverse, healthy, liveable and walkable community to a great extent relies on the available transportation infrastructure and the variety of transportation modes it offers to the users for moving around and meeting their demands. Therefore, providing the infrastructure for pedestrians and transit riders as well as drivers is very important (CNT, 2014).

Implementing transport planning approaches that are in parallel with schemes, policies and guidelines of sustainable transportation initiatives would address different types and levels of demands associated with urban communities and their users while improving the overall liveability of the urban developments.

2.8.10. Outcome

In the above sections different parameters that are considered as major indicators of a sustainable transportation system were discussed and analysed. These indicators are measures that the sustainability of various transportation systems can be evaluated against them. Moreover, they would make the progress towards the objectives of the projects much easier through enabling planners to control, evaluate and readjust the used methods in respect to sustainable transportation requirements. These indicators can help in trend identification, foresee and forecast problems and obstacles, measure and evaluate different options, laying achievement objectives and assessing the performance of a certain authority or organisation. Studying the mentioned indicators has highlighted three parameters in regard to sustainable transportation developments that will be presented as follow:

1. **Sustainable transportation indicators cannot be addressed as singular parameters:**

   Although it is necessary to address each indicator separately, it is important to have in mind that all these indicators function as a whole. It is not possible to provide an affordable transportation or expect economic development from a certain transportation mode, if the measures of transportation accessibility are not met. Similarly, achieving an economically stable transportation system would not be possible without addressing issues related to energy efficiency of that particular system. The mentioned indicators are constantly affecting and being affected by one another.

2. **Sustainable transportation is best achieved through investing in and promoting public transportation modes:**

   Although there are many policies and methods that aim to increase the level of sustainability in private transportation sector, focusing on improving the state of public transportation modes would be a much more efficient way to achieve a more sustainable transportation system.

3. **Public education is as important as developing transport planning policies and guidelines:**

   Creating transport planning and design schemes, policies and guidelines that are in conjunction with principals of sustainable transportation are important actions that should be taken to make achieving the objectives of the developments more feasible. However, increasing public awareness about the harmful impacts of unsustainable transportation and how people can contribute to reaching sustainable transportation goals is as equally important.

To have a better understanding of the correlation of the discussed topics, table (2.1) presents summary of these parameters, their objectives and their evaluation indicators:

Table 2.1: Sustainable transportation indicators summary
Source: By author

Sustainability Goals	Objectives	Performance Indicators
1. Economics		
Economical productivity	Efficiency of transport system. Integration of transport system. Enhance accessibility. Effective charges and inducements.	• Portion of funds allocated for transport. • Congestion delay per capita. • Efficient charges (road, parking, insurance, fuel). • Effective prioritizing of facilities. • GDP per capita.
Economic improvement	Economical and commercial growth.	• Accessibility to educational and employment hubs. • Sustenance of local industries.

Energy efficiency	Reduce funds spent on energy, mainly petroleum imports.	• Consumed energy in transport sector per capita • Usage of imported petroleum per capita.
Affordability	Providing affordable access to the essential transport services and activities to the public.	• Availability and eminence of affordable transport modes. • Portion of households that spend more than 20% of their income on transport.
Efficient transportation manoeuvres	Effective processes and asset supervision to enhance cost efficiency.	• Performance inspection outcomes. • Service provision entity cost compared with peers. • Service eminence.
2. Social		
Equity and equality	Providing a transport system that is suitable for everyone, inclusive of disabled and/or low income people.	• Variety of transport system. • Percentage of destinations that gives access to disabled and low-income people.
Safety and health	Reducing the danger of accidents and crimes and encouraging physical fitness.	• Traffic fatality rates per capita. • Commuter crime rates. • Human contact with dangerous pollutants. • Walkable and bikable percentage of the travel.
Community advancement	Providing complete and attractive communities. Encourage community unity.	• Land use distribution. • Accessibility of destination by walking and biking . • Eminence of road and street surroundings.
Cultural and heritage conservation	Protect cultural and heritage values. Encourage cultural activities.	• Protection of cultural assets and traditions. • Sensitivity to traditional societies.
3. Environmental		
Climate sustainability	Lower global warming effect. Diminish climate change effects.	• Emission of greenhouse gases (CO_2, CFCs, CH_4, etc.).) per capita
Avoid air pollution	Lower air pollution emanations. Reduce contact with pollutants	• Emissions of (PM, VOCs, NO_x, CO, etc.) Per capita.

		• Air quality principles and supervision tactics.
Avoid noise pollution	Reduce traffic noise exposure.	• Transportation noise heights.
Maintain water quality	Reduce water pollution.	• Used fuel per capita. • Supervision of consumed oil, drips, and storm water.
Open spaces and biodiversity preservation	Lower transport services land takes. Support compact expansions. Protect high quality habitation.	• Amount of land considered for transportation provision. • Encouraging smart growth based developments. • Strategies to guard high value farmlands and environment.
4. Good Governance and Planning		
Unified, complete and all-encompassing planning.	Well defined planning procedure. Unified and complete assessment. Determination of the citizens.	• Clearly set objectives, ambitions and pointers. • Having planning data and documents. • Group of people involved in design decisions. • Variety of the considered objectives, impacts and options. • Budget allocated to transportation can be spent on substitute modes and demand supervision.

2.9. General Case Studies

Case studies are often a useful and interesting method of gathering information on various scientific subjects. Performing case studies would enable the researchers to compare their own project's case to other successful or unsuccessful cases. Moreover, it gives the researchers the opportunity to learn from other projects achievements and failures.

In this section of the chapter the main concentration will be on reviewing few case studies from around the world. These cases have attempted to increase the sustainability of their transportation system through enhancing public transportation modes, developing semi-public transportation systems, improving their policies, encouraging private organisational attempts to increase sustainability and employing various other innovative methods.

In the selection of these cases it has been tried to bring samples of both developed and developing countries. This will give us an understanding of different approaches to a similar matter when there are different levels of resources based on the degree of development associated with each case study. Moreover, such a diverse selection range would give us the ability to analyse whether or not the transition towards a more sustainable transportation has been impacted by regional factors such as climate, culture, size of the population, etc.

2.9.1. Brazil

Brazil is among the award winning countries for major developments and achievements in improving sustainable transportation. In the year 2015, three cities of Belo Horizonte, Rio de Janeiro and São Paulo, were the recipients of Sustainable Transportation Award (STA) (ICLEI, 2015). The STA identifies insightful management, perspective, and accomplishment in developing sustainable transportation and enhancing urban livability. Since its establishment in 2005, this

award has been given to different cities that have employed pioneering sustainable transportation projects, every year (STA, 2015).

During 2014, the public transportation system in Belo Horizonte, Rio de Janeiro and São Paulo has undergone massive changes.

Belo Horizonte managed to finish the development of the first phase of their all-inclusive mobility plan by operating a brand new bus rapid transit (BRT) system which is on gold standard level. This system had started its operation on two corridors which cover about 23 kilometres. This system has already increased the number of commuters by 19 percent. This has significantly impacted the accessibility to the zones close these corridors due to congestion free lanes provided for the buses which has increased the mobility speed as well as increased number of buses operating on these lanes. Another major change in the city is reconfiguring the downtown area as a car free zone Zottis, 2014. Although this change has been challenging for a group of commuters since there is no vehicle access to different destinations within the downtown area (Michell, 2015), this change has greatly revitalized this area of the city (Zottis, 2014). The pedestrian-only streets and open spaces have provided the people with safe passages and also they have become an attraction for many cultural and service activities. This has increased the socio-cultural quality of the city's downtown. Furthermore, the authorities have invested in developing 27 kilometre of bikeway network, which has increased the number bike commuters by 9 percent in less than a year and it is expected to increase up to 40 percent within the first five years (Zottis, 2014).

The authorities of Rio de Janeiro have done extensive investments in development of public transportation during the past couple of years. Similar to Belo Horizonte, this city has started the operation of second of four BRT modes that were planned to be operational before the Olympics in 2016. This new BRT corridor is 39 kilometre long and services over 270,000 daily commuters. In addition to the BRT system, the city has invested in development of it Light Rail Transport (LRT) and metro system. It is estimated that when the projects start their operation in 2016, around 60 percent of the citizens will have access to mass transportation. Considering that this number was only 18 percent in 2009, a 330% rise in public

transit rate can be considered a great achievement in a short period of time (ICLEI, 2015; Colin, 2015).

The city of São Paulo has massively invested in expanding the cycling network within the city. The city is on track to have 500 kilometres of cycling network by 2016, out of which 400 kilometres will be operational be the end of 2015. Furthermore, the city has planned and constructed exclusive bus lanes that run for about 320 kilometres. This has resulted in 21 percent increase in bus speeds and therefore has reduced the travel duration for the commuters. São Paulo has an ambitious public transportation master plan and among the milestones of this development plan, elimination of parking minimums and developing parking maximums as substitute has made this city the first megacity to implement such strategy on citywide scale. Doing so has made free spaces that are dedicated to constructing open green spaces available to the public or they are being used as additional residential or commercial lands which on the long run would help reducing property prices in the central parts of the city (ICLEI, 2015; The World Bank, 2014).

Authorities of this city state that although taking these actions has had economical pressure on different governmental and private organizations and sectors, the main ambition is to improve the state of mobility and accessibility and urban liveability for all residents by proving a variety of transportation modes to the users, reducing greenhouse emission and air pollutants and enhancing safety and access for the pedestrians and cyclists. They also state that apart from the financial challenge of these developments, the main challenge remains to be increasing public knowledge and awareness in order for the private modes of transportation to be replaced by public transit modes (ICLEI, 2015; Michell, 2015; Zottis, 2014).

2.9.2. Bremen, Germany

The city of Bremen has a well stablished public transportation system with a long history. History of Bremen tram goes back to early decades of the 20th century. However based on the recent public transportation development master plan, the city will extend the tram lines for an additional 20 kilometres and it is estimated

that this extension will bring 40 to 60% more commuters to the system (ITDP, 2012).

Another milestone of this master plan has been marking the central part of this city, as an environmentally preserved zone. This means that old and high pollutant vehicles are not permitted to enter this zone and only vehicles with Euro 4 Emission Standards (low pollutant vehicles) are allowed in this zone. Taking such action has resulted in 2% reduction in local air pollution level. Moreover, the old vehicles running on the bus networks have been replaced by diesel or electric vehicles and EEV (Enhanced Environment Vehicles) buses (ITDP, 2012).

Similar to the tram system in this city, cycling has been a popular mode of transportation for many years as a zero emission transportation mode. Although usage rate of this transportation mode is often affected by climate condition due to winter time rain and snow in this city; currently 26% of all trips in Bremen are by cycling and the authorities aim to increase the percentage to 30% by the year 2020. Overall there are more than 600 kilometres of cycle paths in this city and there are plans to add 50 more kilometres of cycle ways in different zones of the city. Also to provide better infra structure for the cyclers, 2000 new bike parking have been installed within the city. Also exclusive parking spaces have been considers in various train and bus terminals which enables the cyclers to easily be able to switch their mode of transportation in order to have better access to other destinations which are not easily accessible by cycling. Moreover, there are locations on different buses and trams that are dedicated to bikes. This means that the cyclers can carry their bicycle into the bus and/or tram if they choose to change their transport mode. Such actions have significantly increased the integration of different modes of transportation providing the citizens with a versatile public transportation system (Glotz-Richter, 2016).

Furthermore in recent years, in order to encourage the use of public or green transportation system, policies have given more priorities to these modes of transportation over the private transit system. For example, traffic lights give priority to cyclers and trams or buses. In many zones of the city exclusive lanes are provided for these modes of transportation. Moreover, cyclers can have access to

all roads and street from both ends, regardless of the street being a one-way street or not. This has shortened many of the routs for these commuters, resulting in reduced travel duration and higher accessibility (Glotz-Richter, 2016).

In the private transportation sector, Bremen authorities have implemented efficient and innovative method of car sharing in order to enhance private mode of transportation. This means that people do not need to own a car in order to be able to use it. Similar to bike sharing which is a popular system for providing public bikes that can be rented and used by the public; car sharing enables people to rent a car for the duration of their need. The difference between car sharing system and the service that is offered by car rental agencies is that people simply need to have an electronic access card and use it in any car sharing station around the city to rent a car. This gives all citizens to have access to private transportation any time during the day. This method has significantly increased the equity and affordability as well as accessibility of private transportation (Hurley, 2014).

Developing and promoting the car sharing system in Bremen has reduced the number of cars by more than 2000cars. And based on the estimations this number will reach 6000 cars and 20000 users by the year 2020. Moreover, reduction in the number of cars has decrease the need for parking spaces and construction of underground car parks resulting in reduction in property prices and therefore increasing the affordability of properties in central parts of the city. Application of this innovative system has made Bremen a leader city in car sharing transport (Hurley, 2014).

2.9.3. Guangzhou, China

In the past years, the main focus of Guangzhou's authorities has been on developing a well-integrated BRT system in this city. In early 2010 Guangzhou's BRT system started its operation as a prime transportation mode. This system has the highest capacity of commuters in Asia, and it is the first transportation option to replace the metro system. Carrying over 800,000 passengers on daily basis, the BRT system

has more than three times the peak commuter flow of any other similar systems as well as metro systems in Asia. The BRT routs run along one of the busiest corridors in Guangzhou city and its high integration with bike lanes, bike sharing stations and metro stations have significantly increased the speed and accessibility of transportation in the city (ITDP, 2015).

In addition to the new BRT system, the city has launched the first phase of bike sharing system that has made 5,000 bikes in 113 stations available to for the public use. When completed, this system will provide 15,000 bikes which would make the city home to one of the ten largest bike sharing systems in the world. Also, to make this transportation system more feasible, authorities of Guangzhou have introduced inclusive bike lanes on major roads of the city and along the BRT corridor. They have also installed 5,500 additional bike parking positions at BRT and metro stations (STA, 2011).

Furthermore, constructing a remarkable greenway along a former polluted canal in Guangzhou has had significantly positive impacts on the area. This project which is the first phase of a 60 kilometres high quality greenway project is a 4 kilometre off-street combined bikeway and walkway that connect many different parks, plazas and children playgrounds along with the water canal. In addition to the revival of this zone of the city, development of the greenway has increased the social quality and livability of the area it is located on. Moreover, the preserved environment of the greenway has created habitat for different species of animals (STA, 2011).

All the mentioned changes have placed Guangzhou among most advanced cities in East Asia to address importance of improving public transportation in order to enhance sustainable transportation.

2.9.4. Ahmedabad, India

The city of Ahmedabad is home to the first full-featured and well-designed BRT systems in India that operates on a 72 kilometre route. Within only few months of

its operation, it has been able to make over 115,000 trips per day, providing access to various destinations in the city. By reducing the use of other transportation mode such as motorcycles and private cars, Ahmedabad's BRT has been able to cut 288,000 metric tons of CO_2 each year since 2010 (STA, 2011).

The BRT stations are well-designed to save the commuters from excess sunlight and rain as well as being equipped with e-ticketing service that would enable pre-payment for each ride and therefore would reduce queuing time and delays. The buses used in this system are low emission CNG and EuroIII buses that provide at-level boarding system to elderly and the disabled (ICS, 2013).

In addition to the brand new BRT system, incorporation of cycle lanes along major roads of the city, development of suburban rail and MRT systems, increasing the number of bus fleets from 650 to 1100 vehicles, and enhancing the suburban bus networks are among the actions that has been taken in order to provide a more sustainable, accessible an reliable transportation to the citizens of Ahmedabad (ICS, 2013).

Implementation of these new systems and transportation modes and policies has positively impacted several issues affecting the city of Ahmedabad such as: congestion levels of major roads, high fatalities and low level of road safety and high air pollution levels. However these achievements have not been without challenges. According to authorities of Ahmedabad, dealing with unsuitable transportation infrastructure, planning a well-integrated transportation system in respect to different and poorly planned land uses, public education towards public modes of transit, overcoming seasonal harsh climate condition, setting enforcement policies to improve public traffic behaviour and adapting to existing socio-cultural realities and religious structures have been some of major challenges of this city in application of sustainable transportation (ICS, 2013).

2.9.5. Tehran, Iran

The city of Tehran was chosen as a runner-up at the 2011 Sustainable Transport Awards, which is organized by the Institute for Transportation & Development Policy (ITDP, 2011) (SM, 2011). In recent years, the 13.5 million residents of Tehran have seen significant improvement in sustainable transport through enhancing public transportation infrastructure. Despite the limited resources, this city has stood out as a model city in the region for its comprehensive policies which is implanted into the city's resolution of enhancing the living quality by having a cohesive, well-integrated, accessible, safe, stress-free, comfortable and clean transportation system (Zevitz, 2013).

Tehran is home to a transportation system that has been placed among the top most affordable (if not the most) transportation systems in the world. Currently, the price of a single trip on the metro or the bus is about 0.10 USD and they are free to seniors. On the average, each household spends 6-7% of their monthly income on public transportation (Zevitz, 2013).

Regarding transportation systems development, Tehran has the largest bus and urban rail networks that are accountable for offering accessibility and mobility to a significant number of people. By the end of 2009, Tehran had159 kilometres of city under and over round metro railway. In 2010, an additional 77 kilometres were added and by 2014 Tehran has been able to construct over 300 kilometres of urban rail network (Hashemi, 2011). Today, Tehran's metro provides transportation to more than 19 million people per year for a total of 597 million annual trips, showing 26.7% increase compare to the metro ridership of 2011 (Allen, 2013).

In addition to its urban rail system, Tehran has implemented a BRT network that runs on a total of 168 kilometres, operating on various routes. In 2011 the BRT system carried 1.6 million passengers per day. This number has increased by 35% in 2014 due to expansion of the BRT network. The BRT system has provided the commuters with up to 42% shorter travel time, due to faster speed of the buses and shortcut routes (Zevitz, 2013; Allen, 2013).

Improvements and expansions in the metro and BRT systems accompanied by introduction of bike sharing system and increasing the quality of pedestrian network infrastructure have considerably enhanced accessibility and mobility in this city (Allen, 2013).

Moreover, Tehran has considerably largest number of vehicles, which are natural gas-powered, on its roads. These vehicles that are operating in public and private transportation sector are currently numbering around 1.31 million. Relying on natural gas as fuel has contributed greatly to the economic savings, energy security and environmental conservation of the city. In the recent years, by reducing the subsidies on petroleum and increasing it on the CNG, more individuals tend to purchase hybrid automobiles and this has escalated the decrease in petroleum consumption (Allen, 2013).

Another implemented policy in controlling the traffic and encouraging public transportation usage is creating restricted zones in central part of Tehran. These zones are only accessible to public transport users, private pass holders, and emergency vehicles. Applying this policy has increased the use of public transportation by 53% and reduced congestion by 69% in these areas (Zevitz, 2013; Allen, 2013).

Although public transportation in Tehran has had significant expansion and improvement in recent years, the main challenge remains increasing public awareness, changing traffic and transportation habits of the residents as well as reducing private transport users on the city scale (Montazeri, 2011).

2.9.6. Outcome

Based on the reviewed cases, it was observed that different cities, regardless of their state of development, have invested in public transportation sector in order to enhance the sustainability of their transportation system. They have tried to increase the diversity of their public transportation modes to be able to offer a better service to the users. Also if well integrated, public transportation can significantly increase

mobility, accessibility, equity, affordability, enhance socio-cultural quality and increase the overall livability of the city; while reducing energy consumption, transportation emission and harmful environmental impacts.

Moreover, it was understood that one of the main and most important challenges in improving the sustainability level of a transportation system is transportation behavioural change of the residents. Since the survival of a public transportation system is in hands of its users. Such changes can be achieved through public education or by enforcing different restrictive policies.

Other parameters that impact the choices made by the transport users are climate condition as well as cultural and religious structures. Therefore it is very important to take all these parameters into consideration during planning procedures, since they can be key factors that would encourage or discourage users in choosing public transportation modes over private transit.

2.10. Case Study of Dubai

The past 40 years have brought UAE substantial economic, political and technological growth, influencing the urban structure and functions of this country. In the period of few decades UAE has become highly urbanized with modern and high tech infrastructure. This multi-dimensional growth has impacted emirates such as Dubai on many different levels, resulting in fast expansion of the city over a short period of time. The rapid urbanization of Dubai has been driven by three main factors (Fazli and Faridi, 2010):

- The 1966 oil boom
- Extensive national and international migration
- Globalization

The oil boom in Dubai resulted in rapid economic growth after 1966, making Dubai a new attraction for investors. Economic development accompanied by increasing rate of population growth, mainly due to immense national and international migration, engendered rapid urban development since 1970 (Fazli and Faridi, 2010).

Figure (2.8) illustrates Dubai's urban growth in the span of 30 years; evolving from a rather small colonised city with few roads in 1976 to a developed multi-zone urban settlement with a wide spread and complex urban network. The satellite image of Dubai in 2006 clearly shows the extent of Dubai's urban sprawl on land and sea. Also, by analysing the three images, it can be understood how the development of transportation networks - connecting Dubai to the neighbouring emirates as well as providing inter-connections- has contributed to the morphological urban growth of this city.

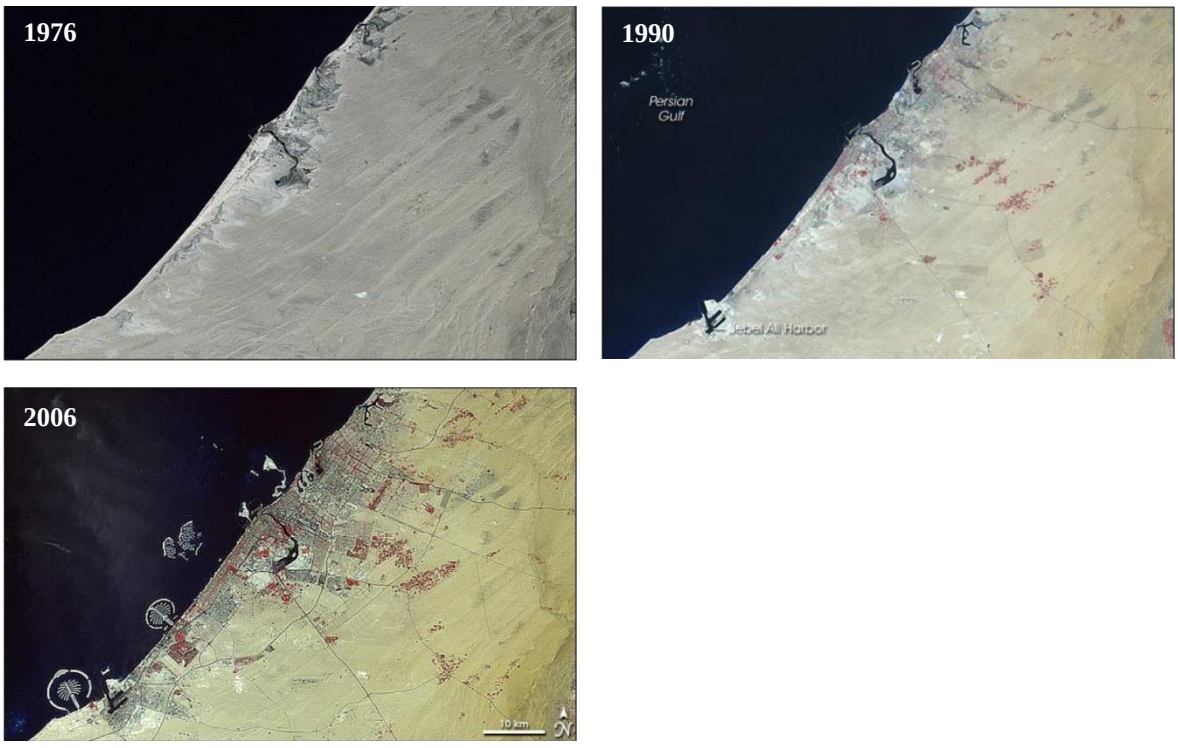

Figure 2.8: Urban sprawl in Dubai
Source: Satellite Images from Earth Observatory, NASA, 2011

Population of Dubai has also seen a significant growth in the past 15 years (Figure 2.9). With 270% increase and a growth rate of 2.7 since the year 2000, today Dubai is home to over 2.3 million people and is still growing rapidly (DSC, 2014).

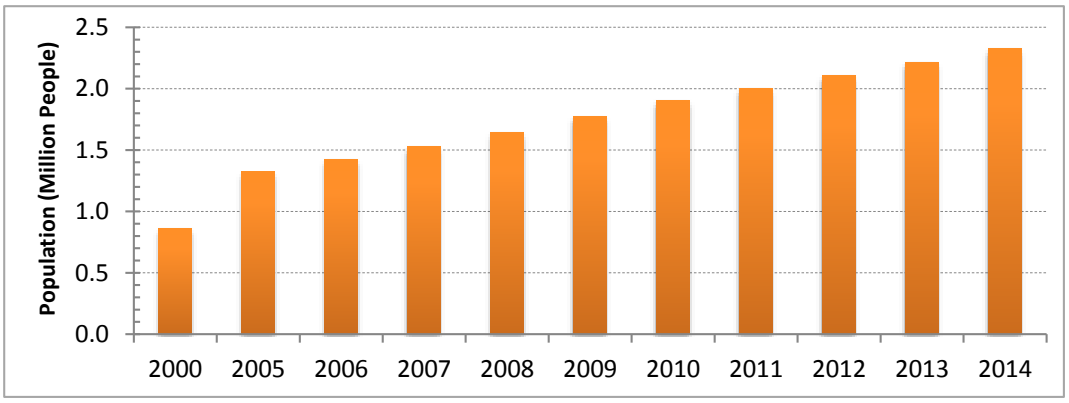

Figure 2.9: Population growth of Dubai since year 2000
Source: Dubai Statistic Centre, 2014

During these years, Dubai has become an emerging metropolis and a pole of interest for international investors and tourists. However, the urban development in Dubai speaks of far more than simple population growth as it has been the deriver of many economic and social structure changes in this emirate. But, this development has not been without a price since this rapid growth is also accountable for numerous environmental and social changes in the urban environment. Dubai's urbanization has become a significant concern of policymakers, planners, public officials and environmental advocates (Gardner and Howarth, 2010).

2.10.1. Sustainable Development in Dubai

The rapid urban development in Dubai during the past few decades has significantly impacted the levels of CO_2 emission of the city (Figure 2.10).

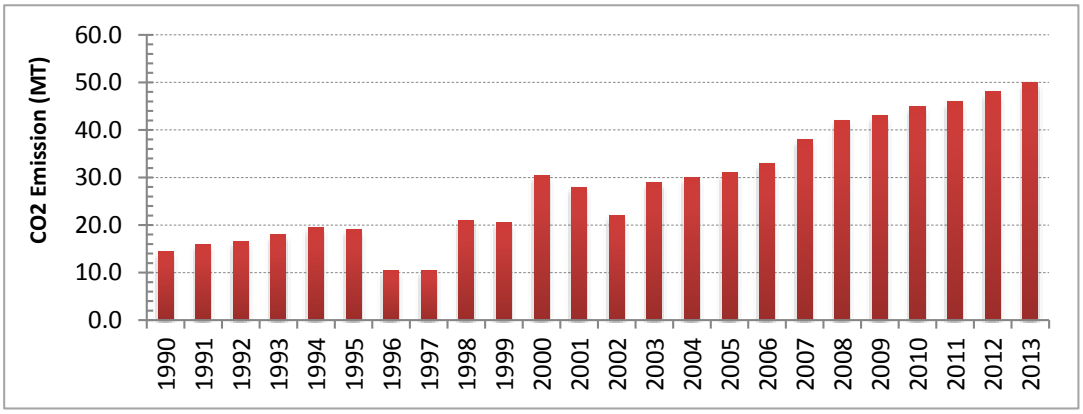

Figure 2.10: Dubai CO_2 emission since 1990
Source: Indexmndi, 2014

As it can be observed from Figure (1.8.2-1) there has been a major rise in the CO_2 emission levels since the year 2000. This rise is associated with the construction and urban development boom in Dubai since this year. In year 2013 alone, Dubai's CO_2 emission has been around 50 million ton out of which nearly 25% is produced by road transportation sector (DCCE, 2014). High production of greenhouse gases and high CO_2 emission has positioned UAE in the third place among countries with largest CO_2 footprint by production versus consumption, with Dubai being one of the major contributors (GFN, 2011).

Therefore in order to reduce the amount of produced greenhouse gases, lower the CO_2 emission, cut down fuel consumption and decrease various negative impacts of the accelerated urban development in Dubai, since the year 2008 developers were mandated to comply with regulations stablished to follow sustainable developments principals (Go Green, 2007).

These regulations that were primarily applied in construction and road and transportation sectors, have placed Dubai among the pioneer cities in the region to implement green buildings regulations such as LEED as well as providing or

enhancing various innovative public transportation modes. Sustainability policies were later applied in energy and economic sector to enhance the efficiency of renewable energy resources. By investing in many projects Dubai has tried to put the security and sustainability of its energy supply as one of the primary targets (Kaye, 2012).

Today Dubai is incorporating new regulations and strategies to significantly decrease its fossil fuel dependency by 2030 and is on the path to reduce its CO_2 emission by 15% by the year 2021(Gulfnews, 2015).

2.10.2. Public Transportation in Dubai

In the recent years Dubai has greatly invested in the transportation and public transportations sectors to provide a better, well-connected, safer and more sustainable service. These investments have been made in developing new policies as well as new modes of transportation.

Paying significant attention to improving public transportation was accompanied by measures such as road tolls were implemented to reduce congestion in the city. In 2007, Dubai was the first city in the region to introduce toll gate system on a number of its major roads. In addition to increasing the cost of using private transportation (personal vehicles) relative to public transportation, toll gates reduced the congestion by diverting traffic flow to alternative routes (Elgendy and Yassine, 2012).

Apart from new and innovative transportation polices, Dubai provides various modes of public transportation. This city is home to the most advanced metro system in the region. Since its operation in 2009 the metro has been successfully carrying around 300,000 people daily within 6 years of operation (RTA, 2015).

In addition to the metro system, Dubai has an extensive bus network operating on urban and inter-urban routes, covering most remote areas of the city. Moreover, the metro stations have also become additional nodes for an integrated multi-modal

transportation system, providing a network of feeder buses that service local areas around the metro stations. According to Dubai Road and Transportation Authority, RTA (2014), by the end of 2013, there have been 1573 operating buses on 103 different routes, carrying over 316,000 passengers on daily basis which has increased by 7% compare to the year 2012.

In 2014 a new mode of urban rail transport system was introduced in Dubai. Operating since late 2014, Dubai tram has been carrying passengers in zones that have no direct access to Dubai metro. The first completed phase of the tram, services areas around Dubai Marina and Al Sofouh road. The integration of the tram with the metro and bus stations has enabled the passengers of either mode to easily interchange to the other in order to reach their desired destination.

Other than the bus service and urban rail transportation systems in Dubai, water taxi service is available to public. Water taxies operate in Dubai Creek and Dubai Marina zones, carrying people to different destinations. Moreover, in recent years, the RTA has tried to encourage people to use more sustainable transportation modes such as bicycling by implementing bicycle sharing systems in various spots around the city.

All the mentioned public transportation modes justify that Dubai has one of the most diverse public transportation systems in the region. However, despite the variety of available transport modes, the RTA (2014) has announced that based on their estimations less than 20% of Dubai residents use public transportation modes as their main transport mode. This fact indicated the importance of constant assessment and evaluation of all transportation system it terms of their ridership, accessibility and mobility provision to make sure that the different available transport modes are capable of providing an effective and efficient transportation service.

2.11. Summary

The literature review presented in this chapter offered a clear study on the history of transportation as well as its important impact on the urban development of cities over the period of time. Moreover, a comprehensive explanation of the sustainable transportation and its indicators was presented.

The reviewed literatures have proven that sustainability of a transportation system relies on various parameters that are closely linked with the accessibility, economic, environmental and socio-cultural needs of the residents of an urban settlement or a city. These parameters impact the transportation systems both individually and as inert-linked parameters. Therefore it is important to know and understand how each of these indicators can impact the state of the other parameters and how they all would impact the transportation system quality within a city. Also, the positive impact of developing and enhancing a sustainable transportation system on economic productivity, urban development and urban liveability was discussed and analysed.

Moreover, it was understood that investing in and improving public transportation systems conditions can significantly increase the transportation sustainability; since it has the ability to address and satisfy many indicators of sustainable transportation all at the same time and it can provide a more affordable and equitable transportation system that would be accessible to all. However achieving effective and efficient public transportation systems is only achievable through constant assessment and evaluation of these systems.

Chapter 3: Methodology

3.1. Overview

In everyday life, different incidents and happenings ascend questions in need of an answer, and that is where the important role of research comes into play. In such cases, a research process starts impulsively and on the surface and deepens progressively up to the point where planning a research outline is required in order to achieve scientifically reliable answers to the aroused question. A general target, often referred to as the research ambition, is established at the beginning of the research procedure. The ambition of a research is usually recognized through a set of objectives which are the paths and means to attaining the final goal. The stages that are taken in order to reach the objective of a research project are considered as methodology of the research. Base of the requirements of the research, in different phases, different methodologies can be employed to aid the researcher in achieving the objectives. The chosen and used methods should be based on previous works that has been done in the same field of investigation. This will increase the validity of the selected methods.

In this chapter a summary of the conducted research to find the most suitable methodology for this project will be presented. Through earlier explorations done on topics that focused on evaluating transportation systems performance and sustainability, different methodologies used to carry out each research are found and the benefits and limitations of each method are analysed. Understanding the pros and cons of each of the used methods has helped greatly in selecting most suitable methods to be used in the current research. Moreover, in this section the implemented tools in each phase of the project will be critically acknowledged and validated and a detailed explanation of the steps and procedures followed to carry out the current study and produce the results presented in chapter 4 will be presented and reviewed.

3.2. Methods Used in Similar Researches

Through reviewing different literature and researches that focus on evaluation of transportation on many different levels and scales, it was understood that there are 4 methods being used dominantly. The selected method for each research was extremely dependent on the nature and the scale of the research. In this section, these methods will be presented, analysed and evaluated.

3.2.1. Field Measurements

Many scientific researches rely on field measurements in order to obtain the required results of the research. On-site data collection through field measurements is simply representing an understanding of the present condition of the research topic into a set of data which would be possible to further exploit in another study. Therefore, in most researches, this technique is often a complementing, yet vital method to the main method used. Moreover, in some cases, it can be used independently to state specific present occurrences, concepts and schemes.

In the field of transportation study, field measurements are often used to conduct a research on rather small scaled topics. Such topics might for example, aim to evaluate pedestrian flow on a certain street or a foot bridge. Or their objective might be to evaluate a certain transportation mode in terms of the number of its users, time efficiency, etc. on limited localities. Field measurements can be carried out through pure observation of the researcher or through installed measurement tools. Although field measurements have a relatively high scientific value and reliability, the validity of the results obtained using this method is highly dependent on the accuracy and the coverage range of the devices used to capture the measurements.

In a research carried out by Lumentut, Gunawan and Diana (2015), field measurements have been used to develop an algorithm for counting the number of passengers on BRT buses in order to evaluate the supply and demand of the system

as well as evaluating the quality of services, fleet supervision and cost-efficiency of the operating buses. In another research done by Shao et al. (2014), based on the data achieved through daily field measurements, a comprehensive model has been developed for assessment of the origin–destination traffic demand during peak hour of Hong Kong downtown.

The researchers of both mentioned studies argue that although the method they used in their research produced accurate results, there are challenges and limitations to field measurements method. The main limitation associated with this method is that the data gathered for a single hour or a single day is often not reliable since issues related to transportation are in constant evolution due to many different parameters that influence them. Therefore in order to gather a reliable set of data, the study should continue for a long period of time, sometimes months or a year. This fact can significantly increase the time allocated to a relatively limited study. Moreover, the environment of the study should be kept unchanged in order for the results to be accurate. For example in the in the research done on downtown Hong Kong by Shao et al. (2014), a partial road closure can impact the measured data which would lead to the inaccuracy of the obtained results; and therefore the measurements should be recorded from the beginning.

It is due to these challenges that this method is often used on small scale researches so that the chance of errors would be minimised.

3.2.2. Social Surveys

Social surveys are useful data collecting method where the topic of study is in close connection with people as the users. Social surveys are often used to understand the personal thoughts and experience of individuals on the research topic and how different groups of individuals would perceive different scenarios related to the research in altering ways.

In transportation related studies since people are considered as the users of transport services, understanding their opinion and response regarding the effectiveness and

level of performance of a certain system can be highly beneficial because it will inform the researcher about the success of that particular system from the users' perspective. Moreover, social surveys are also often used to understand the reasons behind a specific transportation choice people make (as individuals or as a member of a larger group).

Nasrudin and Nor (2013) carried a study on the transportation choices parents make for traveling to and from schools every day in Shah Alam district, Selangor, Malaysia. By preparing a set of questionnaires and employing social survey method, the researchers were able to recognize different modes of transportation that are being used by students to travel to school, as well as the reason for parents to choose on transportation mode over the other modes. To carry this research the study has focused only on one of the sections of the city. Based on a 10% margin error and 95% confidence level, 98 surveys were distributed on random basis to collect responses from parents. The survey sample was selected from low and middle income families so that the research would be able to detect respond of different demographic backgrounds.

Another research done by Schneider (2013) has used this method to study the reasons that drive commuters' choice of a routine transportation mode such as automobile. The ambition of the research was to create an operational framework to escalate the use of sustainable transportation modes such as walking and cycling. The research which was done in San Francisco Bay area, focused on a sample size of 26 people in different ages, so that this parameter would be analysed in their choice of transportation mode.

While the two cited researches have tried to select their sample population based on specific criteria (income and age), in the research by Cheng and Chen (2015) a completely random approach has been taken to select the sample population in order to assess accessibility, mobility and connectivity of the public transportation from the commuters' perspective. The research which has been carried out in city of Taipei the capital of Taiwan and Kaohsiung the second largest city of this country, focused on the users of the metro and bus systems in these two cities.

The previously mentioned researches focused on a more general research topic while in the research carried out by Bachok, Osman and Ponrahono (2014) the survey method has been employed to investigate passenger's aspiration regarding sustainability of transportation on a suburban bus route in Kerian District, Perak, Malaysia. The researchers carried out an on-board survey by travelling on the specific bus during the peak hours and surveying the passengers on that bus. This study shows that surveys can be carried out on various population samples and for studies with different scales of focus.

The researchers of all studies mention that the survey method was a helpful method in their studies since the opinion of different users or groups of people was a concern in their researches and social surveys were the best method to achieve this goal. However they argue that there are several challenges and limitations to this method.

The first challenging part of this method is to create a questionnaire that would cover all the parameters required for the study. Cheng and Chen (2015) mention that this particular factor made the preparation of the questionnaire quite time consuming since they had to consult many expertise in order to make sure that they have a comprehensive survey. The other challenge as stated by Schneider (2013) is to specify the sample population size, since a small sample size might not produce results that would be representative of the larger population or on the other hand selecting a rather large sample population can result in waste of resources such as time and money.

Moreover, one of the major limitations of social surveys identified by Bachok, Osman and Ponrahono (2014) is that when used for a small and limited study, the result of the survey can be very subjective to the time and location of the conducted research therefore it might not be possible to extend the obtained results to a larger population or a more general topic.

3.2.3. Numerical Method

Numeric method, also referred to as numeric modelling and numerical analysis, is a method that focuses on solving problems and result generation through mathematical algorithms and numerical approximations. This method is widely used in engineering fields and physical sciences however, in recent years it has found its way to fields such as life sciences and even arts.

In the fields of applied sciences such as engineering the numerical method is often used as a complementary method to other methods such as examinations, field measurements or social surveys. In the research fields related to transportation studies, the numeric method is often used to assess and evaluate the obtained results from statistical information or other methods used in a research. The outcome of these evaluations can be models and frameworks that produce an optimised solution to a problem, or to present the growth trend in a specific research topic or to make predictions and assumptions for further development of a system.

For developing a behavioural model to analyse how the accessibility level of different destinations and services would impact the users choice of using that specific service, Cascetta, Cartenì and Montanino (2016) have used a numerical model to stablish a relation between users' choices, availability of services and proximity and reachability of them. In order to test the accuracy of their model, the developed model was tested to assess the accessibility of different cinemas in Naples metropolitan area, Italy and how the accessibility of different cinemas would impact the choices made by people in using those cinemas. The result of this analysis was compared against the results of a survey that the researches carried out on the same subject. The outcome of this comparison was that the numerical model was actually capable of predicting the behavioural impact of accessibility on the users' choices.

In a larger scaled topic, Amaral and Aghezzaf (2015) use an optimization numerical model for developing a city logistics and traffic management system based on inner and outer urban transportation flows. On the other hand Jiang, Zhou and Tian (2015) use the numerical model for rather small scaled research to analyse macroscopic pedestrian flow within an L-shaped passage. Their study focuses on

the importance of the concept of shortest distance and how commuters by default try to choose the shortest possible path to reach from an origin to a destination.

Although the numerical methods used in all the mentioned studies have helped the researchers to achieve the ambition of their research, they all agree that the main limitation of the numerical modelling is that mostly they produce the approximate solution and not the exact answer to the problems. Although this problem can be solved through repetitive calibration of the model, based on the scale of the study, model calibration can be very time consuming and it can also increase the percentage error of the results.

3.2.4. Computer Simulation

Computations are now being used in all fields of study. Stablished on several principals of numerical modelling method, this research methodology helps the researches by taking different parameters that impact the research topic as inputs, and producing a set of result data based on various computational simulation, analysis and evaluation which are done by means of different computer programmes and software. Moreover, it lets the researcher to make predictions that should be handled carefully.

Computers simulations enable the user to run unlimited tests with complex nature more accurately and faster than most other research methods, therefore it offers higher efficiency to the user. Furthermore, simulations are able to analyse the situations that have not occurred in the real time yet. They produce prediction data that would show future negative and positive factors associated with the topic of research. The mentioned points are few of reasons for their popularity among the researchers of all fields.

Computer simulations are also considered a simpler and more economical way to study and analyse a virtual model compare to the reality. Improvements happening in developing computer software and programmes are making the use of virtual models and environments even simpler than ever. Additionally, recognition and use

of different software by major authorities and organizations validates this methodology and provides added accuracy to this research method.

Computer simulations are capable of testing complex and interconnected problems which in some cases are nearly impossible to compute using other methods. Therefore, in transportation related studies, due to variety and complexity of the problems and the numerous parameters that influence the problems, many practitioners, organizations as well as researchers rely on computational simulation in order to produce acceptable and realistic solutions to the problems.

Transportation simulation software and models can be used in different large scaled researches with varying objectives. Song et al. (2013) focus on producing a simulation based framework for sustainable transportation evaluation and optimization. They state that using simulation methodology has enabled them to achieve an optimal composition of transportation planning and operation schemes, such as congestion pricing for different vehicles, private cars, bus and rail networks, to reduce general charge of multimodal transport in an exploratory way. In this research, the use of simulation method was found slightly limiting since the researchers were not able to input indicators that could not be quantized such as transportation safety.

In another research done by Hager, Rauh and Rid (2015), it has been tried to analyse traffic behaviour in growing metropolitan areas through employing agent based simulation models. They claim that most of transportation simulations focus on analysing the behaviour of vehicles and they disregard people's traffic behaviour in the cities. However, through using MATsim agent modelling software, they were able to develop a model that would be able to analyse vehicles and people traffic behaviour. This model was later used to analyse the city of Stuttgart as a case study. They found simulation method very useful since it enabled them to obtain numerous potentials for thorough analysis, making agent-based simulation the perfect method for researches in transportation field.

Tong, Zhou and Miller (2015), use computational simulation method to formulate and resolve the problems associated with transportation network design through

increasing temporal and spatial accessibility. The method is stated to be quite beneficial especially during analysis of altering transportation network design. the model has enabled the researchers to parametrically change the input values in search for advanced and evolutionary result.

Also, Gentile (2015) uses a dynamic traffic simulation for real-time analysis of the evolution of vehicle currents and travel duration on large road networks in order to provide solution for reducing road congestions. Using this type of simulation has enabled the researcher to produce a detailed representation of the occurrence of major congestions at nodes of urban networks such as vehicle queues and their spillback, as well as movement clashes in road boundaries and exits. These results have been later used to provide solutions to such problems. From methodology perspective, taking simulation approach in this research has been more consuming in regards to the simulation runtime and memory usage, however, this method has provided a straightforward computation in sequential order while avoiding internal duplications of the data during simulation.

Through reviewing different researches, it was understood that software used for transportation simulation and analysis can be very different in terms of the needed inputs and the production and presentation of the outputs. Therefore the choice of the suitable programme is based on the available resources of each project and the global objective of the research.

3.3. Selected Methodology

The objective of this research is to study, analyse and evaluate the ridership pattern of Dubai metro at the current time and in the future in order to assess its effectiveness in providing mobility and accessibility to the commuters in Dubai.

Having in mind the complexity of the factors that impact transportation mobility and accessibility and their overlapping and interconnection, several methodologies were omitted from this study. Using field measurements is not suitable for

assessment of a transportation mode future ridership since it is not possible to measure and evaluate parameters such as urban development and population growth using this method. Moreover, due to the large scale of this research, obtaining the current ridership of Dubai metro would be nearly impossible. A social survey is used in researches that the personal experience of the user is of value in achieving the objectives of the research. However, the present research has a quantitative approach and using the survey method would not serve the purpose. Using numerical method can be very time consuming specially when various parameters and different scenarios are to be evaluated. Moreover, the complex nature of the involved parameters can increase the probability of faulty results. Due to all the mentioned factors, the most suitable methodology is believed to be the computer simulation method. Computer simulation has been usually employed in similar studies and is selected because of its major advantages over other methods.

Computer simulation will allow various inputs from different factors that influence transportation on differing levels. But, what is more important is that it can help in creating a controllable and editable linkage between all these parameters. Therefore the overlaps and correlation of these various parameters would be implemented during the model simulation. Moreover, computational simulation has the advantage of processing different variations of the developed model in a rather short period of time and yet produces accurate results. This will make calibration of the developed model much easier.

3.4. Selected Software

There is a wide range of software that are used for transportation simulations. Among them, the most common ones are: Quadstone Paramics, PTV Visum, PTV Vissim, AIMSUN, Matsim, SUMO, Repast, MAINSIM, Cube and Saturn. In order to select the most suitable software among these a comparative study was conducted on these software to understand which one would best serve the purpose of this research. Through this research it was understood that each of these software are capable of simulating different type and scale of transportation models.

Transportation models commonly are classified into microscopic, mesoscopic and macroscopic models. The difference between these three models is the scale of their focus on the general transportation system. Microscopic models are usually used to monitor individual features of transportation systems, such as singular vehicle dynamics or on individual commuter behaviour. On the other hand, mesoscopic models are employed for analysing different elements of transportation in small groups. These groups are consisted of homogenous elements that would create a small scale system. A common mesoscopic model is the dynamic of a group of vehicle on the road or travel behaviour on house-hold level. And macroscopic transportation models are often used to simulate the accumulated characteristics of transportation elements, such as combined traffic flow dynamics and travel demand analysis on different zonal levels or the flow and demand of numerous interlinked transportation systems (Hill, 2002).

Based on this knowledge the mentioned software are divided into two major groups. The first group is the software that are used for microscopic and mesoscopic scale simulation such as: PTV Vissim, Quadstone Paramics, SUMO and MAINSIM. And the second group is the software that are used for macroscopic scale simulations such as: PTV Visum, Matsim, AIMSUN and Repast.

Among the mentioned software in the second group, Matsim, AIMSUN and Repast are mainly used for roads and highways simulation whereas PTV Visum is used for various rail, road and water transport simulation such as ridership, demand and accessibility of transport systems. Moreover, among all mentioned software, the software produced by the PTV group is the only software that allows a secondary level of microscopic simulation while performing macroscopic simulations. Using PTV Vissim as a plugin for PTV Visum can be very beneficial since it increases the researcher ability to input more values and parameters. This can help in producing more variety of possible solutions to a problem as well as increasing the accuracy of the final results.

Therefore, based on the unique features and high capability of transportation ridership and accessibility simulations of PTV Visum, this research will be using

this software for conduction the major simulations of ridership pattern and transport supply and demand of Dubai metro.

3.5. Software Validation

PTV Visum is acomprehensive and dynamic traffic planning, modelling and simulation software which is being used by several transport planning practices, organisations and authorities. Moreover, this software has been used in many researches that were able to get published as scientific publications.

Through employing PTV Visum, Żak, Fierek and Kruszyński (2014) were able to conduct a multiple criteria evaluation of differing revitalization alternatives for a certain part of a main street in an average sized metropolitan area to enhance transportation provision in that area. By using this modelling software they were able to obtain a set of specific, quantitative values characterizing the alternatives, such as: volumes of passengers and vehicles flows, capacity utilization ratio and flow velocity in the network.

In another research, Gulhan et al. (2013) have used Visum travel demand modelling software to assess the accessibility measures as one of the important indicators of the performance of a public transportation planning process in Denizli, Turkey. This software enabled them to define various scenarios that consisted of differing transportation criteria that are often not considered during transport planning procedure in this city, such as timetable regulation, central business district restriction and integration with BRT system. The study stated that creating linkage between these criteria was mainly achieved through the multi-layer interface of Visum software.

For stablish the planning process an integrated urban transportation system for an average sized metropolitan area, Fierek and Zak (2012) used the macro simulation software Visum in order to propose an approach that would have a universal character and could be used by urban planners, transport planners and municipal

authorities to design progressive transportation solutions. Using Visum enabled the researchers to produce a set of parameters and measures that was beneficial in recalibration of the designed model for generating more accurate final results. Moreover, the study showed that the transport planning capabilities of this software was significantly beneficial since it made creating different variations of the transport model much easier.

In a research carried out by Solecka and Żak (2014), through using Visum software, the comprehensive procedure for designing and assessing various transportation solutions that would result in a better integration of public transportation system in a city was stablished. Visum software enabled the researchers to simulate the behaviour of considered and designed transportation alternatives to evaluate the overall integration of the transport system. The research showed that the software presents an interface where design and analysis of the considered transportation alternatives can run in parallel. This factor has been found very beneficial since it allows constant calibration and control over the model and at the same time it will reduce the simulation time.

All the reviewed literature agree that this software is able to produce comprehensive and accurate sets of outputs that it most cases have verified to be in compliance with other studies carried out using other methods or software. The only shortcoming of the software in few cases has been the complex interface of the software which requires extensive training of the user. The complexity of the software can increase the possibility of simulation interruptions, error messages and faulty results. However, if the model is stablished with precision, the outcome results can be highly reliable.

3.6. Research Procedure

In this section the main focus will be on the processes taken to achieve the objective of this project. The research procedure has been divided into four sequential stages;

data collection, simulation setup, simulation plan which will be presented in this chapter and the results analysis which will presented in chapter 4.

The data collection section will present the gathered demographical and statistical data. These data will be used in the second stage for preparing the traffic model.

The simulation setup section will present information about the operational basis of the selected software, Visum. Moreover, the parameters that have been taken into consideration during traffic model preparation will be thoroughly explained. Furthermore, the first set of simulation will be performed in order to evaluate the generated results and assess the accuracy level and validity of the stablished traffic model and the results.

In the third stage, the research simulation plan will be set and explained based on the objectives of the project. The results obtained from the simulations performed in this stage will be later presented in chapter 4 where each part of the generated results will be thoroughly explained.

3.7. Stage One: Data Collection

3.7.1. Dubai: General Development Statistics and Demographics

Population growth of a city is one of the main parameters that would necessitate expansion of transportation network and capacity. As it has been previously mentioned in chapter 1, Dubai population has faced a 270% increase since the year 2000. In 2014 the population of Dubai was announced to be 2,327,350 people and it is estimated that this number will increase up to 3,100,000 people by 2020 and up to 4,300,000 by year 2025 (DSC, 2014). Figure (3.1) illustrates the population growth pattern of Dubai from year 2020 up to year 2025. (For exact population values refer to appendix A-1).

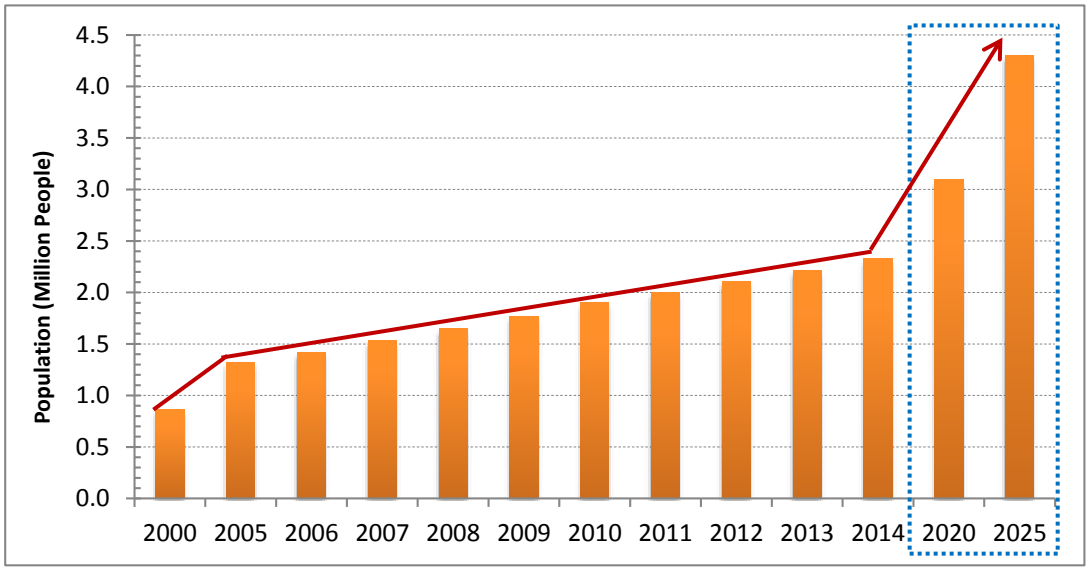

Figure 3.1: Dubai population growth pattern by 2025
Source: DSC, 2014

The growing population of Dubai had been the basis of many current urban development plans which will be completed in the future. The majority of these developments are taking place in areas that are currently undeveloped or are semi-developed. After the complete development and occupancy, the population residing in these areas would determine the transportation need within each urban zone. Currently according to the statistics published by DSC (2014) there is quite a wide range of occupancy in different urban communities of Dubai. Based on this report

the minimum occupancy in Dubai in 2014 was zero which is mainly related to areas which are still under development and the maximum occupancy was around 75,000 people for residential and commercial communities and around 172,000 people in industrial areas. (For exact population values refer to appendix A-2).

Based on the development plans of few urban communities in Dubai which were obtained from various developers, it was observed that most of the expansion plans are set to be completed in three phases, each phase being delivered by the years 2020, 2025 and 2030 respectively. It was observed that due to completion of each phase the local population of those communities faces a considerable rise which is important because the added population would change the transportation demand and supply in those areas. Table (3.1) presents the changed population values in these communities. (Kindly note that due to confidentiality of these plans, the numbers provided in this report present an approximation of the real values; however, the exact values have been used for simulation purposes).

Table 3.1: Expected population growth in few areas of Dubai

Community	2014 Population	2020 Estimated Population	2025 Estimated Population
Al Sufouh 1	2,641	6,100	9,500
Al Sufouh 2	8,437	12,800	16,000
Al Barsha 1	9,351	12,100	15,200
Um Suqaim 3	8,063	11,500	14,600

In addition to the population that reside in Dubai, Dubai has a major amount of floating population. Floating population is referred to the portion of population which are not permanent residents of a city and their presence is temporary on a span of time. Floating population is consisted of national and international tourists as well as people who tend to work in one city and live in another.

Figure (3.2) illustrates the increasing pattern of tourist population of Dubai between 2011 and 2014 and the expected number of tourists in 2015, 2016 and 2020. In year

2014 alone, the number of Dubai's international tourists exceeded 13 million people which has increased by 20% compare to 2013 and is expected to have an additional 15% increase in 2016. Moreover, Dubai authorities have estimated that Dubai Expo 2020 will attract around 20 million tourists.

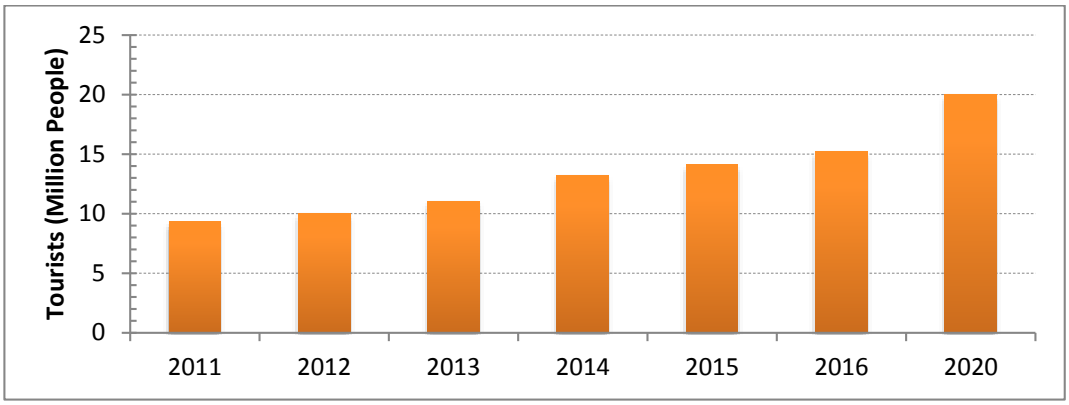

Figure 3.2: Tourist population from 2011 to 2014 and the expected number of tourists in 2015, 2016 and 2020.
Source: Gulf News, 2015

Although public transportation provision plans are designed based on transportation need of the residents of a city, for a city like Dubai with high number of floating population considering a comprehensive transportation plan that would meet the needs of both the resident and floating population is highly necessary. Therefore, the demographic data presented in this section will be used to stablish the transportation demand pattern as an input for performing the traffic simulation.

3.7.2. Dubai Metro

Operating since September 2009, Dubai metro is a driverless, fully automated urban rail service which has carried over 640 million passengers during its six years of operation (RTA, 2014). When completed in 2030, the metro will run on 6 different routes, covering various zones of the city (Figure 3.3).

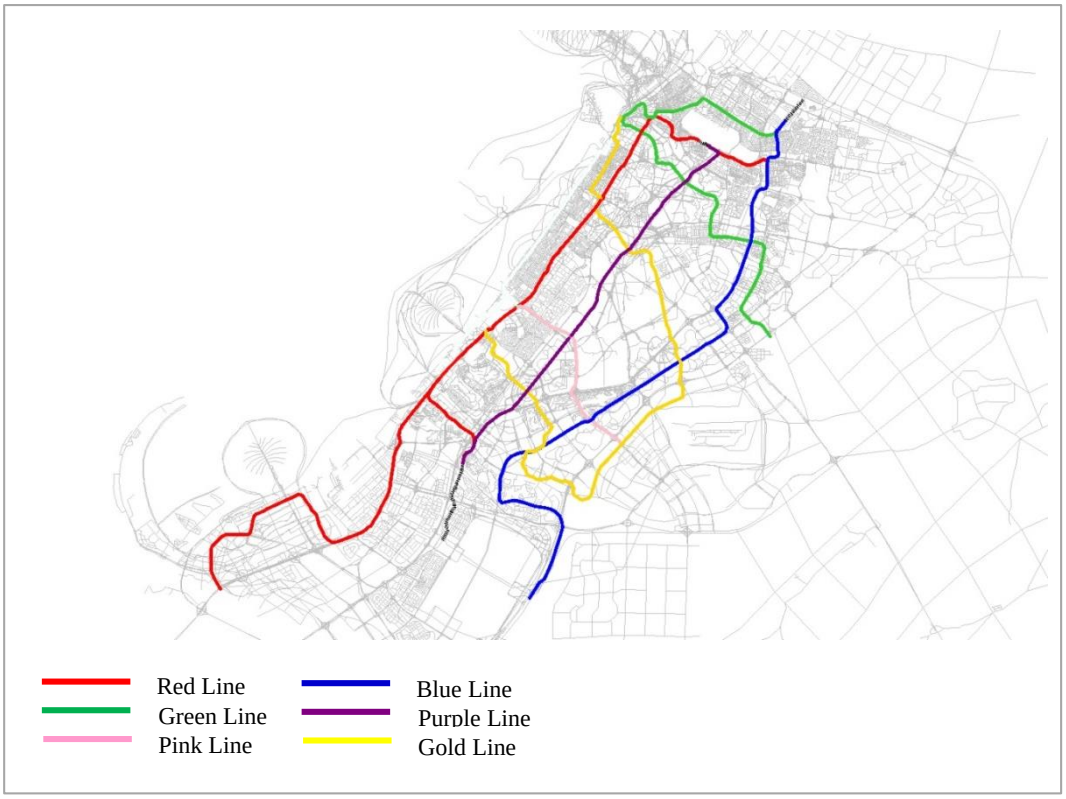

Figure 3.3: Dubai metro routes by 2030
Source: Visum Model

Currently two out of six initially planned metro lines are functional- the Red Line and the Green Line. The Red line operates between Jebel Ali and Rashidiya areas and the Green line runs between Creek and Etisalat zones. These two lines are expected to have major extensions by 2020. The Red line will be extended to Al Maktoum Airport in Jebel Ali area and to Dubai Expo Location; and the Green line will be extended from Creek station up to Emirates Road (Figure 3.4). These two lines course underground in the central parts of the city and on viaducts (elevated railway) in other parts of the city. When completed in 2030 (RTA, 2014), the metro

will traverse within 7 zones; however, currently the red line covers 4 zones while the green line services only 2 zones.

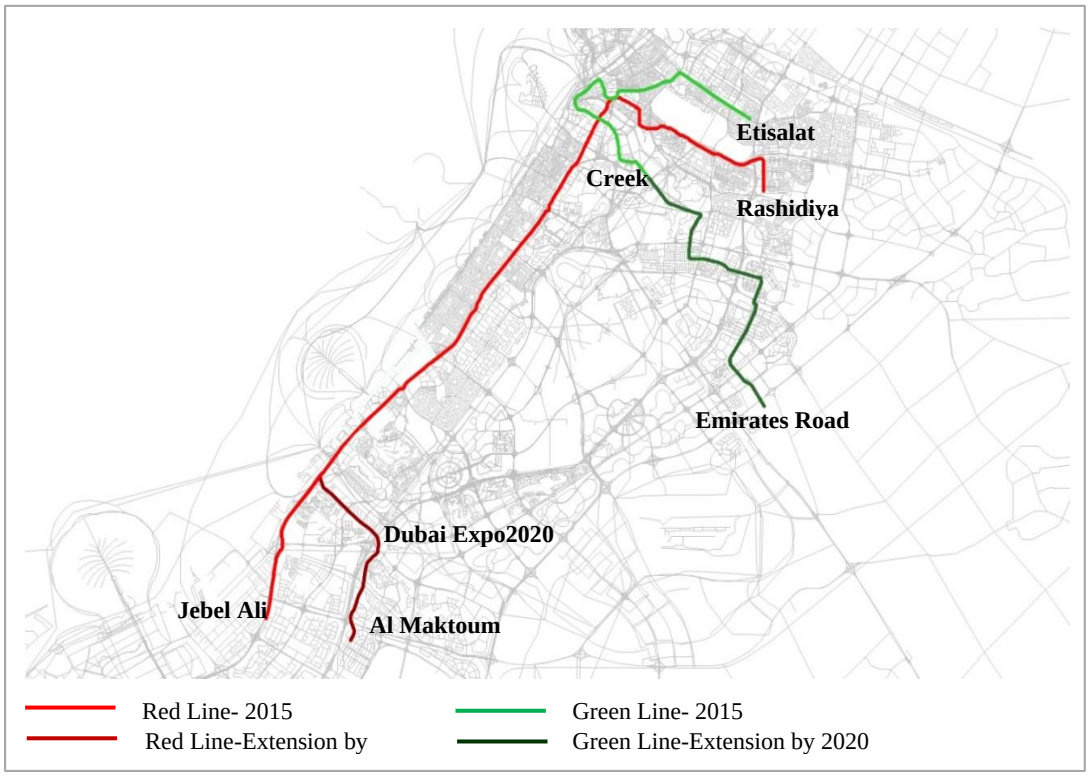

Figure 3.4: Dubai metro map by 2020
Source: Visum Model

Table (3.2) presents a general construction and operation statistic summary of the Red and Green lines.

Table 3.2: Red and green line general summary
Source: RTA, 2014

Line	Terminals	Start of Operation	Length	Number of Stations	Trip Time	Average Speed	Construction Cost
Red Line	Rashidiya – Jebel Ali	Sep.2009 (10 stations) Apr. 2010 (+18 stations) Sep. 2013 (+1 station)	52.1 km (5 km underground)	29	70 minutes	47 km/hr	AED28.0b US$7.6b
Green Line	Etisalat – Creek	Sep. 2011 (18 stations) Mar. 2014 (+2 stations)	22.5 km (8 km underground)	20	40 minutes	38 km/hr	

Prior to the start of operation of Dubai metro it was estimated that the metro would cover 12% of the total the needed transportation in Dubai. After few months' operation of the limited network in 2009, the metro provided transportation to a total of 1,740,578 passengers per month, which is equal to less than 60,000 passengers per day (RTA, 2013). After opening of more stations in the following years, today Dubai metro is providing services to more than 50,000 passengers on daily basis (RTA, 2015). Figure (3.5) illustrates the growth pattern of Dubai metro ridership from year 2009 to 2014. (For the exact values of the total ridership refer to appendix B)

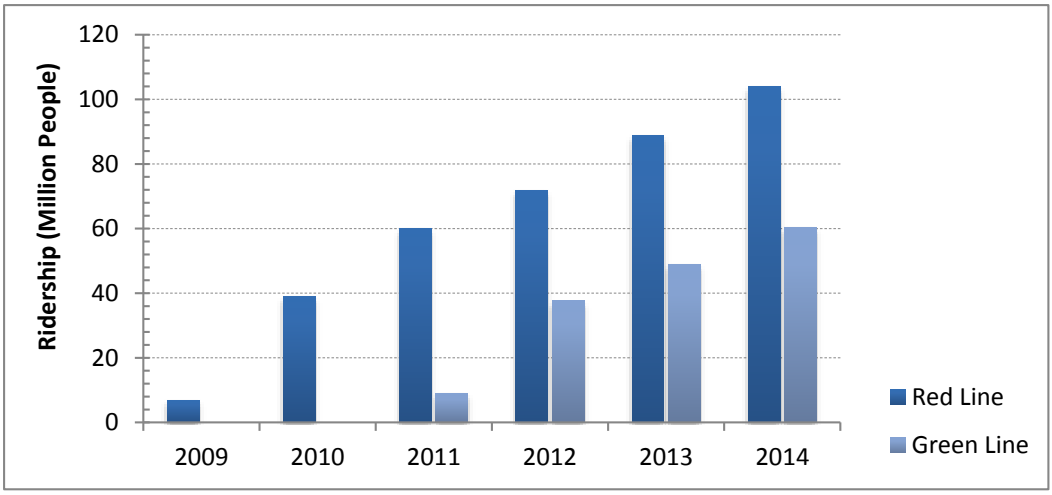

Figure 3.5: Dubai metro ridership from 2009 to 2014
Source: RTA, 2015

3.7.3. Dubai Tram

The Al Sufouh Tram is a part of the overall Dubai rail transportation system which links numerous commercial, residential and leisure centres in Dubai Marina area and along the Al Sufouh Road in Dubai. The tram is consisted of two phases out of which the first phase has become operational in November 2014 (RTA, 2015).The first phase of the tram runs between Jumeirah Beach Residences (JBR)/Dubai Marina area and Dubai College with 11 stations of which 4 are elevated and 7 are at–grade. After the completion of second phase, the tram will extend from Dubai College to Madinat Jumeirah and Mall of the Emirates.

Among the 11 stations, there are two stations (3 & 5) which provide a direct passenger transfer between the Al Sufouh Tram and Dubai Metro Red Line at Dubai Marina and Jumeirah Lake Towers stations. Furthermore, there is an indirect passenger transfer between the Al Sufouh Tram and Palm Jumeirah Monorail at station 9.

In the following pages, Figure (3.6) shows a general plan of Dubai railway network and Figure (3.7) shows a detailed plan of the Al Sufouh tram. Moreover Figure (3.8)

illustrates the tram-metro connection. Also, Table (3.3) presents the general statistical data of the tram.

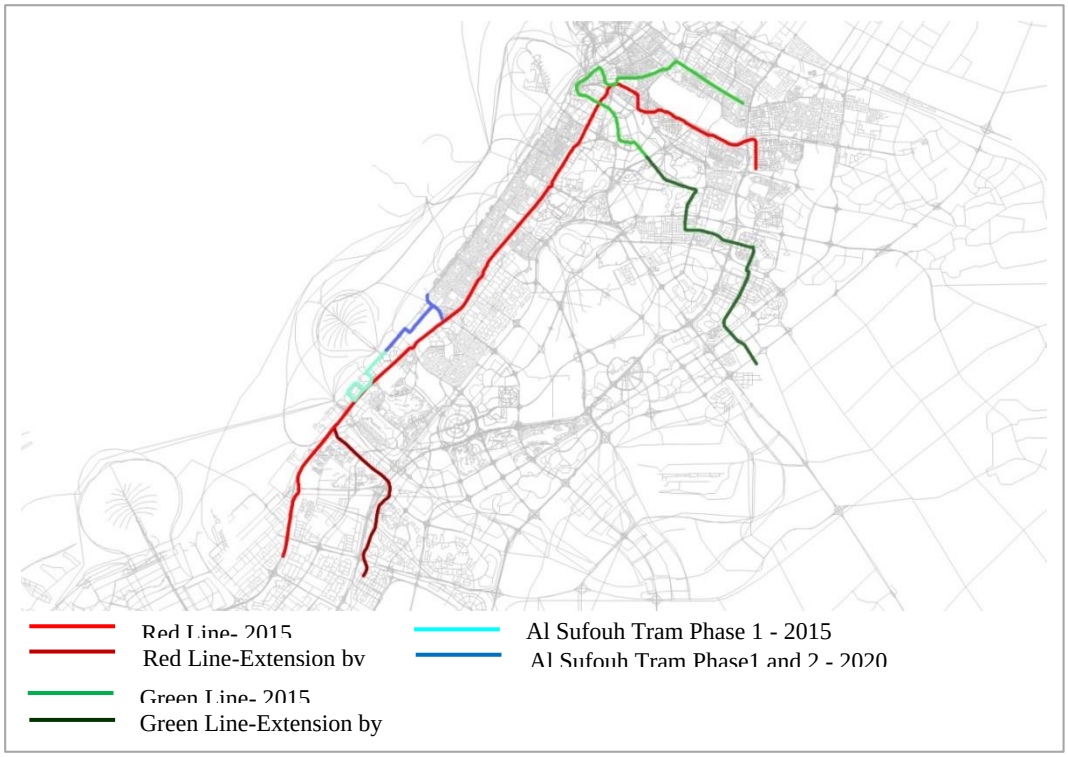

Figure 3.6: Urban railway network of Dubai by 2020
Source: Visum Model

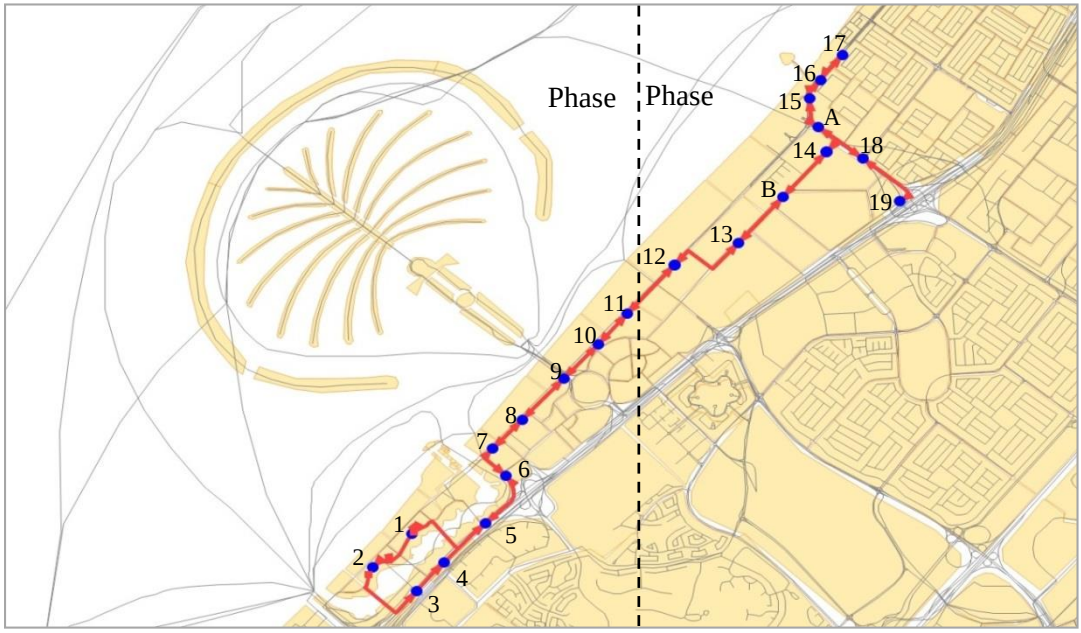

Figure 3.7: Al Sufouh tram phase 1 and 2
Source: Visum Model

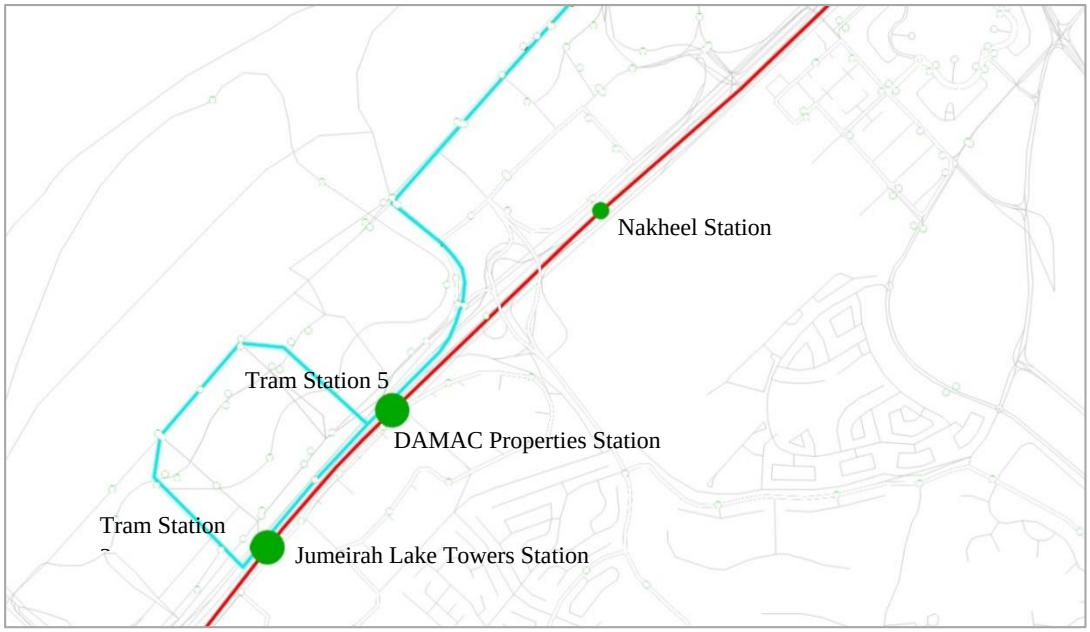

Figure 3.8: Dubai metro and Al Sufouh tram connection
Source: Visum Model

Table 3.3: Al Sufouh tram general statistics
Source: RTA, 2015

Line	Terminals	Start of Operation	Length	Number of stations	Trip Time	Average Speed	Cost
Phase 1	Jumeirah Beach Residences- Dubai College	2014	9.5 km	11	42 min.	13.6 km/hr	AED 3.18 Billion
Phase 2	Dubai College- Mall of the Emirates/ Madinat Jumeirah	By 2020	4 km	10	NA	NA	NA

The main focus of the present research is on evaluation of Dubai metro in the future years and it would not focus on evaluation of the Al Sufouh tram. However, due to integration of the tram and the metro in few stations, it is important to use the

collected data of AL Sufouh tram as a part of the input data in order to have an all-inclusive traffic model that would help us in generating accurate results.

3.8. Stage 2: Simulation Setup

Simulation procedure of Visum has an algorithmic nature. The algorithmic computation of Visum is based on an editable user setup file which contains the user's input data and a non-editable Mother Data File which contains various regional data such as economic growth factor, urban development factor, traffic flow indicators and many other parameters which are defined by different organizations and authorities of a city or country. The user setup file is consisted of two major modules that contain **demand model** data and **network model** data. These two modules are used to create the **impact models** which are used for analysis and evaluation of transport supply. Impact models contain three sets of data:

- User model: This model is used for simulation of public transport commuters and car drivers travel behaviour. User model calculates traffic volumes and service skims such as time of the journey, number of transfers, etc.
- Operator model: This model which is mainly derived from the demand model, indicates the operational parameters of a public transport service such as service kilometres, vehicle kilometres, number of vehicles, operating cost, etc.
- Environmental model: This model provides several methods for assessment of motorized transportation impacts on the environment.

In the final stage of the simulation process, the overall data generated by the impact model can be extracted as listings and statistics or if applicable, graphical analysis. Figure (3.9) illustrates a summary of the simulation parameters and process.

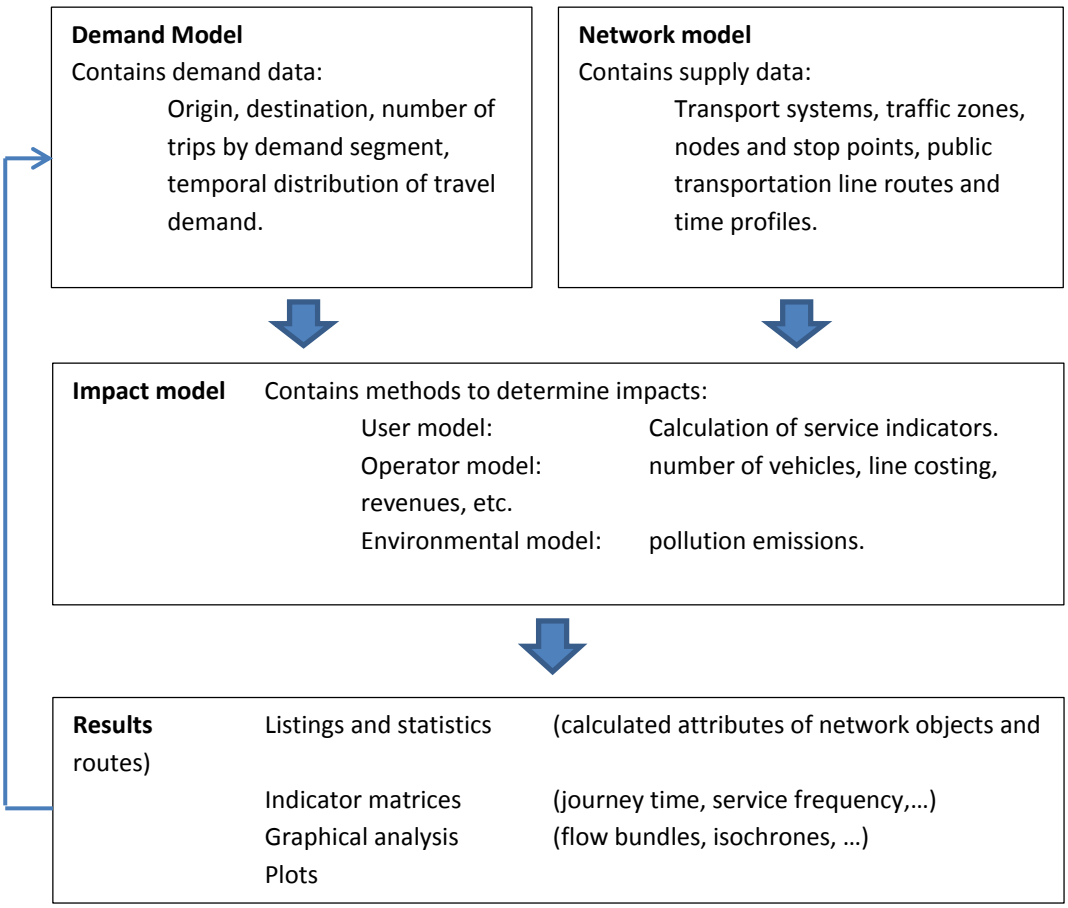

Figure 3.9: PTV Visum simulation process
Source: By author

The explained steps are considered general procedure of any transport simulation in Visum. However, based on unique requirements of different simulations, configuration of the demand model and network model and therefore impact model can vary. For example, temporal distribution of travel demand is a parameter that is needed for road transportation simulation and evaluation and it is not applicable to rail transportation.

3.8.1. Model Setup and Validation

Model Setup

Based on the parameters that have been explained in the previous section, a traffic model of Dubai metro and tram was prepared. The setup file of this model was created based on four sets of data. The first set of data is based on the data collected from the current condition of Dubai metro and tram such as location of the routes, location of the stations, etc. The second set is the data obtained from the RTA traffic data file which contains parameters (whether variable or constant) that are usually calculated by transport authorities based on the overall transportation logistics and statistics. The third set of data is based on the demographic data collected from Dubai Statistics Centre (DSC) and contains the general population data. These data have mainly been used for simulating the current scenario of the metro and tram, and for simulation of later stages in the upcoming years, the fourth set of data has been used which is demographic data of years 2015 to 2025, obtained from development plans of different areas of the city. The data that has been inputted in the software are briefly explained below:

Origin and Destination: This parameter indicates the start and end point of a transportation network which in this project is as follow:

- Metro-Red Line: Rashidiya to Jebel Ali and return
- Metro-Green Line: Dubai Creek to Etisalat and return
- Tram Phase 1: Station 1(Jumeirah Beach Residences) to Station 11 (Dubai College) and return

Number of trips: This value indicates the number of trips considered per person per day. Based on the RTA traffic data file, this value is calculated to be 0.03 trips per person per day.

Local population: Local population is considered as the number of people that live (in residential areas) or work (in commercial and industrial areas) in the neighbouring areas of each metro or tram station. These values have been calculated based on DSC statistics for the current scenario and based on the development plans

data for the future scenarios. Local population is one of the most important parameters because it will be used to generate the potential ridership demand associated with each station.

Potential Ridership Demand: This value is generated based on the available population in each zone of the city and their proximity to the stations location. Population proximity to the metro or tram stations impacts the number of people that use these services; meaning that people located in areas closer to the stations tend to use these transportation modes more often compare to people who are located in farther areas. Therefore potential ridership demand has a direct relation to the users' proximity. This value is calculated through defining an attraction radius(or catchment radius) for each station node. This radius will define the potential number of passengers that a specific station feeds to the system.

The attraction radius considered in this research is calculated based on the walking distance from each station. A research done by Cary (2005) shows that in the most effective scenario, an individual would consider using a specific transportation mode if it can be reached within 10 minutes of walking. If the transportation node is located beyond 10 minutes walking span, the probability of using that transportation service by population located in that area is significantly reduced. Also this research indicated that the average walking speed of human is about 5km/hr. Based on these values, and the population attraction factor from the RTA traffic data file, catchment radius used in this project has been calculated and illustrated in Figure (3.10).

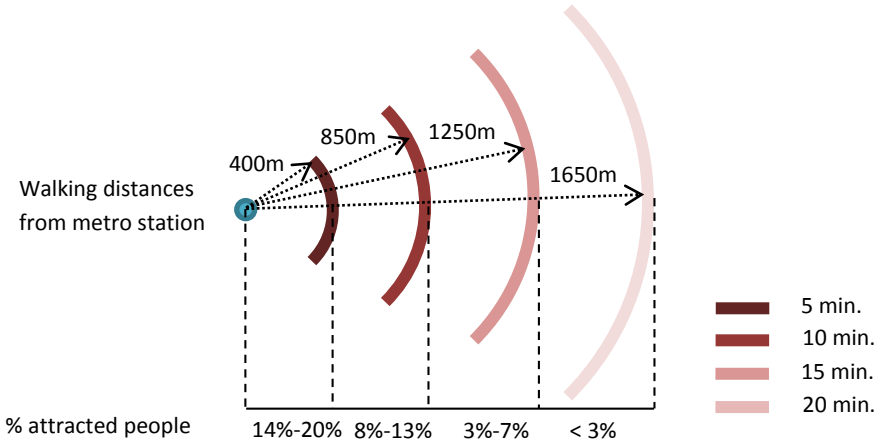

Figure 3.10: Population attraction percentage per walking distance radius
Source: By author

Transport System: The main focus of this research is on simulation and analysis of Dubai metro transportation system. Therefore, all the parameters would be adjusted in order to satisfy this objective. However in order to produce **mode share data** which is the comparisons between the rail and road public transportation and private transportation mode usage percentage, values regarding road transportation have been extracted from the RTA traffic data file. These values contain data related to public and private road transportation system.

Traffic Zones: The model's traffic zones are set based on the RTA traffic zoning plan for Dubai metro and tram. According to this plan Dubai has been divided into 7 different traffic zones which are illustrated in Figure (3.11). Each of these zones would contribute differently to the generated ridership of Dubai metro based on their population and the number of stations located in each zone.

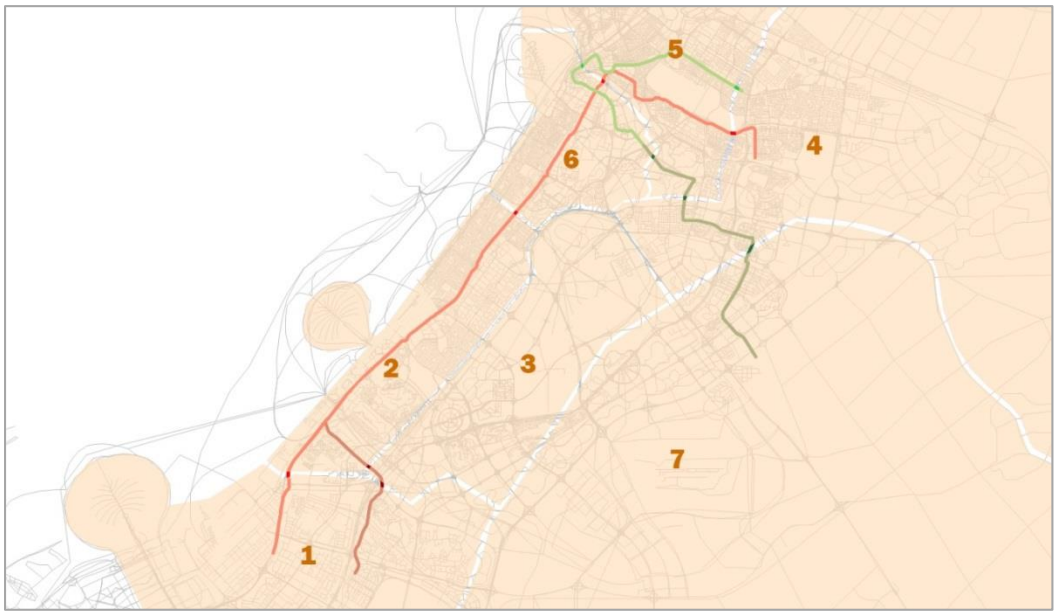

Figure 3.11: First zoning set: RTA traffic zoning of Dubai metro and tram

Nodes, Stop Points and Transportation Line Route: The routes of Dubai metro and tram and their stations have been modelled in the software based on the actual location of the routs and stops as well as 2020 and 2030 railway extension plans.

Time Profile: Time profile refers to the frequency of flow in a transportation system, which in this case would be the time schedule of Dubai metro and tram are as presented in table (3.4):

Table 3.4: Dubai metro and tram time profile
Source: RTA, 2015

Dubai Metro- Red and Green Lines		
Operation Hours	**Peak Hours Frequency***	**Off-peak Hours Frequency***
Sat–Wed: 5:30am-12:00 midnight	3 minute intervals	5-6 minute intervals
Thursday: 5:30 am to 1:00 am	3 minute intervals	5-6 minute intervals
Friday - 10:00 am - 1:00 am	-	6 minute intervals
Dubai Tram		
Sat-Thu: 6:30am to 1:30 am	10 minute intervals	12 minute intervals
Friday: 9am to 1:30 am	-	12 minute intervals

*Peak hours are as follow: Sunday-Wednesday: 7:30am-10:00am / 4:30pm-7:00pm
Thursday: 7:30am-10:00am / 4:30pm-8:00pm

Time Span: Time span refers to the test period. Based on the scale of a project, the model can be set for simulation of hourly data, weekly data, monthly data and yearly data. In the current project, based on the objective of each simulation, the time span has been set to produce hourly data, monthly data or yearly data.

All the above discussed parameters are used as inputs to create and develop the user setup file which would be used for performing the traffic simulations.

Model Validation

In order to test the accuracy and validity of the developed setup file and the designed traffic model, a number of simulations on Dubai metro and Al Sufouh tram has been carried out. These simulations were performed to calculate the ridership of these two transport modes in the year 2014. By ge to assess the gene:

1- Simulation of Red line and Green line metro routes to obtain yearly ridership.
2- Simulation of singular metro stations based on the objective of the task.
3- Simulation of the tram line to obtain yearly ridership.
4- Simulation of singular tram stations based on the objective of the task.

Based on the generated setup file and the explained simulation plan, the first group of simulations were performed to generate the ridership data for:

- Dubai metro ridership for the year 2014: for the Red and Green metro lines and 4 singular stations
- Dubai tram ridership for the first half of year 2015: for the complete route and 3 singular stations.

The result of this simulation was evaluated against the actual statistics provided by the RTA (2015) for each system in the mentioned duration to examine the accuracy of the prepared traffic model and the generated results. The summary of this comparison is presented in table (3.5).

Table 3.5: Model validation: Ridership of Dubai metro in 2014 and Dubai tram in the first half of 2015
Source, RTA, 2015 and Visum simulation, 2015

Simulation Task			2014 (RTA)	2014 (Visum)	Percentage Error
Dubai Metro	Route	Red Line	104,018,269	102,005,205	1.93
		Green Line	60,288,811	60,430,510	2.45
	Singular Stations	DAMAC Properties	2,232,347	2,189,936	1.89
		Dubai Internet City	5,872,726	6,042,516	2.89
		Mall of the Emirates	6,410,906	6,270,860	2.18
		Abu Dhabi Commercial Bank	6,693,307	6,546,991	2.18
Simulation Task			**First half of 2015 (RTA)**	**First half of 2015 (Visum)**	**Percentage Error**
Al Sufouh Tram	Route	Phase 1	1,854,005	1,814,998	2.10
	Singular Stations	Station 1 (Jumeirah Beach Residences 1)	180,009	176,479	1.96
		Station 5 (DAMAC Properties)	420,183	429903	2.31
		Station 11 (Dubai College)	103,594	106,098	2.41

After comparing the generated results with the statistics data provided by RTA (2015), the average percentage error of ±2.23% was calculated.

Through reviewing the researches carried out by Gulhan et al. (2013), Żak, Fierek and Kruszyński (2014), Fierek and Zak (2012) and Solecka and Żak (2014), it was understood that if the generated results through computer simulations have a percentage error of up to ±5% compare to the actual available data, the simulation model and the results can be highly acceptable while if the percentage error was up to ±10% the results would be acceptable for a single simulation but after performing

several continues simulations on the same model, there is a high chance of generating inaccurate results with percentage error of over 10% .

Therefor it can be claimed that based on the percentage error of the performed simulation (±2.23%), the developed traffic model and setup file are reliable to perform other simulation tasks for generating the ridership data of future years up to year 2025.

3.9. Research Simulation Plan

To achieve the objectives of this research, the simulation process was divided into two major stages:

In the first stage, a general simulation was performed to generate the ridership data of Dubai metro lines, starting from year 2015 to year 2025. The generated data were used to create, study and analyse the ridership pattern of the urban rail network during the mentioned years. Furthermore, based on the generated mode share data, the usage percentage of different transportation modes was generated.

In the second stage, a number of simulations were performed on 7 singular metro stations. These simulations were carried out in order to study, analyse and evaluate the impact of Dubai Expo 2020 as well and urban development and population growth on these stations ridership patterns. The selected stations are as follow:

Dubai Expo Station: This station which provides access to the Expo site, was simulated to study and analyse its ridership pattern during and after Dubai Expo in 2020 and 2021.

DAMAC Properties Station: This station which is located in one of the high density residential communities of Dubai was selected in order to analyse and evaluate the connection between Dubai metro and AL Sufouh tram. Moreover, since there are no feeder buses servicing this station, in a secondary simulation, a feeder bus route was added to the transport network of this station to understand and analyse the impact of this integrated transport mode and the increased accessibility on the ridership of this station.

Dubai Internet City Station: This station is located in neighbourhood of Al Sufouh 2 commercial Community. Based on the development plan of this area, a significant increase in the number of occupants of this zone is expected by 2025. Therefore this station was selected to study and analyse the ridership pattern of a developing commercial zone.

Mall of the Emirates Station: The main reason for selection of this station was its connection to one of the major shopping centres of Dubai. Moreover, this station is located in the proximity of Al Sufouh 1 zone which is a residential developing area and a considerable population increase in this area is expected by 2025.

Noor Bank Station: This station which is located between two residential and commercial communities was selected in order to study the impacts population growth and urban development in an area with different types of land use.

Financial Centre Station: This station was selected to evaluate the population growth impact on a high density and developed commercial zone

Abu Dhabi Commercial Bank Station: This station which is located in the highest density zone of Dubai was selected for this simulation to study its changing pattern of ridership which is derived by population growth and urban development of Dubai in the future years.

Based on these simulations, numerous sets of data were generated which will be presented and analysed in the next chapter.

Chapter 4: Results and Discussions

4.1. Overview

Base on the methodology stated in chapter 3, a comprehensive traffic model of Dubai metro, tram and general road transport system was developed. This model was later used to run numerous traffic simulations based on the research simulation plan presented in previous chapter. The outcomes of these simulations were several sets of data that represent Dubai metro ridership in different years and different scenarios.

In this chapter, the achieved results and a detailed explanation of the extracted data from all the performed simulations is presented focusing on significant findings and behaviour.

4.2. Dubai Metro: Complete Simulation

In this part the generate results of the conducted simulation on the complete metro network will be presented and analysed. These results are divided into two separate sets, which provide information regarding Dubai metro ridership as well as Dubai general transportation mode share from year 2014 to 2025. Each set of generated results will be explained, analysed and discussed in the following sections.

4.2.1. Ridership Forecast and Analysis

Based on the population growth pattern from year 2014 to 2025, foreseeable urban development, logistics of Dubai Expo 2020 and further expansion of the Dubai metro Red and Green lines, a simulation was performed in order to generate and investigate the rising or falling pattern of Dubai metro's ridership in years 2014 to 2025. The summary of these results are presented in Figure (4.1). (Refer to Appendix C-1 for the detailed values of the bellow chart).

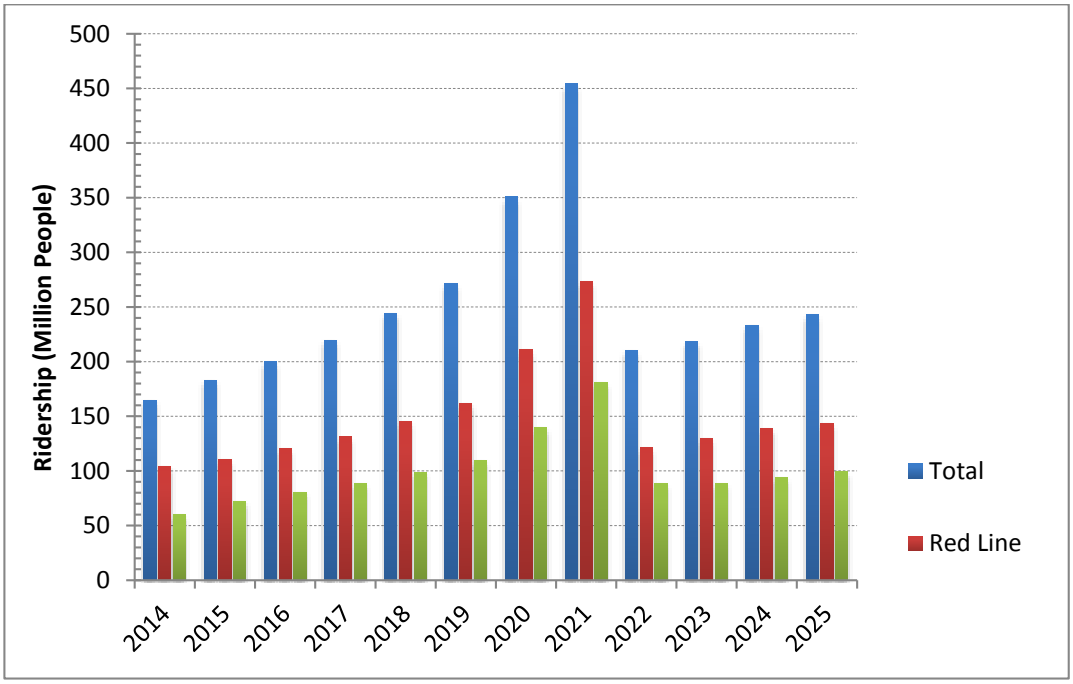

Figure 4.1: Ridership forecast of Dubai metro Red and Green lines from 2014 to 2025
Source: Visum generated data

As it can be observed from Figure (4.1), the metro rider ship has a rapid increase from year 2014 to year 2019. This increase is justifiable based on the increased urban development in the years leading to Dubai Expo in 2020 and2021. Dubai Expo has created and will create many job opportunities as well as tourism awareness before 2020.This, as it can be seen in the above chart; will result in increasing metro ridership during these years. Starting from 2015 till the end of 2019, Dubai metro experiences an average of 10.33% ridership increase each year compare to its previous year. Also by the end of 2019, the generated results show that the amount of ridership has increased by 63.50% compare to the amount of ridership recorded in 2014.

Dubai metro ridership growth becomes very significant during years 2020 and 2021, when Dubai will be hosting the world Expo, starting from 20th October 2020 through 10th April 2021. As it was mentioned before in chapter 3, it has been estimated that the Expo will attract over 20 million tourists. Therefore it can be claimed that in years 2020 and 2021, tourists form the major portion of Dubai metro users. In the year 2020, metro ridership shows an increase of 29.08% compare to that of 2019 and in year 2021 the ridership percentage increase reaches to 29.48% compare to the year 2020 and 67.14% compare to the year 2019.

Based on what can be observed from Figure (4.1), Dubai metro ridership will reach its peak in the year 2021 merely because the major duration of the Dubai Expo will be in this year (3.5 months out of 6 months). However, after 2021, the metro will experience a considerable amount of 53.70% drop in its ridership. The main reason for this drop is the significant decrease in the number of tourists that will visit Dubai compare to the years 2020 and 2021. Furthermore, after the years 2020 and 2021, a new wave of migration will take place, this time from Dubai to other destinations. Due to reduced rate of urban development after 2021, less number of professionals and labours would be needed in Dubai to carry out different projects milestones. This would result in a decrease in the number of population as well as population growth rate. Consequently, the two mentioned factors, as it can be understood from Figure (4), would hugely impact the ridership rate of Dubai transportation including Dubai metro ridership. Moreover, the generated results also show that the metro

ridership in year 2022 would be very close to that of 2016, with only 4.82% increase compare to 2016.

After 2022, a gradual increase in the metro ridership can be observed. From 2022 to 2025, Dubai metro ridership experiences and average 4.93% yearly increase. Year 2025 shows a total of 15.53% ridership increase compare to that of 2022 and it has almost the same value of the ridership in the year 2018 with 0.59% decrease compare to the mentioned year.

Figure (4.1) showed that the peak of Dubai metro ridership in the next decade would be in years 2020 and 2021. However, in order to better understand the impact of the World Expo 2020 on the significant jump of metro ridership, a single simulation has been conducted focusing solely on metro station allocated to Dubai Expo 2020. The result of this simulation is presented in Figure (4.2).

In 2013, the plan to add an exclusive metro station to service Dubai Expo in 2020 was approved by the authorities. This station will be located on the extension of the metro's Red line. The generated results show that in years 2020 and 2021, Dubai Expo metro station alone is responsible for 71.1 million and 141.5 million of the total ridership of each year respectively (Refer to appendix C-2 for exact values). In year 2020, 20.2% of the total metro ridership and in the year 2021, 31.17% of the total metro ridership will be to or from this station. However, in years following 2021, the ridership of this station shows a significant decline. By reaching below 1 million ridership per year, in 2022 this station faces 98.9% and 99.2% decrease compare to year 2020 and 2021 respectively. Although between 2022 and 2025, there is a 69.6% total increase in the ridership of this station, Dubai Expo metro station remains among the station with considerably low ridership during these years. As the main reason of the very low ridership it can be pointed to the under-developed status of the neighbourhood of this station. Although authorities claim that after the 2020 Expo, the allocated site and its neighbourhood would be further developed to be used as a knowledge and innovation centre (Expo 2020 Dubai, 2015), this development is not expected to reach its occupancy period before 2025.

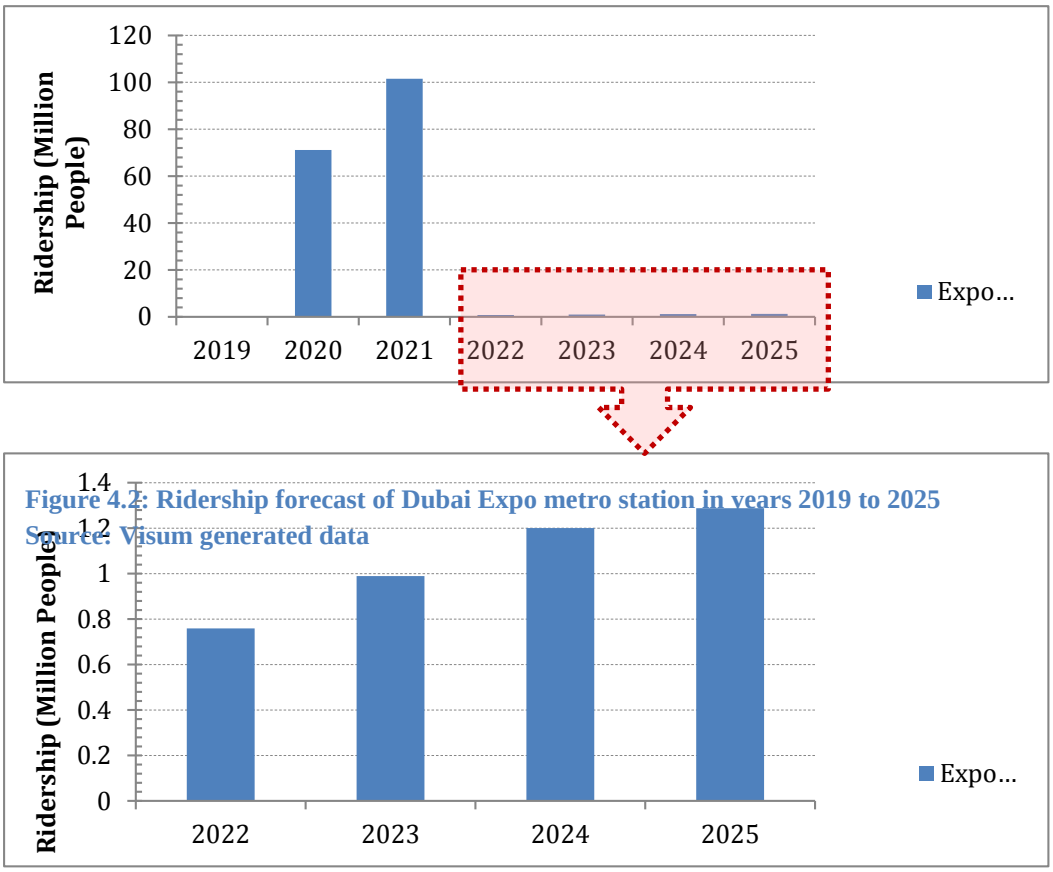

Figure 4.2: Ridership forecast of Dubai Expo metro station in years 2019 to 2025
Source: Visum generated data

Considering the mentioned factors, the question that would arise is that: would constructing an extension to Dubai metro only to provide access to Dubai Expo 2020 be the most efficient option? Is it not possible to provide the needed mobility and accessibility through an alternative transportation mode such as expanding the bus network?

The answer to these questions is that, providing an acceptable and standard level of mobility and accessibility to the location of Dubai expo for the large number of visitors of this event only through the bus network and road public transportation would be nearly impossible. Although the construction of this extension would have major economic and environmental emission impacts on Dubai, it can guarantee a safe, fast, affordable mode of transportation to the visitors while providing a transportation mode that has considerably low emission at the point of use compare to the road public transportation mode. Moreover, this extension of the metro line

will be further developed to reach the new Al Maktoum Airport, where it will provide transportation services to the commuters that travel to and from this terminal. And finally, in future years and after the completion of Dubai metro master plan, this extension will provide a connection to the Purple line, and therefore enhancing the integration and connectivity of this transportation mode.

4.2.2. Dubai Transportation Mode Share

Transportation mode share specifies the share of each transportation mode in providing mobility to the commuters. Figure (4.3) illustrates the generated results of Dubai's transportation mode share from year 2014 to year 2025.

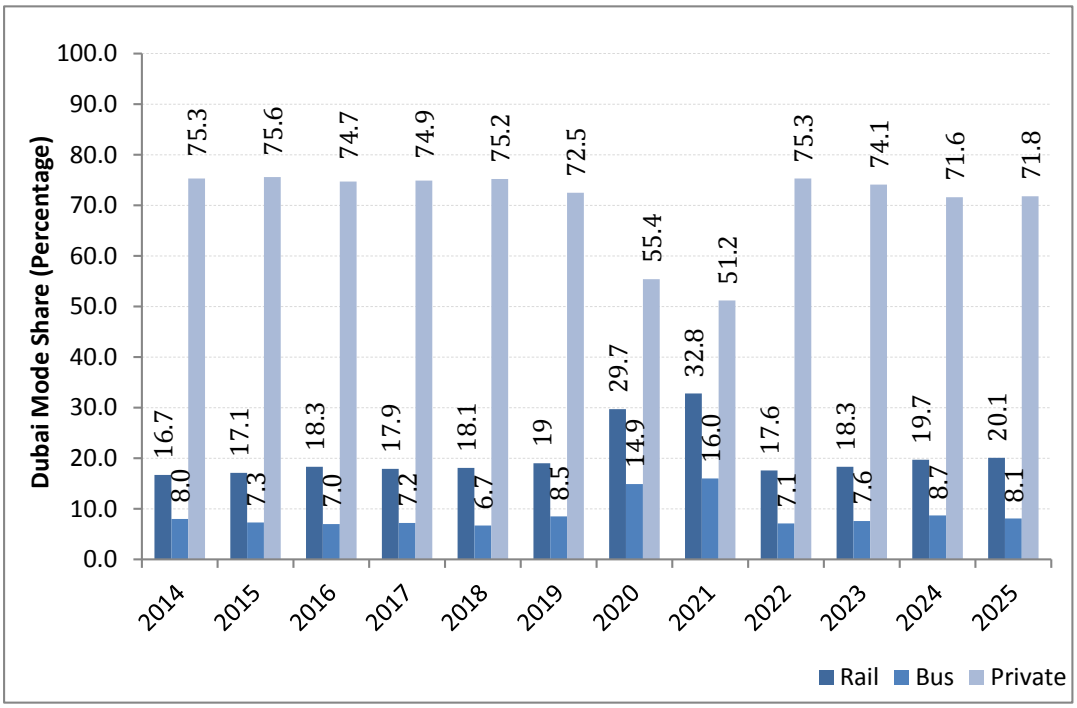

Figure 4.3: Dubai transportation mode share percentage by transportation mode
Source: Visum generated data

The main point that can be understood from the below chart is that Dubai residents predominantly rely on public transportation as their main mode of transit. As it can be seen, more than 70% of transit taken place in 9 out of 12 simulated years is

allocated to private transportation. The private transit mode share experiences a considerable decline in years 2020 and 2021. This drop is achieved through the increased ridership of Dubai metro due to the World Expo 2020 Dubai. However, it should be stated that the metro ridership increase in these two years is mainly due significant increase in tourism rate in the mentioned years and numerous travels made to and from Dubai Expo station. This can be justified by studying the mode share pattern of the post Expo years, where the private transportation mode again forms the major portion of transit taken place in these years.

Throughout the 12 simulated years, public transportation continuously holds the second position in providing mobility to the commuters. Between the two main modes of public transportation, Dubai's urban rail stands in the first place, while the bus system occupies the second place in transit provision to the commuters.

Although in the previous section, the general ridership of Dubai metro showed an average of 47.79% ridership increase in 2025 compare to that of 2014, Figure (4.3) shows only 3.4% increase in its mode share of year 2025 compare to that of year 2014. The main point that can be understood from this comparison is that although the metro ridership will have a gradual increase over the span of a decade, at the same time, private transit mode will experience the same increase in its number of ridership; and this would explain the relatively unchanged mode share pattern of Dubai transportation modes in these years.

This being said, the 3.5% decrease in private transportation mode share in 2025 compare to the year 2014 should not be ignored. This decrease results in a 3.4% increase in rail transit mode share and 0.1% increase in bus transit mode share in 2025. This can be a positive indication that more number of commuters tend to choose public transportation over private transportation. A survey carried out by Shahbandari (2014) shows that more people tend to used Dubai metro everyday mainly because it provides a faster and more affordable mode of transportation which would help them save on time and money. However, accessibility to the metro remains one of the main issues for major portion of the daily commuters, hence they choose private transportation mode over the public transit modes.

Therefore it would be highly important to study and analyse different parameters that play an important role in commuters' decision making process when it comes to selection between private or public transit modes. Moreover, developing different transportation polices such as removing the subsidises of petroleum, giving priority to public transportation users, assigning congestion restrictions in central parts of the city where it has high congestion rates, etc. would make private commuters to look for an alternative mode of transportation which would give them faster and cheaper mobility and increase their accessibility to restricted congestion areas. Such policies can be implemented in order to create an acceptable balance between public and private transportation mode shares.

4.3. Dubai Metro: Singular Stations Simulations

In this part, the generate results of the conducted simulation on 6 different metro stations will be presented and analysed. As it has been explained before in chapter 3, these stations have been selected and simulated in order to compare the impact of urban development, increased population and increased accessibility on the ridership of each one of these stations. The performed simulations on these stations are divided into two phases. In the first phase, the general impact of the increasing population on the rider ship of each station is evaluated. In the second phase of the simulation, a number of stations are selected for conducting a detailed simulation that would assess the impact of increased accessibility of the metro stations on their level of ridership. Each of these simulations have been conducted for years 2015, 2020 and 2025 mainly due to different phases of Dubai development plans that are expected to be completed in these years.

The results of the conducted simulations are presented in the following sections.

4.3.1. Singular Stations Analysis: Impact of Population Growth and Urban Development

In this section, the generated results of simulation conducted on 6 stations of Dubai metro will be presented. These stations are located in six different neighbourhoods in terms of land use and development level and the aim of this set of simulations was to evaluate the impact of local urban development and local population growth on the ridership of each station. The results are as follow.

Figure (4.4) illustrates the ridership pattern of six stations of Financial Centre, Mall of the emirates, Abu Dhabi Commercial Bank (ADCB), Noor Bank, DAMAC Properties and Dubai Internet City in years 2015, 2020 and 2025.

It can be observed that as expected, all stations experience over 100% ridership increase in year 2020 Due to Dubai World Expo. However, this increase is not similar in all stations. While of Financial Centre, ADCB, Noor Bank and Dubai Internet City stations experience 105% to 118% Ridership increase in 2020, Mall of the emirates and DAMAC Properties stations show 208% and 230% increase respectively, during the year 2020. This considerable difference in the increased ridership of these two stations compare to the other four can be justified based on the fact that these two stations provide accessibility to two of Dubai tourist attractions which are Mall of the Emirates one of the major shopping malls of Dubai and Dubai beach and marina area. Moreover, in case of DAMAC Properties station, another contributor to the significant increase of ridership in this year is that this station provides a connection between Dubai metro and Al Sufouh tram. And this can considerably impact the amount of ridership in this station.

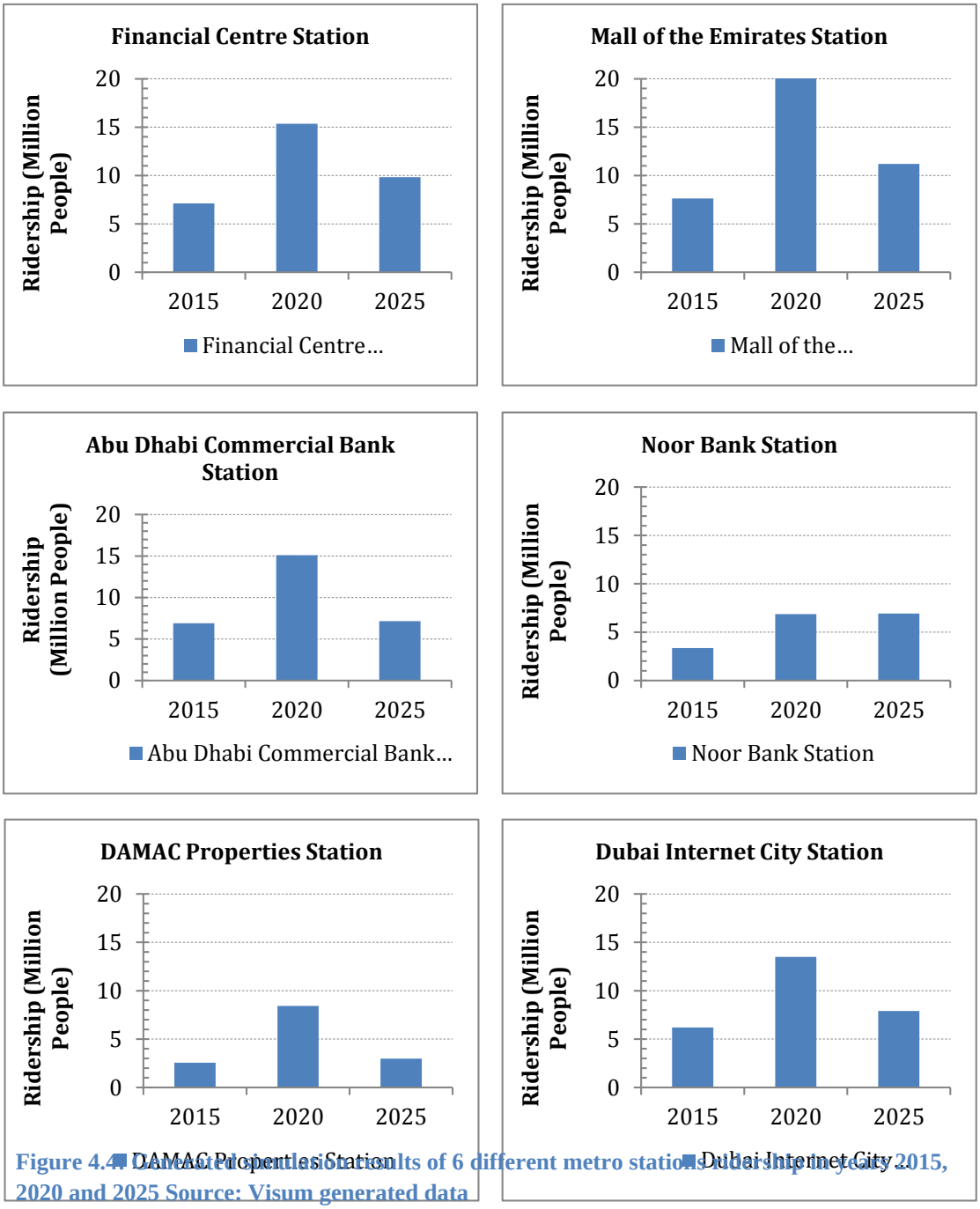

Figure 4.4: Generated simulation results of 6 different metro stations ridership in years 2015, 2020 and 2025 Source: Visum generated data

Apart from the increased ridership during the year 2020, the other major parameter that actually serves the purpose of this set of simulations is the comparison between the stations ridership in 2015 and 2025.

As it has been mentioned before, Dubai population is estimated to reach 4.3 million people by 2025. Undoubtedly, this population increase would impact the overall ridership of Dubai metro. However as it can be observed in Figure (4.4) not all the stations would experience considerable increase in their level of ridership in 2025. Stations that are currently located completely developed and majorly residential areas would not face a major change in their ridership rate in 2025. ADCB station is an example of such stations which is expected to have only 3.5% increase in its ridership by 2025.

On the other hand, Stations such as Mall of the Emirates, Noor Bank and Dubai Internet City experience respectively 46%, 106% and 27% ridership increase by 2025. This increasing pattern specially in case of Noor Bank station in merely because of increased urban development and therefore occupancy of the currently vacant area near these stations. Moreover, increasing ridership pattern in stations such as Financial Centre station which are located in currently developed commercial area of the city, can indicate that there would be more job opportunities in that specific area of the city which would justify the increased ridership of that particular metro station.

Overall, this simulation showed that although the general population of Dubai will increase by the year 2025, this increase would not impact all the metro stations ridership at the same level and their increasing ridership pattern would highly rely on the current development state of their neighbouring areas as well as their future development plans.

4.3.2. Singular Station Analysis: Increased Accessibility

The main focus of the simulation conducted in this section is to study and analyse the impact of increased accessibility on the ridership pattern of a single metro station.

For this study, DAMAC Properties metro station was selected. This station offers transportation services to the residents of two major areas of Dubai Marina, located

on the northern of side of the station and the JLT area which is located on the southern side of the metro station. Moreover, this station has a unique situation due to the connection of Al Sufouh tram station 5 to this particular station (Figure 4.5).

On the Marina side, this station is accessible to farther neighbourhoods through Al Sufouh tram. However, on the southern part, the JLT zone, currently there is no supplementary transportation mode that would provide a better and faster access to the metro station for the residents of this area (Figure 4.5). Therefore in this particular simulation, a new feeder bus route has been added in order to understand whether or not the integration of bus system would impact the ridership of this station (Figure 4.6).

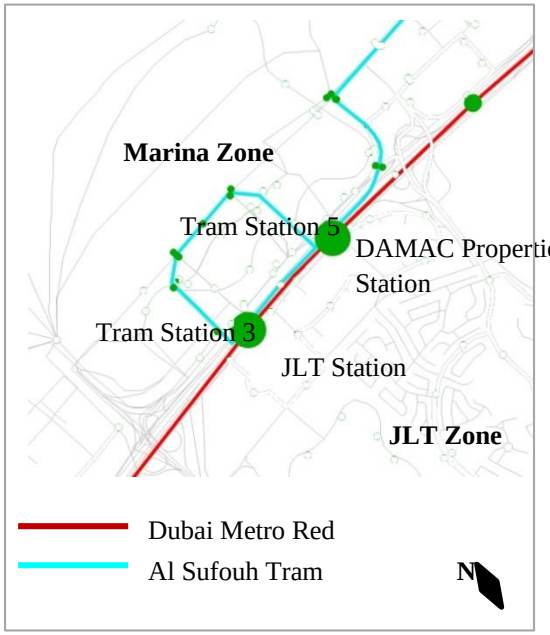

Figure 4.5: Location of different zones in neighbourhood of DAMAC Properties metro station and integration of Al Sufouh
Source: Visum model

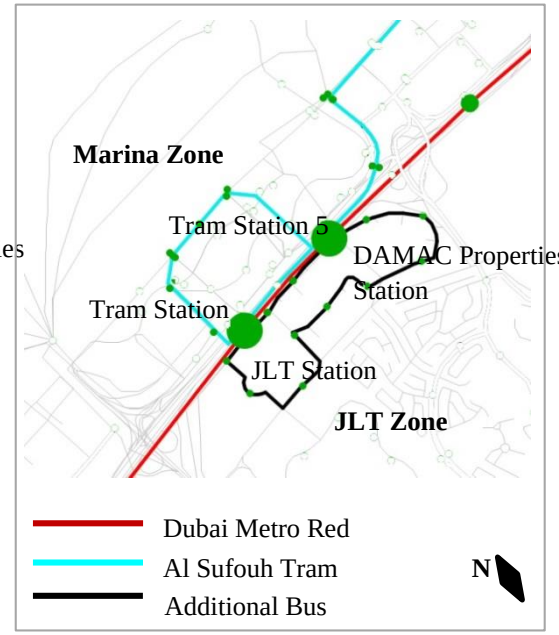

Figure 4.6: Additional feeder bus rout in DAMAC Properties metro station on the JLT zone
Source: Visum model

Two sets of simulations were performed on this station to evaluate its ridership pattern in both scenarios, before and after the introduction of the feeder bus route, in year 2020. The results of these simulations are presented in Figure (4.7).

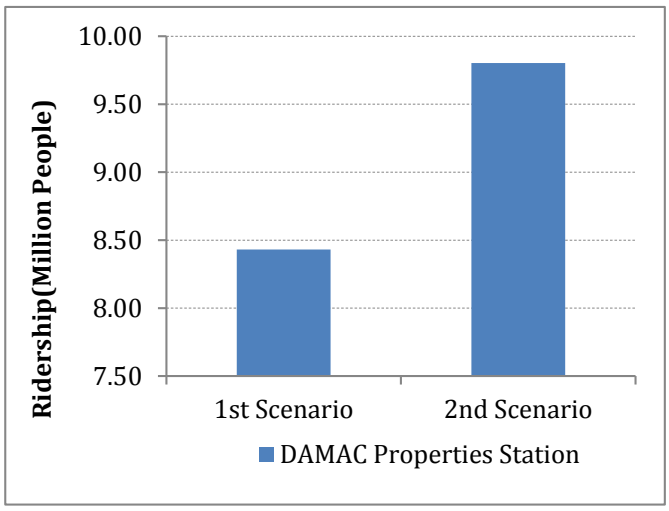

Figure 4.7: Ridership of DAMAC Properties metros station before and after adding an extra feeder bus route
Source: Visum generated data

Figure (4.7) illustrates DAMAC Properties station ridership before (1st scenario) and after (2nd scenario) introduction of an additional feeder bus route in the JLT zone. This figure shows that the additional bus route has increased the ridership of this metro station by 16.26% through providing better access to this metro station. Moreover, Figures (4.8) and (4.9) show the origin of the created ridership in this station. As in can be seen in the first scenario, 64% of the commuters of this station are the users that have directly accessed this station and 36% of the commuters have accessed this station via Al Sufouh tram. On the other hand, in the second scenario it can be seen that in addition to the direct access and Al Sufouh tram access, 12 % of the commuters would have access to this metro station through the integrated feeder bus.

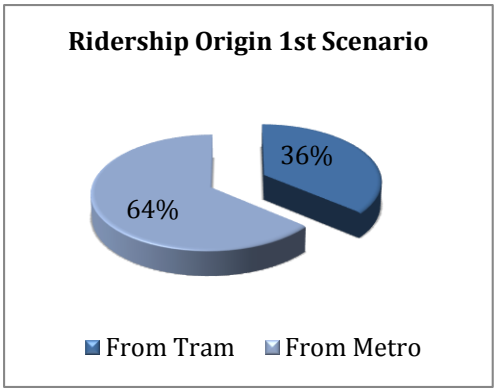

Figure 4.8: Ridership origin of DAMAC Properties metros station before adding an extra feeder bus route
Source: Visum generated data

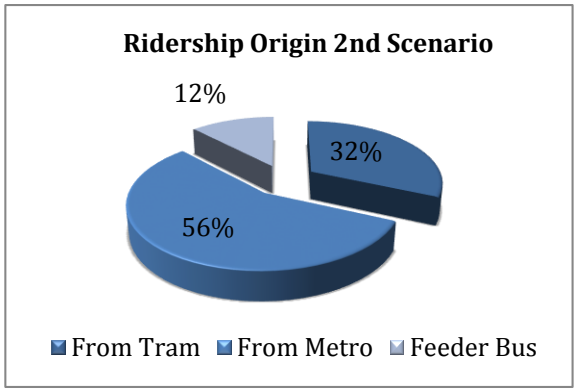

Figure 4.9: Ridership origin of DAMAC Properties metros station after adding an extra feeder bus route
Source: Visum generated data

This simulation shows the importance of a well-integrated transportation system. specially in case of Dubai that in the most time of the year, harsh weather condition acts as a major discouragement for the commuters to use public transportation mainly because the access points to these modes of transportation is located in a far proximity compare to the commuters origin. In case of Dubai, and intelligently integrated transport system would not only help in increasing the public transportation ridership, it will also help in increasing the overall efficiency of the public transportation systems, including Dubai metro.

4.4. Outcome

In this chapter, the obtained results from various traffic simulations were presented and explained.

Through analysing the metro ridership in years 2015 to 2025, it was understood that in the next decade, Dubai metro will experience a rather gradual increase in its ridership. Although the two years of 2020 and 2021 should be considered as exception since Dubai Expo 2020 would significantly impact the ridership of the metro in these years.

The generated metro ridership results for the years of Dubai Expo (2020 and 2021) show the complete capability of this system in providing mobility for almost 300% more number of people compare to the year 2015. However, based on the obtained results it was understood that in 2015 alone, nearly 75% of transits taken place in Dubai are in private transportation sector. This means that less than 25% of the total Dubai transits are made through public transportation, out of which nearly 17% of it would take place using the metro system. Moreover, it has to be mentioned that a large portion of the metro ridership in 2015 and other years is created by the transit of tourists and temporary visitors. Considering this fact would mean that even a lesser percentage of the residents of Dubai choose public the transportation as their main mode of transit.

Moreover, it was understood that despite the fact that increasing ridership rate of Dubai metro during the simulated years indicate that more number of commuters will be using this system as their main transit mode; the parallel substantial increase in the private transportation ridership will still place this mode of transportation in the first place among other transportation modes (road and rail public transportation modes) from 2015 to 2025. The low percentage of Dubai metro mode share, as it is been stated by Shahbandari (2014), is majorly due to the fact that many commuters find accessibility of the metro stations difficult and therefore they tend to choose a more accessible transportation mode which in this case is mainly Private transportation mode. The validity of this claim was partially justified when the results of the last conducted simulation showed that by creating a linkage between different transportation modes such as feeder buses, metro network and tram network, a higher level of public transportation accessibility will be provided to the user which would eventually result in the increased ridership and the overall usage of the public transportation mode.

As a general evaluation of Dubai metro transport system, based on the performed simulations and based on the reviewed literature in chapter 2, it can be claimed that Dubai metro system is a green, safe and affordable public transportation system which services millions of commuters each year and it is and will be capable of meeting the transportation needs of its users at the present and in the future.

However, a public transportation system can be considered efficient when it is able to reduce the car dependency of private commuters which would result in decrease in private transportation dependency rate. In case of Dubai metro, this system has not yet been able to initiate a major chance in the transportation behaviour of the general commuters of Dubai and this is one of the major factors that should be addressed thoroughly investigated.

Therefore, major suggestion that can be given in this section is that before investing in further development of Dubai urban rail network, related authorities and organizations should firstly invest in increasing the public awareness towards sustainable transportation; secondly, they have to pay special attention to increasing the integration of the current transportation system in order to increase accessibility and mobility and thirdly, they have to develop a set policies and schemes that would help in achieving a more sustainable transportation system within the city.

Chapter 5: Conclusion

5.1. General Conclusion

Transportation remains one of the major derivers of any urban development throughout the time and today, sustainable transportation is considered as one of the pillars of any sustainable urban development. A well planned and sustainable transportation system can have numerous positive impacts on the urban settlement through providing economic growth, environment preservation, offering more opportunities and increasing the overall living quality. Therefore understanding the principals of sustainable transportation and implementing them in design and policy making procedures can significantly improve the quality of transportation in any community.

The main ambition of this research was to explore and evaluate the effectiveness and efficiency of Dubai metro system. This goal was reached through exploring major principles and guidelines of sustainable transportation, and furthermore by means of computational modelling of Dubai metro and other public transportation system.

Using traffic planning and simulation software, Visum, a general model of Dubai metro and public transportation system was developed to simulate and calculate the total estimated ridership of Dubai metro in years 2015 to 2025. The results obtained from this simulation showed that despite the considerable increase in metro ridership in 2020 and 2021due to Dubai Expo, Dubai metro will experience a steady and rather slow increase in its ridership from 2015 to 2025. Furthermore it was understood that during Dubai Expo,

In the second stage of the research, by focusing on strategically selected metro stations, the computational model was further developed to study the impact of parameters such as further urban development, population growth, increased tourism rate on Dubai metro ridership. The results generated from this stage of simulations indicated that the population growth between years 2015 and 2025 will result in increasing metro rider ship. However, this increase will mainly affect the stations that are located in developing urban zones and stations that are located on

fully developed urban zones will not experience drastic changes in their annual ridership.

The last stage of the research was dedicated to analysing the impact of integration of different public transportation modes such as Dubai Bus, Tram and Metro on the ridership pattern of Dubai Metro. This test was carried out on a single station and it was understood from the results that increasing the integration of different transportation systems can positively impact the ridership of public transportation such as the metro system and it can increase the overall mobility and accessibility of transportation.

On a general note, it can be concluded from the presented results and discussions that Dubai metro is able to meet the transportation need of its commuters at the present and the future. However, despite the massive investment in providing and improving public transportation systems in Dubai, currently majority of Dubai residents rely on private transportation mode as their main mode of transit. This is majorly due to insufficient accessibility to public transportation system including the metro network, low integration of different transportation modes within local urban communities and low levels of public awareness regarding the benefits of using public transportation modes. This fact has decreased the efficiency of Dubai metro system since it has not been able to majorly reduce the private transportation dependency of Dubai commuters.

The trend of private transportation dependency would even continue in the future years unless some serious actions are taken for encouraging the commuters to choose public transportation mode over the private. However, making such a considerable change would not be easily achieved since it requires a major transportation behavioural change throughout an urban community. This will need an extensive amount of resources such as time and money and is achievable through increasing the public awareness regarding sustainable public transportation, investing in creating an efficiently integrated public transportation network consisted of different transportation modes and developing policies and regulations that would help in reaching the final goal which is a more sustainable transportation system in Dubai.

5.2. Research Challenges and Limitations

The field of transportation in general and sustainable transportation specifically, is a vast and complex scientific field which is composed of many parameters and is in close correlation with many other scientific fields such as architecture and urbanism, economics, social science and even politics. Conducting a research and investigation on this topic can be quite challenging due to numerous quantifiable and non-quantifiable parameters that have direct impact on the transportation system of an urban settlement.

Furthermore, transportation developments take place over a relatively long period of time. And their impacts (economic, environmental, social, etc.) cannot be evaluated until after an operational period of a particular transport system. Therefore most transportation studies rely on the currently available data and development plans to be able to make future assumptions and prediction. However, there is no 100% guarantee that a specific development would take place as it has once been scheduled. And such irregularities reduce the validity period of any transportation simulation and prediction. Therefore, it should be kept in mind that transportation evaluation are extremely time sensitive since the overall development rate of a city or a country can impact transportation systems in terms of their usage as well as their development rates and this would have direct impacts on the assessment results. Therefore even a slight change in the development rate of a community can impact the previous evaluations of a transport system.

In respect to the challenges and limitations face in the simulation process of this research, it should be pointed out that Visum software simulation process extremely time consuming. Visum simulation is based on singular simulations for every evaluation task. This means that it would be possible to generate the yearly ridership data of a metro route in one simulation. However, the generated data would not provide the yearly ridership data for every single station on the simulated metro route. Therefore, in order to achieve the yearly data related to each station, a new

simulation should be performed for every station. And this fact considerably increases the time that should be allocated to performing the simulations.

Moreover, the procedure of model preparation and configuration was experienced to be rather difficult, time consuming and challenging. To prepare the setup data file, numerous variables and parameters had to be input into the software which at time were found confusing due to overlapping values and parameters. Additionally, the simulation runtimes were very long; specially for major simulations such as generating the general ridership of Dubai metro which the runtime was more than 7 days. However, once the results are generated, given that the model validation has been done successfully, the results have high validity.

5.3. Recommendation for Future Investigations

The subject of transportation and sustainable transportation are vast scientific fields which this research tried to focus on a rather portion of it. Therefore in conjunction with the present research there are several topics that can be developed and investigated further. These topics are:

- Impact of assigning hourly congestion restriction zone in central parts of Dubai on the public and private transportation modes ridership
- Impact of reducing fuel subsidises on the public and private transportation modes ridership
- Research on the level of public awareness regarding benefits of public transportation
- Impacts of tax allocation to automobile owners on the public and private transportation modes ridership
- Impact of increasing toll gate charges on the public and private transportation modes ridership
- Conducting a survey in order to understand the decision making process of different transportation users in selecting their main mode of transportation

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Appendices

Appendix A-1

Table A-1: Dubai population from year 2000 to 2025 - Source: Dubai Statistic Centre, 2015

Year	Population
2000	862,387
2005	1,321,453
2006	1,412,812
2007	1,529,792
2008	1,645,973
2009	1,770,978
2010	1,905,476
2011	2,003,170
2012	2,015,875
2013	2,213,845
2014	2,327,350
2020(Estimated)	3,100,000
2025(estimated)	4,300,000

Appendix A-2

Table A-2: Dubai population Distribution by urban sector in2014 - Source: Dubai Statistic Centre, 2015

Community Code	Sector & Community	2014
101	NAKHLAT DEIRA	0
111	AL CORNICHE	1,439
112	AL RASS	13,445
113	AL DHAGAYA	19,270
114	AL BUTEEN	5,606
115	AL SABKHA	4,800
116	AYAL NASIR	25,610
117	AL MURAR	38,262
118	NAIF	53,562
119	AL REGA	13,227
121	CORNICHE DEIRA	0
122	AL BARAHA	21,844
123	AL MUTEENA	36,100
124	AL MURQABAT	56,080
125	REGA AL BUTEEN	4,058
126	ABU HAIL	31,857
127	HOR AL ANZ	62,846
128	AL KHBEESI	2,093
129	PORT SAEED	10,602
131	AL HAMRIYA PORT	341
132	AL WAHEDA	21,346
133	HOR AL ANZ EAST	19,078
134	AL MAMZER	12,577
	TOTAL	**454,043**
213	NAD SHAMMA	2,445
214	AL GARHOUD	14,889
215	UM RAMOOL	2,776
216	AL RASHIDIYA	40,575
221	DUBAI AIRPORT	0
226	AL TWAR FIRST	13,695
227	AL TWAR SECOND	6,474

228	AL TWAR THIRD	9,119
231	AL NAHDA FIRST	14,019
232	AL QUSAIS FIRST	44,494
233	AL QUSAIS SECOND	14,658
234	AL QUSAIS THIRD	6,945
241	AL NAHDA SECOND	21,532
242	AL QUSAIS IND. FIRST	5,251
243	AL QUSAIS IND. SECOND	5,727
244	MUHAISANAH THIRD	4,495
245	MUHAISANAH FOURTH	22,461
246	AL QUSAIS IND. THIRD	644
247	AL QUSAIS IND. FOURTH	1,664
248	AL QUSAIS IND FIFTH	37
251	MURDAF	33,583
252	MUSHRAIF	59
261	MUHAISANAH FIRST	6,935
262	AL MEZHAR FIRST	12,437
263	AL MEZHAR SECOND	9,231
264	MUHAISANAH SECOND	171,954
265	OUD AL MUTEEN FIRST	9,502
266	OUD AL MUTEEN SECOND	2,408
267	MUHAISANAH FIFTHMUHAISANAH FIFTH	0
268	OUD AL MUTEEN THIRD	3,663
271	WADI ALAMRADI	2,432
281	AL KHAWANEEJ ONE	4,877
282	AL KHAWANEEJ TWO	2,233
283	AL AYAS	1,134
284	AL TTAY	20

	TOTAL	**492,368**
301	JUMEIRA ISLAND ONE	0
311	AL SHANDAGA	5
312	AL SUQ AL KABEER	47,160
313	AL HAMRIYA	29,549
314	UM HURAIR FIRST	4,481
315	UM HURAIR SECOND	4,269
316	AL RAFFA	35,090
317	AL MANKHOOL	37,010
318	AL KARAMA	75,780
319	OUD METHA	10,853
321	MADINAT DUBAI AL MELAHEYAH (AL MINA)	8,900
322	AL HUDAIBA	10,275
323	AL JAFLIYA	20,000
324	AL KIFAF	0
325	ZAABEEL FIRST	2,339
326	AL JADAF	857
332	JUMEIRA FIRST	20,090
333	AL BADA	37,890
334	AL SATWA	39,990
335	TRADE CENTER FIRST	12,850
336	TRADE CENTER SECOND	9,038
337	ZAABEEL SECOND	4,349
342	JUMEIRA SECOND	9,693
343	AL WASL	16,200
345	BURJ KHALIFA	6,335
346	AL KALIJ AL TEJARI	7,535
347	AL MERKADH	3,051
352	JUMEIRA THIRD	13,023
353	AL SAFFA FIRST	8,886
354	AL GOZE FIRST	20,186
355	AL GOZE SECOND	1,669
356	UM SUQAIM FIRST	12,291

357	AL SAFFA SECOND	6,732
358	AL GOZE THIRD	30,561
359	AL GOZE FOURTH	11,523
362	UM SUQAIM SECOND	12,228
363	AL MANARA	7,012
364	AL GOZE IND. FIRST	23,808
365	AL GOZE IND. SECOND	113,619
366	UM SUQAIM THIRD	8,063
367	UM AL SHEIF	3,421
368	AL GOZE IND. THIRD	17,726
369	AL GOZE IND. FOURTH	29,434
372	AL SAFOUH FIRST	2,641
373	AL BARSHAA FIRST	9,351
375	AL BARSHAA THIRD	9,151
376	AL BAESHAA SECOND	8,437
381	NAKHLAT JUMEIRA	10,500
382	AL SOFOUH SECOND	4,769
383	AL THANYAH FIRST (V. RABIE SAHRA'A)	7,887
384	AL THANYAH SECOND (JEBEL ALI HORSE RACING)	115
388	AL THANYAH THIRD (EMIRATE HILLS SECOND)	6,754
392	MARSA DUBAI (AL MINA AL SEYAHI)	28,361
393	AL THANYAH FIFTH (EMIRATE HILLS FIRST)	16,815
394	AL THANYAH FOURTH (EMIRATE HILLS THIRD)	10,603
	TOTAL	**889,155**
412	AL KHEERAN	1,697
413	RAS AL KHOR	0

414	AL KHAIRAN FIRST	0
415	AL KHAIRAN SECOND	0
416	NAD AL HAMAR	12,983
421	AL WARQAA FIRST	4,100
422	AL WARQAA SECOND	6,273
423	AL WARQAA THIRD	4,943
424	AL WARQAA FOURTH	6,611
425	AL WARQAA FIFTH	0
431	WADI ALSHABAK	2
	TOTAL	**36,609**
501	NAKHLAT JABAL ALI	0
502	AL WAJEHAH AL BHARIYAH	0
511	HESSYAN FIRST	1,169
512	HESSYAN SECOND	0
513	SAIH SHUAIB 1	2
516	JABAL ALI INDUSTRIAL THIRD	500
518	JABAL ALI INDUSTRIAL SECOND	10,945
521	MADINAT AL MATAAR	14
531	SAIH SHUAIB 2	12,500
532	SAIH SHUAIB 3	7,066
533	SAIH SHUAIB 4	9,914
591	JABAL ALI FIRST	45,961
592	JABAL ALI SECOND	1,299
593	JABAL ALI THIRD	1,513
594	MENA JABAL ALI	31,318
597	DUBAI INVESTMENT PARK2	19,336
598	DUBAI INVESTMENT PARK1	45,063
599	JABAL ALI INDUSTRIAL FIRST	109,167
	TOTAL	**295,767**

611	BU KADRA	14
612	RAS AL KHOR IND. FIRST	690
613	RAS AL KHOR IND. SECOND	571
614	RAS AL KHOR IND. THIRD	14,310
615	NAD AL SHIBBA SECOND	1,684
616	NAD AL SHIBBA THIRD	11
617	NAD AL SHIBBA FOURTH	1,186
618	NAD AL SHIBBA FIRST	2,700
621	WARSAN FIRST	35,066
622	WARSAN SECOND	909
624	WARSAN FOURTH	980
626	NADD HESSA	8,915
631	HADAEQ SHEIKH MOHAMMED BIN RASHID	153
643	WADI AL SAFA 2	3,033
645	WADI AL SAFA 3	1,986
646	WADI AL SAFA 4	0
648	WADI AL SAFA 5	2,696
664	WADI AL SAFA 6 (ARABIAN RANCHES)	11,200
665	WADI AL SAFA 7	1,141
671	AL BARSHA SOUTH FIRST	5,451
672	AL BARSHA SOUTH SECOND	1,251
673	AL BARSHA SOUTH THIRD	578
674	AL HEBIAH FIRST	4,636
675	AL HEBIAH SECOND	1,835
676	AL HEBIAH THIRD	2,200
681	AL BARSHA SOUTH FOURTH	1,486
682	AL HEBIAH FOURTH	4,146
683	AL HEBIAH FIFTH	19

684	AL BARSHA SOUTH FIFTH	3,527
685	ME'AISEM FIRST	877
686	ME'AISEM SECOND	1,800
	TOTAL	**115,051**
711	AL AWEER ONE	2,348
721	AL AWEER TWO	3,477
724	ENKHALI	0
727	AL WOHOOSH	0
731	LEHBAB FIRST	2,288
735	AL MERYAL	2
736	NAZWAH	370
	TOTAL	**8,485**
811	WARSAN THIRD	9,466
812	AL ROWAIYAH FIRST	4,101
813	AL ROWAIYAH SECOND	6
814	AL ROWAIYAH THIRD	3,550
821	MEREIYEEL	12
824	UMM AL DAMAN	2
826	LE HEMAIRA	2
831	LEHBAB SECOND	1,132
835	UMM AL MO'MENEEN	3
841	MARGHAM	787
845	AL MAHA	14
847	UMM ESELAY	12
851	REMAH	5
857	MARGAB	447
861	YARAAH	10
891	HATTA	11,796
	TOTAL	**31,345**
911	UMM NAHAD FIRST	0
912	UMM NAHAD SECOND	0
913	UMM NAHAD THIRD	3
914	UMM NAHAD FOURTH	0
915	AL YUFRAH 1	2
916	AL YUFRAH 2	0
917	AL MARMOOM	972

921	AL YALAYIS 1	0
922	AL YALAYIS 2	2
923	AL YALAYIS 3	0
924	AL YALAYIS 4	12
925	AL YALAYIS 5	2
931	AL LESAILY	2,345
941	GRAYTEESAH	12
945	AL FAGAA'	345
951	SAIH AL SALAM	820
956	AL HATHMAH	0
961	AL SELAL	4
967	GHADEER BARASHY	2
971	SAIH AL DAHAL	2
975	AL O'SHOOSH	0
978	SAIH SHUA'ALAH	0
981	MUGATRAH	4
978	AL LAYAN 1	0
988	AL LAYAN 2	0
991	HEFAIR	0
	TOTAL	**4,527**

Appendix B

Table B: Dubai metro ridership during its 6 years of operation- Source: RTA, 2015

Year	Red Line	Green Line
2009	6,892,544	_
2010	38,887,718	_
2011	60,024,794	8,982,794
2012	71,914,902	37,576,839
2013	88,886,539	48,872,719
2014	104,018,269	60,288,811

Appendix C-1

Table C-1: Dubai metro ridership between 2015 and 2025

Source: Visum generated data

Year /Metro Lines	Red Line Ridership	Green Line Ridership	Total Ridership
2012	71,914,902	37,576,839	**109,491,741**
2013	88,886,539	48,872,719	**137,759,258**
2014	104,018,269	60,288,811	**164,307,080**
2015	110,240,587	72,379,154	**182,619,741**
2016	120,258,961	80,273,419	**200,532,380**
2017	131,128,001	88,505,080	**219,633,081**
2018	145,570,320	98,702,500	**244,272,820**
2019	162,009,851	109,627,183	**271,637,034**
2020	211,093,880	139,547,320	**350,641,200**
2021	273,020,098	181,002,400	**454,022,498**
2022	121,267,509	88,924,021	**210,191,530**
2023	130,000,987	88,257,021	**218,258,008**
2024	138,998,721	94,021,007	**233,019,728**
2025	143,302,503	99,529,743	**242,832,246**

Appendix C-2

Table C-1: Dubai Expo station ridership between 2019 and 2025

Source: Visum generated data

Year	Dubai Expo Station Ridership
2019	0
2020	71157637
2021	101527391
2022	759337
2023	989044
2024	1201031
2025	1287961