Social Behavioral Change for Sustainable Urban Transportation under TDM Concept: A Case Study of Istanbul

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This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science in Industrial and Systems Engineering.

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I, İrfan BATUR, declare that this thesis titled, 'Social Behavioral Change for Sustainable Urban Transportation under TDM Concept: A Case Study of Istanbul ' and the work presented in it are my own. I confirm that:

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Signed: İrfan

Date: 29 August 2014

"Yesterday I was clever, so I wanted to change the world. Today I am wise, so I am changing myself. "

Rumi

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Abstract

Increasing population in urban areas necessitates increasing levels of mix and modes of transportation, roads, land use, which all lead to pollution and waste of all sorts. Usually longer, wider and larger urban and interurban roads for motorized vehicles lead to further increases in number of cars with fewer, usually single, people in them, forming an unavoidable basis of an unsustainable society and mobility. In order to achieve sustainable cities and economies, in addition to smart use of land, intelligent transportation systems, clean and green vehicles, it is vital to achieve social behavioral change for shifting our modes of mobility from motorized means to cleaner, greener, healthier and more economic means such as walking, cycling, and public transportation. Economic, environmental, and social concerns about growth of traffic and congestion have caused several mega cities in the world and academics towards the investigations and introduction of different policies and measures in urban areas. Among many policy options, Travel Demand Management (TDM) policies mainly aim to promote the sustainable modes and to increase an effective use of existing infrastructure by voluntarily controlling the demand. With such circumstances, the objectives of this study are as follows: (1) to review existing academic, industrial, governmental and non-governmental literature to examine and understand various sustainable society, sustainable development, sustainable mobility concepts, mechanisms and policies developed and tested in other parts of the world; (2) to establish a framework of social behavioral change policies particularly developed and tested for urban mobility and traffic; (3) to compare various mega-cities on different indicators to better understand the case of Istanbul; (4) to evaluate potentials of TDM policies in Istanbul as well as to find out traffic congestion perception of the residents by conducting face-to-face surveys; (5) to determine current conditions of traffic congestion in Istanbul for the projections of traffic conditions in the coming years of 2018 and 2023, with the help of determined potentials from the survey results under different scenarios by using a micro simulation program PTV VISSIM. As a result of this study, it was revealed that the traffic conditions in Istanbul tend to become worse year by year, but it was also seen that the TDM policies offers noteworthy potential for increased use of sustainable mobility modes and to help significantly reducing congestion levels.

Keywords: Travel Demand Management, Social Change, Istanbul, PTV Vissim

YTY Konsepti Altında Sürdürülebilir Kent Ulaşımı İçin Sosyal Davranış Değişimi: İstanbul Vaka Çalışması

İrfan Batur

Öz

Kentlerdeki artan nüfus ulaşımın, karayollarının, toprak kullanımının ve her çeşit kirliliğin artışını da zorunlu kılmaktadır. Genellikle daha uzun, daha geniş ve daha büyük kent içi ve kentler arası karayolları, içerisinde birkaç kişi hatta çoğunlukla yalnız başına seyahat edilen araç sayısında artışa neden olmakta ve bu da sürdürülemez bir toplum ve mobiliteye temel oluşturabilmektedir. Akıllı toprak kullanımı, akıllı ulaşım sistemleri, temiz ve yeşil araçlara ek olarak sürdürülebilir kentlere ve ekonomilere ulaşabilmek için, ulaşımda kullandığımız motorize yöntemlerden ziyade yürüme, bisiklet, ve toplu taşıma gibi daha temiz, daha yeşil, daha sağlıklı ve daha ekonomik ulaşım yöntemlerine kaymak için sosyal davranış değişimi çok büyük önem arzetmektedir. Trafik sıkışıklığının gitgide artıyor olmasının neden olduğu ekonomik, çevresel ve sosyal kaygılar, dünyada bir çok şehri ve akademisyenleri farklı politika ve çözümlerin araştırılmasına ve bunların kentlerde uygulanmasına yöneltmiştir. Bu politika ve çözüm alternatifleri arasında, Yolculuk Talep Yönetimi (YTY) politikaları esas olarak, sürdürülebilir yöntemleri ve gönüllü olarak talebin kontrol edilmesiyle mevcut altyapının daha verimli kullanılmasını teşvik etmektedir. Bu çalışmanın amaçları şu şekildedir: (1) literatür taraması ile dünyanın muhtelif yerlerinde geliştirilmiş ve uygulanmış çeşitli sürdürülebilir toplum, sürdürülebilir gelişim, sürdürülebilir mobilite mekanizmalarının ve politikalarının incelenmesi ve anlaşılması; (2) özellikle kent mobilitesi ve trafiği için geliştirilmiş ve test edilmiş olan sosyal davranış değişimi politikaları için bir çerçeve belirlemek; (3) İstanbul vakasının daha iyi anlaşılması için farklı göstergeler kullanılarak muhtelif şehirler ile karşılaştırma yapmak; (4) YTY politikalarının İstanbul'da uygulanabilirliği potansiyelinin belirlenebilmesi ve şehir halkının trafik algısının öğrenilebilmesi için yüz yüze anket çalışması yapmak; (5) İstanbul'un mevcut trafik yoğunluğunun belirlenmesi ve PTV VISSIM mikro simülasyon programı kullanılarak anket sonuçlarının neticesine göre belirlenen potansiyeller ile farklı senaryolar altında İstanbul trafik yoğunlunun 2018 ve 2023 yılları için projeksiyonlarının yapılması. Bu çalışmanın sonucunda, İstanbul trafiğinin yıldan yıla daha kötü olma eğiliminde olduğu görülmektedir, ama YTY politikalarının sürdürülebilir mobilite kullanımının arttırılabilmesinde ve trafik yoğunluğunun azaltılabilmesinde kayda değer ölçüde potansiyele sahip olduğu da ayrıca görülmektedir.

Anahtar Sözcükler: Yolculuk Talep Yönetimi, Sosyal Değişim, İstanbul, PTV Vissim

This thesis is lovingly dedicated to my parents. Without their love, encouragement and endless support, this thesis would not have been possible.

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Chapter 1

Introduction

1.1 Background

Our ways of living are unsustainable. They have become associated with "over"; over-production, over-consumption, over-pollution, over-weight etc [34]. The impacts of our lifestyles are putting excessive pressure on our earth and are causing unfavorable environmental, economical, social and health-related effects. As we do not change our current lifestyles into much more environmental friendly modes, the projected growth in economy and population and the consequent waste and pollution will inevitably lead to environmental as well as social degradation. Thus, sustainability as a way of thinking, living and envisioning is necessary more than ever to contain the environmental and social devastation resulting from our actions.

1.1.1 Sustainability and Transportation

Sustainability is related to the quality of life and it requires all households – individual, community, national, and global – to live in to ensure our societies can continue to exist without destroying the environment. Development of cities, countries, and economies in a sustainable mode has vital importance in this direction. According to the report of Bruthland Commission of United Nations, the most widely known definition of Sustainable Development is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs [35]." In this perception, the use of own resources, resource efficiency, and recycling are becoming increasingly important.

Sustainable development is a broader concept. According to the Agenda 21 [36] – a non-binding, voluntarily implemented action plan of the United Nations with regard to sustainable development – sustainable development has different dimensions from social and economic dimensions to conservation and management of resources for development. Agenda 21 offers policies and programs to achieve a sustainable balance between consumption, population and the Earth's life-supporting capacity. These policies and programs are grouped in 40 chapters under sustainable development concept. Among those chapters, transportation is considered in the context of several chapters such as Chapter 7- Promoting sustainable human settlement development, Chapter 4- Changing Consumption Patterns, Chapter 6 - Human Health, and Chapter 9 - Protection of the atmosphere. As a result, it can be concluded that transportation is one of the critical components of sustainable development.

Beginning with the early human history, transportation has been one of the crucial elements of cities and countries. Without transportation there would have been neither trade nor development. In addition to transportation's economic role in allowing businesses to function, it also has an essential social role in linking societies, communities and social groups together. In contrast to positive effects, transportation also produces a variety of undesirable side-effects, many of which are harmful to the environment and health of living creatures including humans. These include air and water pollution, congestion, climate change, noise pollution, upstream and downstream pollution (vehicles production and end-of-life), accidents, costs of scarce infrastructure, and disturbance or destruction of habitats.

Besides the undesirable side-effects, transportation is also a major consumer of one of the most critical resources in the earth: energy, mainly oil-dependent. It is the largest end-use of energy in developed countries and the fastest growing one in most developing countries [37]. According to European Environment Agency [38], transportation has been the fastest-growing sector in the case of energy since last two decades and it is now the largest consumer of final end-use energy. In fact, transportation has been the only sector in which oil demand has been growing over the past thirty years. In addition to this, based on implementations of Agenda 21 policies and programs, it is noted that transportation is expected to be the major driving force behind a growing world demand for energy over the next two decades. This will, surely, put an ever increasing unsustainable pressure on natural resources as well as on environment.

On the basis of environmental impacts of energy usage such as air pollution, global warming, and oil pollution, decreasing energy-related pressures on the environment is becoming increasingly important. Undoubtedly, one way to reduce energy-related pressures on the environment is to use less energy. This can be provided by reducing the demand for energy-related activities, or by using energy more efficiently (thereby using less energy per unit of activity), or a combination of the two [39].

Energy efficiency offers a powerful and cost-effective solution for achieving a sustainable future. To illustrate, energy efficiency can reduce overall emissions, decrease fuel consumption, and diminish overall demand for energy while maintaining the same level of energy service to users. However, even with improvements in energy efficiency it is expected that global energy demand will be doubled by 2050 [40]. Therefore, the combination of energy efficiency and reduction in the demand for energy-related activities are required.

As being the major energy-related activity, it is expected that energy demand in the transportation sector will be increasing by 120% by 2050 in a baseline scenario [40]. This means that the global transportation sector will face unusual challenges related to continued growth in global economics, global population, urbanization, and motorization. The main driver of demand for energy usage is economic growth, namely the rate of GDP growth. Higher GDP growth means higher quality of life. Likely, as people's income increases, so does their demand for goods and services as well as energy. For future estimation, global GDP per capita is expected to grow by 187% to $24.400 by 2050 [40].

Another critical driver for energy usage is global population growth. It is clear that as much as population grows, the demand for travel will grow as well. The world's population is expected to grow by 0,9% per year averagely, from an estimated 6,9 billion in mid-2010, to 9,2 billion by 2050 [1]. As a result of this growth, energy usage will be increasing at about the same rate.

Urbanization is also very critical social and technological process affecting the need for energy efficiency and demand reduction for energy usage as urban areas being in the center of economic and population growth. Urbanization refers to a process in which large numbers of people moves permanently to live together in close proximity in urban areas sharing majority of facilities such as roads and other public areas and utilities. Urbanization happens because people move to urban areas in search of economic advantages, educational opportunities, better health care services and promise of jobs. The 20th century and 21th century are related to the phenomenon of rapid urbanization. There was very limited urbanization up until recently- about 200 years ago. At the beginning of industrialization era, the share of the world's population living in urban areas was just 3 percent. It has increased to 14 percent in 1900s and reached 30 percent by 1950. Nowadays, for the first time in human history, over half the world's population lives in urban areas and, this number is expected to increase to 60 percent by 2030 and it will reach to 70 percent by 2050 [41]. On the other hand, the difference between more developed regions and less developed regions is remarkable today which is 45 percent for less developed regions and 77 percent for more developed regions. However, it is expected that the difference of urbanization rate between more developed regions and less developed regions will not be significantly important. Basically, it is expected to be 65 percent for less developed regions and 85 percent for more developed regions (See Figure 1.1).

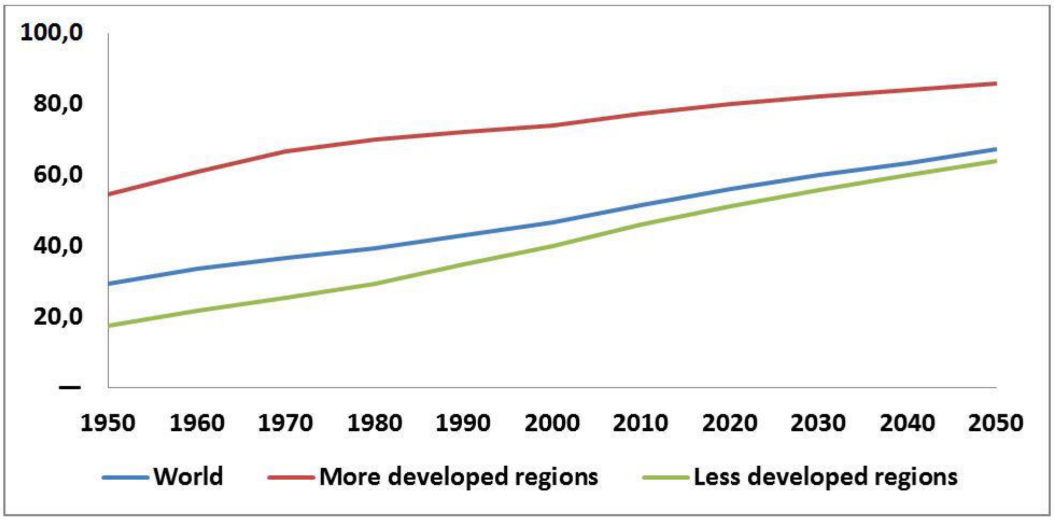

FIGURE 1.1: The percentage of urban population of the world [1]

Yet, urbanization is more than just the process leading to density. The rapid growth of urbanization causes harsh economical, ecological and social problems such as global warming, traffic congestion, climate change, energy inadequacy, and inequality, social unrest, scarcity of resources, unavailable education, and environmental degradation. To illustrate this, despite cities are built on just two percent of land's surface, they contribute to up to 70 percent of the total greenhouse gas emissions which is one of the major factors responsible for climate change [42]. It is also estimated that 70 percent of humanity will live in cities in 40 years, and will cause more than 90 percent of the world greenhouse gas emissions [43]. Therefore, dedicated and innovative solutions are extremely important in managing these and other difficulties as the world's urban areas swell. Some individuals try to escape these difficulties by moving away from urban areas which a process is called counter-urbanization. However, the ultimate solution must be to make cities equally distributed and sustainable.

Another catalyst for increased energy demand growth is motorization, which is most commonly defined as "the level of private car ownership" [44]. Motorization levels or car ownership in the world has increased by more than one third from 1980 to 2010 [45]. The high use of cars in urban areas has significant impacts in terms of accident, pollution, congestion, time and less physical activity which have severe consequences on the public health and well-being of societies. In urban areas the myth is that increasing travel demand will ever be satisfied by building more infrastructures. By satisfying this increasing travel demand and decreasing its impacts to our lives, it is important focusing on what changes to transportation and urban form to reduce energy consumption excluding building more infrastructure. In this multifaceted scenario, achieving an acceptable urban transportation model within sustainability concept is a complicated and challenging task. In the light of facts mentioned above, we will particularly focus on how this task can be accomplished in a sustainable way in the context of this study. Therefore, one particular part of this study concerns the role of sustainable urban transportation as major consumers of energy and generators of pollution, congestion, fatalities, etc. By doing this, we will research into how it has been handled in the past and how it is today in literature. As our case problem in this study, Istanbul, where we were born and live now, has been chosen.

1.1.2 Case Study: Istanbul

As a widely-used trade route, and the capital city of three empires, Istanbul has been an important central city of culture, trade, and knowledge, especially during the last two millennia; mainly due to its geo-political prominence. As the economic, financial and industrial center of modern Turkey, it is currently one of the largest cities in the world by population. The status quo of Istanbul in terms of population has been contributed by the historical and geopolitical importance of the city. This is mainly caused by the unique geographical position of Istanbul, and the economic and political benefits associated with it. First, Istanbul acts as a bridge between Europe and Asia, which places it on one of the shortest pathways between Asia and the Eastern and Central Europe for the purposes of trade. Istanbul's significance on the historic Silk Road is a historical example. Second, Istanbul had been the capital city of the several nations and states that possess vast amount of lands in both Europe and Asia, as in the Byzantine and Ottoman Empire examples. Third, Istanbul is considered as having religious importance for both Orthodox Christians and Muslims, which increased the cultural value of the city.

The traces of human settlements in Istanbul backs to 7th millennium B.C. [46], thanks to the archaeological findings discovered during the construction of a metro station in 2008. In the Anatolian side, the earliest settlement is from 6th millennium B.C. [47]. In 685 B.C., the city was colonized by Greek settlers, prior to Byzantium colonization. During the Late Roman period, the city was declared as the capital of the Roman Empire. After the partitioning of the Roman Empire in 395, Istanbul (Constantinople back then) became the capital of the Byzantine (Eastern Roman) Empire. At the beginning of 13th century, Istanbul was captured by western Europeans during the Fourth Crusade, and became a part of new Latin Empire until 1261, when Byzantines recaptured the city [48]. In 1453, Istanbul is annexed by Ottoman Empire, and became the capital city of Ottoman Empire until its collapse in 1923. The newly formed Turkish Republic has changed the capital city from Istanbul to Ankara, but the economic, cultural and historical significance of Istanbul has remained the same.

Population of Istanbul has experienced wide fluctuations during the Byzantine era, ranging from 400,000 in 500 C.E. and 500,000 in 6th and 7th C.E. [49] to under 50,000 by the time of the Ottoman Conquest [50]. After the conquest of Istanbul by the Ottomans, the population of Istanbul has increased dramatically, reaching 660,000 by 1550, being the most populated city after Beijing which had a population of 690,000 at that time [50]. However, the increase had largely ceased in the following centuries, resulting in a population around 1,000,000 in 1950, after a series of fluctuations between 1800 and 1950. Starting with the Democratic Party era (1950s), the uncontrolled mass urban immigration resulted in a dramatic increase in the population of Istanbul. At one point, population if Istanbul has almost doubled within a window of ten years during the military coup in the years between 1980 and 1990.

The immense rate of increase in population, contributed mainly by the mass urban immigration, increase in the life expectancy, and high fertility rates as well as by the decisions of policy-makers to expand the city and the relative economic stability, especially in the 1980s and 2000s, resulted in a population of 14 million by the year of 2014 [50]. Also, it is projected that the population of Istanbul will increase one million in every four-five years in the forthcoming decades. Figure 1.2 provides a visualization of the change of the population in Istanbul from 1950 to 2010 as well as of future projections till 2023. As a result, Istanbul has experienced an enormous growth in terms of population, recording a growth rate higher than anticipated in the last 30 years and it is expected that the trend in population growth tends to continue for foreseeable time.

In addition to aforementioned factors that are mostly based on historical and demographic visualization, nowadays, Istanbul is at the heart of Turkey from many perspectives. To illustrate, Istanbul is the economic and industrial center of Turkey and concentrates 27% of national GDP, 38% of total industrial output and more than 50% of services, and generates 40% of total national tax revenues [26]. Istanbul has half of total Turkish exports, which is impressive within a country with one of the highest trade-to-GDP ratios among OECD countries. It is, only by itself, processing 60% of the country's total trade volume [51]. On the other hand, Istanbul is one of the most important tourism spots not only in Turkey but also in the world. In 2012, Istanbul had almost 12 million visitors and they spent approximately 11 billion dollars which contributed the proportion of 37% of national tourism revenue [52]. In the light of these indicators, it can be concluded that Istanbul has a vital importance from many aspects for Turkey.

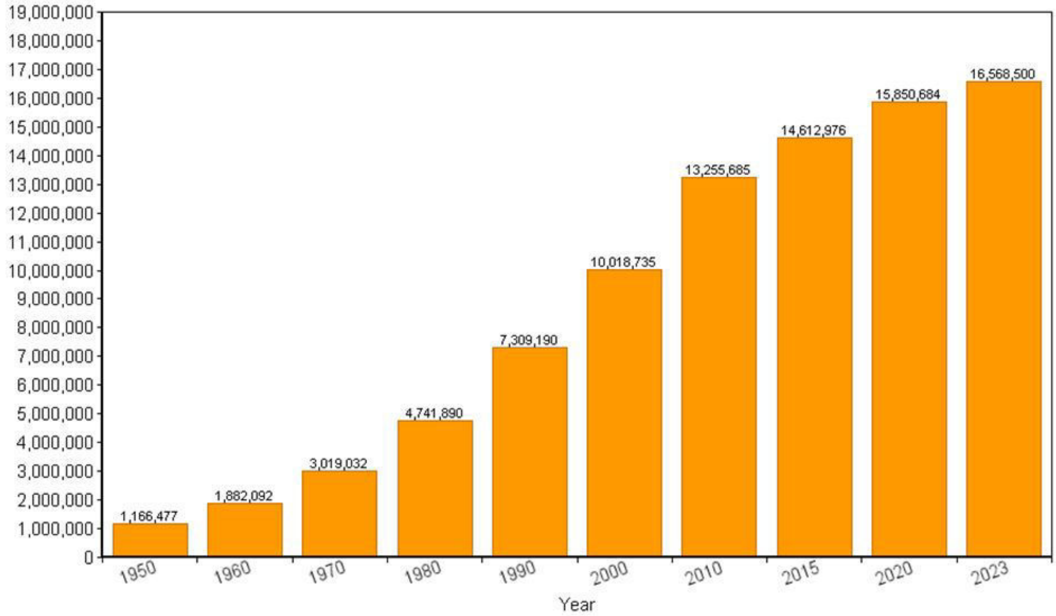

Figure 1.2: Population increase and projections in Istanbul from 1950 to 2023 [2]

The unharnessed growth of Istanbul in terms of population has led to infrastructural, environmental, social and economical problems. Some examples of these problems are air pollution, traffic congestion, lack of sufficient housing and environmental degradation. One of the more perceivable one among the aforementioned problems by the inhabitants of Istanbul is the traffic congestion.

Traffic congestion is a widespread and common problem in Istanbul. According to a survey undertaken as part of a research [53], participants have replied the question "What is the biggest problem in Istanbul?" as 'traffic congestion' by %31,3 and it is followed by 'population density' by %21,2 and 'security' by %14,7. Another survey as part of the Urban Age research has been undertaken to look at what residents really think about the quality of life in Istanbul [25]. According to that survey, participants were asked "What concerns you the most about the city?", the result is that %55 of participants think that it is 'traffic congestion'.

At last decade, the number of vehicles is almost tripled in Istanbul from approximately 1,2 million to 3,1 million while population has increased from 9,6 million to 13,4 million. In other words, traffic is growing three times faster than the population in Istanbul [13]. As a different illustration of the traffic congestion problem in Istanbul, Tom-Tom annual congestion index [54] – a navigation company releases annual congestion index report comparing congestion levels in between and initial year versus previous one in 161 cities across 5 continents every year– shows that Istanbul is the second most congested city with the congestion level of %55 in the world among the 161 cities after Moscow. In details, average delay per hour driven in Istanbul is 33 minutes in any day of the year while it is 16 minutes in London, 13 minutes in New York and 20 minutes in Los Angeles. Furthermore, the delay in Istanbul is 48 minutes in morning peak times and 75 minutes in evening peak times while the delay in morning peak times is 33 minutes in London, 21 minutes in New-York and 33 minutes in Los Angeles, similarly the delay in evening peak times is 33 minutes in London, 30 minutes in New York, and 46 minutes in Los Angeles.

In summary, Istanbul has faced uncontrollable growth at a higher rate than was anticipated in the last 30 years and this has resulted in unplanned urban settlements and chronicle traffic problems unlikely in other metropolitan regions, hence these have been sources of the motivation for this dissertation. In this manner, it is important to take a picture of Istanbul regarding traffic congestion and make comparisons with similar urban areas to find out the differences and similarities between cities. This can help to manage traffic growth in the city. Within this framework, the projections of future traffic congestion conditions of Istanbul is required for better decision making and finding appropriate successful approaches which has already been successful in other parts of the world.

1.2 Research Objectives

This research thesis aims to investigate chronicle traffic congestion problems of Istanbul within the concept of sustainability and then to focus on the questions: (1) how worse current traffic congestion levels would become in following years and (2) what possible solutions offer potential for contributing sustainable transportation in the city of Istanbul by alleviating congestion levels. Most studies on sustainable urban transportation generally focus on supply side and land use side of transportation more than demand side measures. Since supplying more roads makes driving more attractive, demand side measurements recently draw attentions by controlling demand and using existing infrastructure more efficiently. Additionally, the demand side measurements of urban transportation and short or medium term projections of traffic congestion levels were not studied sufficiently in Istanbul. Therefore, this research will be the first attempt to fill this research gap in sustainable urban transportation of Istanbul literature by considering the role and potential of travel demand management policies as well as with short and medium term projections of the traffic congestion levels in the city.

In this sense, the main objectives of this thesis are as follows:

1. Reviewing literature to examine and understand various sustainable society, sustainable development, sustainable mobility concepts, mechanisms and policies developed and tested in other parts of the world;

2. Establishing a framework of social behavioral change policies particularly developed and tested for urban mobility and traffic congestion;
3. Comparing various cities on different indicators to better understand the case of Istanbul;
4. Evaluating potentials of the selected policies in Istanbul as well as finding out traffic congestion perception of the residents by conducting face-to-face surveys;
5. Determining current conditions of traffic congestion in Istanbul for the projections of traffic conditions in respective years with the help of determined potentials from the survey results under different scenarios

1.3 Organization of the Research

The rest of the research is organized as follows. In the second chapter, a brief recap of sustainability, sustainable development, sustainable transportation, urbanization and motorization concepts are summarized as well as with transportation related problems in mega-cities. Then, urban transportation management and sustainable solutions for urban transportation are presented with details. Furthermore, as being our case study, Istanbul's analysis and comparisons with different cities were given in the same chapter. In the third chapter, the methodology of this current study is discussed. The methodology is divided into two parts; simulation and survey. The first part on Simulation, which is used to make short term and midterm projections for traffic congestion levels in Istanbul, were presented with the details of chosen simulation software, pilot district, data collection methods and modeling of the simulation. The second part on Survey consists of generation of questionnaire according to willingness of people for change and predicting potential of travel demand management measures. Additionally, calculating potentials of the measures and generation of scenarios with respect to willingness of people for change were described with details in the same part of the chapter. In the fourth chapter, results of survey is provided as representativeness of sample, traffic perceptions of the residents and overall of effects of TDM measures to decrease congestion levels under different scenarios. According to survey results, which are input for simulation modeling, projections of congestion in Istanbul in respective years is also been provided in the same chapter. Finally, research findings are summarized, and the future work is pointed out in the following conclusion chapter.

Chapter 2

Literature Review

2.1 Overview

To begin with a background analysis of this study, first, it is necessary to understand and define a framework of the general subject, which is "sustainability". In addition to presentation of various definitions of sustainability, in the first section, a discussion on the history and development of sustainability concept at a broad and commonly used sense will be included. Eventually, this discussion will narrow down to issues pertaining to sustainable transportation or mobility. Consequently, urbanization will be taken into account as one of the most serious facts and drivers of transportation problems. Final focus of literature review will be specifically on the field of sustainable urban transportation. Since one of the main foci of this thesis is the role of travel demand management policies as part of sustainable urban transportation will be brought in to understand people's travel behavioral patterns so as to identify existing policies and to develop new appropriate policies to change people's travel behavioral patterns towards more sustainable modes, and hence cities. In the last part, our case, city of Istanbul will be investigated towards motorization and transportation infrastructure and the city will also be compared in detail with various cities on different sustainable transportation related indicators to recognize positive and negative sides of Istanbul transportation and possible gaps in the management level.

2.2 Sustainable Development

Recently, the issue of sustainability is widely recognized by world leaders, social and physical scientist, development planners, business and finance sector, etc, and it is at the top of political agendas in all developed countries and almost in every developing country. Sustainable development is considered as a common problem and a serious topic of discussions at academia, education, media, and environmental organizations in many parts of the world.

Although, the term of sustainability was discussed first at the United Nations (UN) Conference on the Human Environment held in Stockholm in 1972 [55]; sustainable development was popularized in *Our Common Future* also known as the Bruthland Report, a report published by the World Commission on Environment and Development in 1987 [35]. The conference in Stockholm created a series of recommendations led to the establishment of the UN Environment Programme (UNEP) and various national environmental agencies as well as it has further led to elaborate sustainability at the Bruthland report. The most widely known and classic definition of sustainable development was taken place in the Bruthland report as follows:

> "Development that meets the needs of current generations without compromising the ability of future generations to meet their own needs"

This definition was the first effort to interlink environment and economic development as one single intertwined issue. Yet, it has become clear that this definition is too broad to be useful. Hence, the Bruthland report has paved the way for *1992 Rio Declaration on Environment and Development* and Agenda 21 [56]. The Rio declaration included 27 principles of sustainable development, which later known as Rio principles. Some of the prominent principles;

> Principle 1
> "Human beings are at the center of concerns for sustainable development. They are entitled to a healthy and productive life in harmony with nature." [56]
>
> Principle 8
> "To achieve sustainable development and a higher quality of life for all people, States should reduce and eliminate unsustainable patterns of production and consumption and promote appropriate demographic policies." [56]

Agenda 21, refers to 21st century, is considered as the first extensive action plan of the United Nations (UN) regarding sustainable development, which is non-binding and voluntarily implemented [57]. It is a 300-page document separated as 40 chapters, which are categorized into four groups. Agenda 21 indicates actions under these groups with regards to *Social and Economic Dimensions of Sustainable Development, Conservation* *and Management of Resources for Development, Strengthening the Role of Major Groups, and Means of Implementation [36].* Following a recommendation as part of Agenda 21, the Commission on Sustainable Development (CSD) was officially established by the UN General Assembly in December 1992, which has been considered as a milestone in sustainability era.

These both *Rio Declaration Environment and Development* and *Agenda 21* produced basic ideas for the global institutionalization of Sustainable Development on the twentieth anniversary of Stockholm Conference. By the participation and agreements of 179 countries, these gave rise to highly increases in public awareness towards sustainability. This declaration marks a significant step in the establishment of sustainable development priorities at the international level.

Since 1970s, an increasing number of international and national conferences regarding sustainability, sustainable development, sustainable urbanization, etc. have been held in many parts of the world, especially in developed countries. Prominent conferences among these are the follow-up conferences of the Rio Declaration after five, ten and twenty years. These are namely the 1997 Earth Summit+5 in New York, the 2002 Earth Summit + 10 in Johannesburg, and the 2012 Earth Summit +20 in Rio de Jenario [58]. These important UN-CSD meetings were primarily reviews of progress, and positive and negative implementation efforts after Rio Declaration and Agenda 21. These summits also resulted in a series of commitments, which prioritized certain targets. These included the following issues and targets [59]:

- *Elimination of poverty,*
- *Changes to consumption patterns and non-viable production,*
- *Protection and management of natural resources,*
- *Improving efficiency in resource use especially in energy,*
- *Ensuring that economic growth does not cause environmental pollution at a global and regional level.*

After all these remarkable efforts to build public awareness with regards to shaping our own future, the well-being of others, and the earth as natural boundaries; it has been widely agreed by majority that there is no alternative to sustainable development. By treating sustainability as a goal today, the quest for sustainability is already starting to transform the way we think more environmental-friendly about products, technologies, systems, and our lifestyles. Nowadays, everywhere we can see "green" practices such as shying away, if not banning, from using plastic bags, implementing carbon taxes, increasing use and awareness of recyclable products, hybrid cars, etc. However, the overall impact of these significant efforts towards sustainability is still small so that we have much more to go for a sustainable world.

2.3 Sustainable Transportation

A very basic way of defining transportation is movement of people and goods from one location to another. In the past, the economic wealth and development level of a nation is closely linked to the efficient methods of transportation. Transportation plays a vital role in the economic and social development of our communities. From economic perspective, all business operations are strongly dependent on transportation of their products, raw materials and people. Without transportation, all economies would stop. From social perspective, it has a significant impact on the lives of people by contributing to job creation and improving accessibility to social services and to one another.

Transportation is one of the major components of every national economy. It enables raw materials to be delivered to manufacturers who in turn deliver their outputs to their markets. Everyday transport systems carry millions of people to work and home again, enable millions of business trips to be made. It also contributes to the economy by providing millions of jobs. For example, in European Union (the EU), about ten million people are employed in transport sector, accounting for about 5% of total employment in the EU [60]. Briefly, transportation as a sector of economy moves people and goods, provides millions of jobs, generates high revenues, and consumes materials and services produced by other sectors. Transportation demand is closely connected to economic growth, measured broadly by Gross Domestic Product (GDP), which strongly depends on transport energy consumption. Figure 2.1 shows the results, which display growth of passengers and good transportation as well as growth of GDP from the year 1995 to 2010 in the 27 European Union Countries [3]. It is clear that the GDP growth rate closely follows growth of transportation.

Access to basic human needs such as emergency services, public services, health care, basic food and clothing, education services, etc. is an essential part of individual and social well-being. Many researchers agree that there is a strong relationship between people's accessibility and their mobility to their social welfare [61]. In fact, freedom of movement and accessibility are also considered as a basic human right [62]. Another important fact for quality of life is easy access to family, friends, and community. Without transportation, being physically contacted to family, relatives, and friends would be

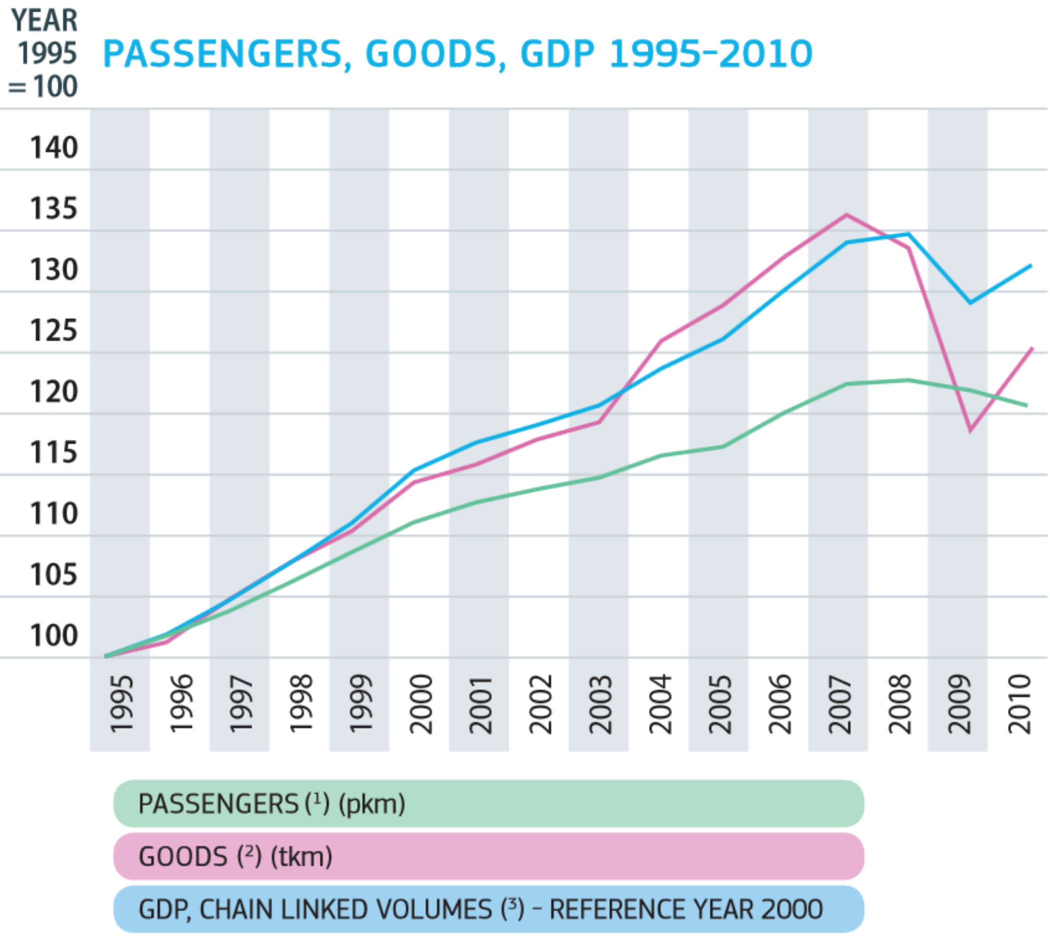

FIGURE 2.1: Growth of passengers and goods transportation & GDP of 27 EU countries between 1995-2010 [3]

extremely difficult. To provide such basic human rights, efficient transportation systems become very essential for every society.

The transportation sector plays a very critical role in not only economic growth and social well-being, but also environment. Transportation sector causes many critical environmental impacts such as climate change, air quality, land degradation and depending on finite resources. According to United Nations Economic Commission for Europe [63], Transportation sector is highly dependent on finite resources (%96 from petroleum products), which currently cause %30 of CO_2 emissions in developed countries and %23 of CO_2 emissions in the case of the total man-made CO_2 emissions worldwide. Emission is one of the main causes of climate change that puts the earth and human lives in danger. Transport related emissions contain various hazardous chemicals and particulates worsen the air quality, which is damaging the human health. Transportation sector is the main reason for noise pollution, and additionally, because of transportation's requirement of high percentage of open space for its infrastructure, it causes environmental degradation hampering the lives and continuity of animals and plants. Moreover, oil spills and vehicle disposal as part of transportation industry causes water and land pollution. Elimination of these impacts of transportation sector are vital to environment.

Although transportation is one of the most important human activities with economical, social, and environmental vitality, current transportation systems and methods are not sustainable because of its huge pressure on environment and health of creatures. Therefore, it is imperative to find a balance between social welfare, environment, and economic development. Sustainable transportation concepts as a human development issue arise at this critical juncture. From this perspective, sustainable transportation is the implementation of sustainable development concepts into transportation systems. Although there is not just one definition of sustainable transportation, the most common definitions can be summarized as follows:

> "Sustainable transportation is achieved when needs for access to people, services, and goods are met without producing permanent harm to the global environment, damage to local environments, and social inequity." [64]

> "The goal of sustainable transportation is to ensure that environment; social and economic considerations are factored into decisions affecting transportation activity." [65]

> "Sustainable transport system as one that provides transport and mobility with renewable fuels while minimizing emissions detrimental to the local and global environment, and preventing needless fatalities, injuries, and congestion." [66]

These definitions are supporting the idea that current transportation systems particularly automobile dependent transportation is not sustainable because it mostly uses petroleum reserves, which are finite, it puts pressure on environment by polluting air, water and land, and it also causes high fatalities and congestion. In this perspective, there has been a need for sustainable transportation systems that can provide needed mobility without the negative impacts on environment and human health.

2.4 Urbanization and Motorization

2.4.1 Urbanization

> "The city is a place where a lot of problems are concentrated; but the city also has the resources to overcome these problems and be the place of development" Prof. Valentino Castellini, Italy, 1998.

Urbanization refers to a process in which large numbers of people moves permanently to live in urban areas. The 20th century and 21th century are related to the phenomenon of rapid urbanization. As urbanization has been steadily increasing in recent decades, it is now near at the top of agendas for every country. According to United Nations Population Division [5], a major historical demographic milestone has been marked in 2007 when, for the first time in human history, the earth became more urban populated than rural area, which means urban areas became the dominant habitat for humankind (See Figure 2.2). According to latest projections of United Nations [4, 5], it is estimated that a further approximately one billion people will be urbanized by 2020 and it is also indicated from the projections that 60% of the world's population will be urbanized by 2030 and 70% by 2050. This rapid urbanization shift has tremendous impacts on the current and future dynamics of human, social, economic development as well as on the environment and earth.

Urban areas have been always dynamic and growth centers of social life, literature, arts, education, industry, finance, commerce and trade, social services, and government. That is the main reason for urban areas (cities, metropolis) to be more efficient than rural or smaller places in the sense of production, economic development, and contributing to higher standard lives. Rush to the urban areas especially in the developing world for the benefits and promises of jobs, high wages, educational opportunities, better health services etc. have created massive mega-cities, which are generally defined as concentrations of urban populations with over 10 million inhabitants. There are now about 500 cities in the world with over one-million population. Of these, as depicted in Figure 2.3, 23 are mega-cities with populations more than 10 million compared to 2 mega-cities in 1950s, and it is expected that this number will rise to 27 by 2020 [67]. Over half of this rise in mega-cities has been in developing world as it is expected that the proportion of developing world will be increased further both for cities over one million population and mega-cities.

This enormously rapid growth of urban areas and population causes severe economic, social, and more importantly ecological problems that are difficult to measure, predict, and hence, to manage. The problems of urban areas are generally considered as local but

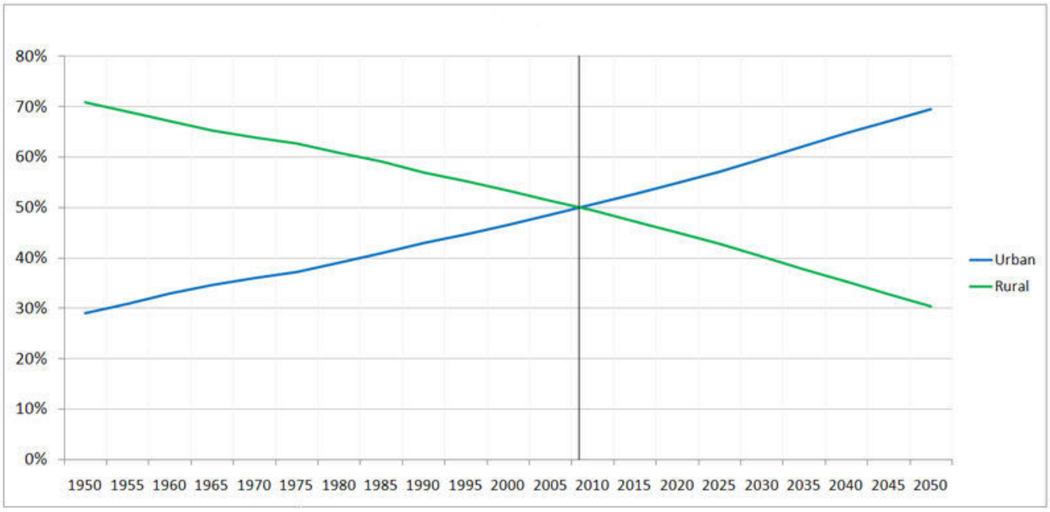

FIGURE 2.2: Percentage of world population [4]

Population of Mega-Cities with 10 Million Inhabitants or More, 1950, 1975, 2000, 2015

(All populations in Millions; estimated population for 2015)

1950	1975	2000	2015
New York, USA **(12.3)**	Tokyo, Japan **(26.6)**	Tokyo, Japan **(34.4)**	Tokyo, Japan **(35.5)**
Tokyo, Japan **(11.3)**	New York, USA **(15.9)**	Mexico City, Mexico **(18.1)**	Mumbai, India **(21.9)**
	Mexico City, Mexico **(10.7)**	New York, USA **(17.8)**	Mexico City, Mexico **(21.6)**
		Sao Paulo, Brazil **(17.1)**	Sao Paulo, Brazil **(20.5)**
		Mumbai, India **(16.1)**	New York, USA **(19.1)**
		Shanghai, China **(13.2)**	Delhi, India **(18.6)**
		Kolkata, India **(13.1)**	Shanghai, China **(17.2)**
		Delhi, India **(12.4)**	Kolkata, India **(17.0)**
		Buenos Aires, Argentina **(11.8)**	Dhaka, Bangladesh **(16.8)**
		Los Angeles, USA **(11.8)**	Jakarta, Indonesia **(16.8)**
		Osaka, Japan **(11.2)**	Lagos, Nigeria **(16.1)**
		Jakarta, Indonesia **(11.1)**	Karachi, Pakistan **(15.2)**
		Rio de Janeiro, Brazil **(10.8)**	Buenos Aires, Argentina **(13.4)**
		Cairo, Egypt **(10.4)**	Cairo, Egypt **(13.1)**
		Dhaka, Bangladesh **(10.2)**	Los Angeles, USA **(13.1)**
		Moscow, Russia **(10.1)**	Manila, Philippines **(12.9)**
		Karachi, Pakistan **(10.0)**	Beijing, China **(12.9)**
		Manila, Philippines **(10.0)**	Rio de Janeiro, Brazil **(12.8)**
			Osaka, Japan **(11.3)**
			Istanbul, Turkey **(11.2)**
			Moscow, Russia **(11.0)**
			Guangzhou, China **(10.4)**

Source: United Nations, Department of Economic and Social Affairs, Population Division (2006)

FIGURE 2.3: Population of mega-cities with 10 million inhabitants or more in different years [5]

they have become critical and multifaceted problems at global dimension, mainly, due to the fact that they generate inequality both within and with outside. For instance, despite urban centers are built on just two percent of the Earth's surface, their population uses around 75% of the world's resources and similarly discharging same amounts of wastes [68]. Another important fact is that these 23 mega-cities consume approximately 80% of the world's energy and generates similar amount of greenhouse gas emissions worldwide

[69]. These remarkable facts of unequal concentration show that sustainable development cannot be reached without addressing the issues of sustainable urban development. The management of these urban centers, especially mega-cities, providing basic social services, education, mobility, job opportunities, and a livable habitat to their residents in an economically, socially, and environmentally sustainable manner has become a major challenge in this century.

2.4.2 Motorization

The term motorization under the transportation field has various definitions with regards to its intended purposes of use. Generally speaking, it has two common definitions; (1) it refers to the general level of mechanization in transport in its broadest sense, and (2) it refers to the level of private car ownership in its narrowest sense [44]. In this dissertation, the second definition of motorization will be used. From this angle, motorization's historical background and present values, its social economic and environmental impacts on our life, its causes and finally motorization-related problems, especially in mega-cities, will be examined.

According to historians and sociologists, the 20th century has been described as the century of the automobile, our society as an automobile society, our age as the age of automobile [70]. Without doubt, there are other inventions and discoveries that shaped the 20th century such as telecommunication, globalization, etc., however, hardly any other reshaped where we live, where we work, how we live, how we interact socially, etc. or contributed economic welfare, or caused ecological destruction as automobile did. Before automobile, walking was the primary means of urban transportation, railways was the primary means of intercity transportation, and the transportation of goods was mainly dependent on horsepower. Therefore, people both lived in the city and worked in the city, or lived in the country and worked in the country. After the invention and rapid spread of automobile, it enabled people to live in the outskirts of cities and work in the cities, which resulted in the growth of suburbs and cities later on. Automobile has also created new jobs for the world's growing population such as highway constructions, production of automobile, state traffic policies, gas stations, auto shops, auto repair shops etc.

Furthermore, motorization has not only played a role as a catalyst for economic growth because of automobile sector through both consumption and production, but also has been an outcome of economic and technological development of a nation. At the beginning of the automobile era, cars were toys for rich people, but later on as it become affordable due to Fordist developments, its popularity increased rapidly among the public because it enabled people to travel whenever and wherever they want to. Nowadays, it is a trademark of industrialized and developed nations, and it is closely related to wealth of nations. Table 2.1 comparatively tabulates the entirely-motorized 26 nations, World, European Union and Turkey motorization levels, as well as their car ownership rates per 1000 people and GDP per capita. These 26 nations have 67% of world vehicle fleet, 53% of world's total GDP, but less than 8 percent of world's population [18, 19]. Out of these, 23 countries are western or westernized countries and all can be described as wealthy nations based on their GDP rates. At the same time, these countries have the most motorization rates. For example, the United Kingdom (UK) has 518 motor vehicles per 1000 people and $35,455 GDP per capita while the world average is 168 motor vehicles per 1000 people and $8,655 GDP per capita. On the other side, as some developing countries close the gap with developed countries with respect to GDP per capita, they are also rapidly approaching to high motorization rates. For example in Beijing, the number of private cars fleet has swiftly increased from approximately 120,000 in 1995 to 1 million in 2001, 1,5 million in 2004, and around 2,3 million in 2008 [71]. This trend can be seen in almost all developing countries like India, Mexico, Turkey, Indonesia etc.

Economic growth and urbanization has been strongly associated with motorization [72]. Economic growth increases demand for transporting goods and people and it also triggers urbanization to take advantage of economies of scale and supplies required workforce [73]. Accordingly, people tend to own a car when their income increases. There are also personal catalysts for increased motorization levels other than rapid pace of urbanization and improved economic power. One of them is that car is the symbol of social status. With car, one wears his/her status on the road thorough the brand and type or you have the status of whether owning a car or not. Another is that cars offer people more rapid, flexible, comfortable, personalized, and reliable mobility compared to other modes of transport. Therefore one can go anywhere anytime he/she desires and whether it is winter or summer time with companions or alone. These can be said as the main causes of increased motorization levels.

Despite various advantages of motorization such as better accessibility in terms of commercial, public, and private transportation, and improved social well-being as a result of increased mobility, flexibility, and reliability; increased motorization levels have many negative effects in the sense of sustainability of our world, public health, and social well-being, etc. These negative effects are mainly congestion, air pollution, climate change, noise, and land-destruction, which are most apparent in mega-cities especially in the developing world. For example, city center or downtown weekday travel speed average is 10 km per hour or less in Bangkok, Mexico City and Shanghai which leads to loss, if not lack, of life quality; waste of time, energy and wealth; public health problems due to polluted air and noise etc [74]. This situation is not special to these cities, it is almost

Table 2.1: Most entirely motorized nations in 2009 and their indicator of GDP per capita ($) [18, 19]

Country	**Motor Vehicles Per 1000 People**	**GDP Per Capita**
United States	803	46.999
Liechtenstein	803	134.617
Iceland	748	38.039
Luxembourg	739	99.282
New-Zealand	718	27.562
Australia	691	42.722
Malta	681	19.636
Italy	672	35.724
Canada	608	40.764
Spain	592	31.368
Japan	590	39.473
France	578	40.488
Norway	578	78.457
Greece	573	28.695
Austria	569	45.872
Slovenia	567	24.051
Germany	564	40.270
Switzerland	562	65.790
Lithuania	555	11.649
Belgium	551	43.834
Cyprus	539	29.428
Finland	532	44.838
Netherlands	523	48.174
Kuwait	523	37.161
Sweden	519	43.640
United Kingdom	518	35.455
World	168	8.655
European Union	540	32.598
Turkey	148	8.626

same in every mega-city throughout the world and it seems that it will continue for a long time.

2.5 Transportation Related Problems in Mega-cities

2.5.1 Congestion

Traffic congestion is probably the most visible, most pervasive, and most immediate chronicle problem of mega-cities among the problems caused by rapidly increasing urbanization and motorization rates. In general sense, traffic congestion occurs when the number of vehicles attempting to use a network or a network element (e.g. road, intersection) exceeds capacity or ability of the infrastructure to carry the load [75, 76]. Congestion may occur from variety of situations which either create or increase congestion such as high traffic densities, temporary reductions in normal road etc. These situations can be classified as two basic types; (1) recurring congestion, and (2) non-recurring congestion [75].

Recurring congestion is defined as congestion caused by routine traffic volumes operating in a typical environment [77]. Recurrent congestion generally occurs at the same place and same time interval due to excessive traffic volumes (due to high traffic demand). To illustrate this, it is expected to be more congested in urban free ways during weekdays at commuting periods (peak times) than during the middle of the day. Similarly, more congestion is expected during middle of the day than at night. While, non-recurring congestion is defined as unexpected or unusual congestion caused by an event that was unexpected and transient relative to other similar days [77]. It may result from variety of factors such as lane blocking accidents and disabled vehicles, construction lane closures, inclement weather, concerts and sport meetings.

It has many negative impacts on economy, social life, and environment. It slows down even daily business activities by causing delays, late arrival of employment, meetings, goods, etc., and also decreases the reliability of expected travel times which is critical at planning stage for both personal and business activities [78]. As a non-productive activity for most people and businesses, therefore, congestion leads to unaccountable amount of waste of time, energy and opportunity for motorists, passengers and all related people. Furthermore, due to unnecessarily increased levels and frequency of idling, acceleration and breaking, traffic congestion increases air pollution and carbon dioxide emissions from environmental perspective, and it also increases frequency of repairs and replacements on automobiles leading to secondary type of unaccounted negative impact on economy [79, 80]. In addition, it is also harmful to motorists and passengers' health by increased stresses, and lack of exercise, which can lead serious health problems [81]. Another critical impact of traffic congestion occurs in case of emergency situations, congestion delays, if not prevents, emergency vehicles to reach their destinations at the required time and routes leading to serious fatal results. Finally, any attempt to control and alleviate congestion effects in mega-cities contributes to sustainability of cities from many perspectives [82, 83].

Table 2.2: Transportation % contribution to local air pollutants [20, 21]

City	CO	Volatile Organic Compounds	NO	SO_2	Particles
Beijing	39	75	46	-	-
Budapest	81	75	57	12	-
Delhi	90	85	59	13	37
Istanbul	69	-	89	1	20
Lagos	91	20	62	27	69
Mexico City	100	54	70	27	4
Sao Paulo	97	89	96	86	42
OECD	70	31	52	4	14

2.5.2 Air Pollution

By far, the most critical environmental impact of urban transportation is air pollution. United Nations Environmental Program (UNEP) and the World Health Organization (WHO) have conducted an urban air quality program to point out the issue of air pollution in urban areas for more than 30 years [84]. According to results of this program, mega-cities all have serious air pollution problems [84]. Transport related emissions, which include air pollutants particularly nitrogen oxides, particles, carbon monoxide, sulfur dioxide and hydrocarbons all have a damaging impact on the health of individuals, animals and vegetation, significantly contribute to this problem. For example, according to a study conducted by European Environment Agency [85], the contribution of the transport sector to nitrogen oxides (NO_x) pollution is 58% while the rest 42% is from non-transport activities. According to the same study, transportation sector in 32 European Union countries contributes to primary particles by around 25%, to carbon monoxide by 30%, to sulfur dioxide by 21%, and to hydrocarbons by 18%. These pollutants causes millions of people die or suffer serious health effects every year. According to World Health Organization [86], an estimated 4 million people die because of respiratory diseases, asthma, chronic obstructive pulmonary disease, cardiovascular disease and cancer of the lung, which are mainly caused by air pollution, and there is only one way to stop these illnesses and deaths: clean up the air and stop polluting it further. Not only air pollution is damaging to human health, but also it is threatening economic and social welfare by damaging plant and animal life and contaminating water sources. Table 2.2 shows some big cities suffering from serious air pollution and contribution of transportation to local air pollutants.

2.5.3 Climate Change

Climate change by global warming, which is mainly caused by the greenhouse gases (GHG), is considered as one of the most serious threats to the earth, humankind and environment for the next generations. Emissions of the greenhouse gases are directly related to fuel consumption. Due to having the largest proportion of the fuel consumption, transportation sector is largely responsible for the pollution as it contributes with the three of the greenhouse gases: carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (NO). According to International Energy Agency [87], transportation activities accounts 43% of global emissions in 2010. For example, in 25 European Union countries, transportation accounts for approximately 32% of total energy consumption, and resulting in a 30% net increase of greenhouse-gas emissions [60]. Transportation is also the fastest growing source of CO_2 emissions, which is considered as the main contributor for climate change. For example in the U.S., the transportation sector fuel consumption is 67% of total national petroleum usage, and it accounts 32% CO_2, and this percentage will rise to 35-40% by the year 2020 [88, 89]. If no intervention takes place, global CO_2 emissions from transportation are projected to increase more than threefold by 2030 compared to the levels of 1990 [90]. Hence, to reduce the greenhouse gases emissions, an international agreement has been made between almost every country under United Nations, which is known as Kyoto Protocol. All parties of the agreement have accepted the binding GHG emissions reduction targets to reach back to 1990 emissions levels, and it is clear that transportation plays a critical role to accomplish these targets.

The most important threat of rapid urbanization and motorization may be global climate change. World greenhouse gas emissions, one of the major factors responsible for climate change, have increased 70% between 1970 and 2004 [91]. Much of the increase is due to growth in the sectors of energy (+145%), transportation (+120%) and industry (+65%) and to the reduction of forest land and land use changes (40%) [91]. Therefore, any attempt to reduce transportation related problems will be helpful to alleviate climate change effects.

2.5.4 Noise

Transportation related noise particularly from road vehicles is another serious environmental and health problem in many mega-cities. Noise is known as one of the most annoying urban problems. Sources of noise from transportation include engine noise, tire noise, car horns, car stereos, and squeaking breaks. Noise at urban areas disturbs sleep, hinders work, impedes learning, disrupts activities, and most importantly causes stress. According to World Health Organization[92], noise not only causes serious annoyance and sleep nuisance but also it causes communication problems, and even learning problems in children. The proportion of the population exposed to high noise levels (equivalent to 55-65 dBLAeq over 24 hour) leading to serious annoyance and health problems is estimated about 65% in European region [92]. Despite technological progress to reduce noise at source such as vehicle engines, it is expected that noise levels will continue to grow due to rapidly increasing motorization and urbanization rates, which causes ever-increasing volumes of traffic.

2.5.5 Land Use

Transportation is also a great consumer of space at urban areas when all of its infrastructure (roads, parking spaces, sidewalks etc.) and supporting facilities (petrol stations, terminals etc.) are considered. Land use is a key issue from two sides; it enables transportation activities from one side, and on the other side, it is a contributor to environmental stress. Before automobile era, proportion of transportation land consumption at urban areas was about 10%, however, this proportion has increased to around to between 30% to %60 at urban areas at present times [93]. In an entirely motorized urban area, if 30% of lands are used for roads, another approximately 20% is required for off-street parking. However, sidewalks devoted to pedestrians is just between 10% and 20% of a road's right of way [93]. In urban areas where land is limited, it is very critical to use the land efficiently, finding the balance for the trade-offs between transportation infrastructure for automobiles, bicycles, and pedestrian facilities.

2.6 Sustainable Solutions for Urban Transportation

On one hand, there are growing needs for mobility in urban areas, however, on the other hand, to meet these needs with conventional solutions put pressures on sustainability of urban areas. Therefore, managing transportation needs in urban areas, or shortly as urban mobility, still remains as one of the toughest problem to tackle in the coming decades. There are various measurements available worldwide for any transportation management programs to meet transportation needs of an area such as building new roads, transit facilities, or managing demand, or increasing access conditions. Meyer has properly categorized these measures into three groups include supply management, land use management, and demand management as illustrated in Figure 2.4. Instead of developing and implementing measures from single category, applying a coordinated program including a combination of measures from three groups is necessary as a formidable solution to address long-term transportation problems of urban areas, particularly of mega-cities [94].

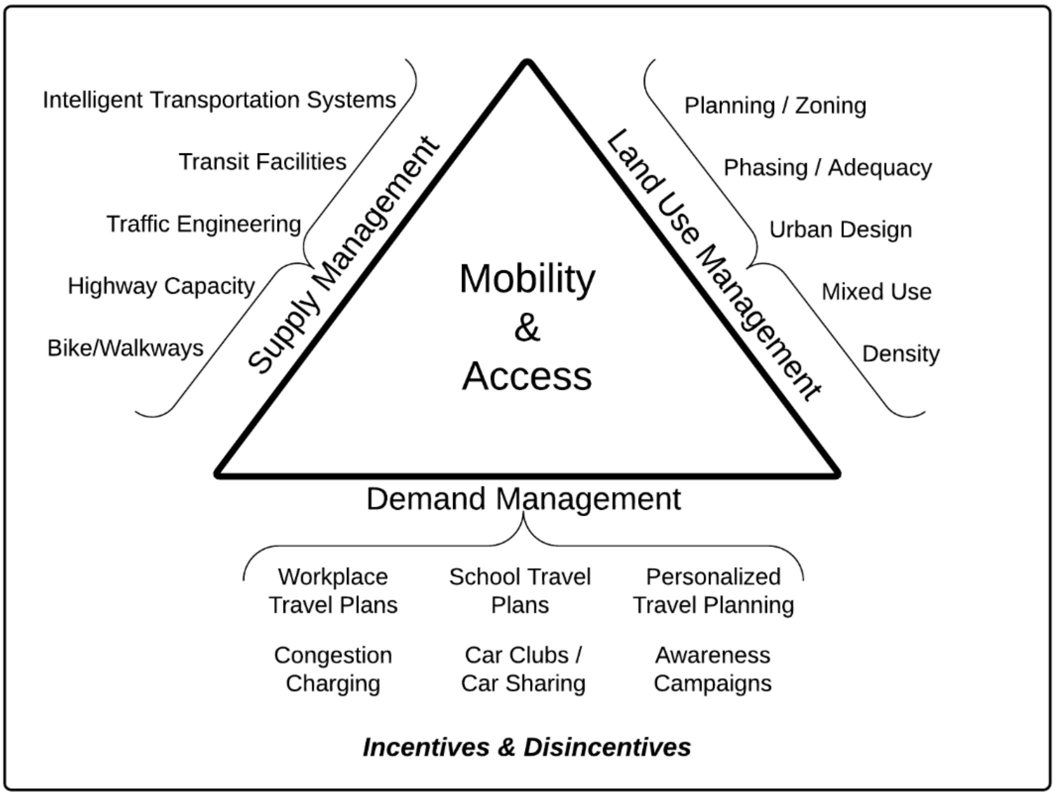

FIGURE 2.4: Elements of Mobility and Access Management (reproduced) [6])

Of the three groups, supply management measures and strategies are the most common response policy makers and city managements have taken to come up with solutions for traffic related problems simply by supplying more. Supply management methods such as widening of existing roads, building new highways and transit facilities aim to increase the capacity of transportation infrastructure to meet the growth of traffic and transportation needs. These kind of management policies are useful since it reduces most of the traffic related problems especially traffic congestion. To reduce air pollution and climate change problems, technological solutions are also very effective as they provide more fuel efficient, cleaner engines or near-zero-emission engines or new forms of road surfaces to reduce the level of traffic noise and friction related energy losses. However, these supply side measures, both building more and technology side improvements, are only effective in short-term requiring expensive investments and, in fact, generating further transportation, social and economic related problems, and they are not be able to meet long-term sustainable urban mobility goals. Because it has been realized that the added road capacity makes driving more attractive, thus it increases demand to use the roads leading to further traffic related problems again [95–97]. Also, improvements of at least 50% in technology side are needed to keep up with current congestion levels in order to cope with 178,000 cars are entering into the traffic every day [98]. There are also other obstacles in supply side policies, particularly in heavily urbanized areas, the construction of these actions can be costly, face with strong opposition, and takes a long time to complete. Sometimes, it is even infeasible to do these actions because of limited spaces especially in old towns and island towns. For example, Singapore is small island city nation where land is limited and precious which is requiring very careful use and allocation. Thus, it is not always feasible to add or widen roads in old towns and small areas with high population densities.

2.6.1 Land-Use Management

Land use means simply how the land is used, in other words, what human activities are conducted and what location is allowed for constructions. From the perspective of transportation management, knowledge of the geographical settlement patterns of social and economic activities is crucial at planning stage of transportation policies. To put simply, trip-making patterns, volumes, frequency and modal distributions are simply related to spatial distribution and use of land. It has the answers for supply management questions: how much, what type and where to supply when increasing transportation capacity of a city. It is also critical for demand management when exercising control over the trip generating characteristics of the land use in an area to use for providing the resultant demand being consistent with the existing transportation infrastructure and the desired level of service.

To illustrate this, there is a study conducted in the UK by Social Exclusion Unit (SEU) 'collated a wide body of research evidence to demonstrate that transport and land-use policies in the UK have interactively worked to systematically create and reinforce social exclusion'[99]. This study identified that transportation is a significant barrier for various important services and human activities such as health-care, education, food shopping etc. The report finds out that these problems occurred due to lack of adequate transportation supply and the location of these services. These main problems related to accessibility limitations are summarized as follows:

Access to health-care: 31% of people without a car have difficulties travelling to their local hospital, compared to 17% of people with a car. Over 1.4 million people say they have missed, turned down, or chosen not to seek medical help over the last 12 months because of transport problems.

Access to food shops: 16% of people without cars find access to supermarkets difficult, compared to 6% of the population as a whole.

Access to work: Two out of five job-seekers say lack of transportation is a barrier to finding a job.

Access to social, cultural, and sporting activities: 18% of people without a car find seeing friends and family difficult because of transportation problems, compared with 8% for car owners. People without cars are also twice as likely to find it difficult getting to leisure centers.

The land-use management is fundamental to achieving various national and local objectives other than transportation purposes [100]. However, without the proper planning and management of land-use, whatever actions both supply-side and demand-side are taken will be just effective in short-term to reduce transportation problems in mega-cities. Therefore, even if a city has the best supply and demand management policies, to achieve desired effectiveness and sustainability goals it needs to be coordinated with the existing and planned land-use policies [6].

2.6.2 Travel Demand Management

As discussed in previous sections of this study, automobile use has been steadily increasing at a growing rate during the past few decades. In addition, the number of passenger kilometers by private car per capita has been increasing due to aggressive growing of cities and consequently longer, more frequent working and personal trips. On the other hand, the average number of passengers traveling in the same car has been decreasing at the same time. As a result, problems related to this uncontrollable growth such as congestion, air pollution, noise, traffic accidents are continuing to rise. Besides, vehicles take up much space in urban areas, which narrow down people's living spaces. For example, many streets, which are assumed to be a habitat for many activities, are captured by traffic along with its associated problems. As discussed above, many strategies have been proposed to overcome these problems. To arrive at a more sustainable urban transportation system in the future, however, cleaner fuels and reduced car use will be necessary [101]. Technological solutions are effective at reducing the impact per vehicle and per kilometer. However, the mitigating effects of new technological solutions are not expected to keep up with the increasing growth of mobility and accessibility needs and use of various vehicle use [102]. Reduced car usage strategies are aimed at influencing people to change their behaviors to more sustainable transportation modes to improve quality of urban life. Such behavioral change strategies are known as Travel Demand Management (TDM) policies [103].

Travel Demand Management (TDM) was defined by Meyer as "any action or set of actions intended to influence the intensity, timing, and spatial distribution of transportation for the purpose of reducing the impact of traffic" [6]. In other respects, the primary objective of TDM policies was explained by Dorsey as "to reduce the number of private vehicle trips while providing a wide variety of mobility options to those who wish to travel." [103]. TDM includes a broad set of policies designed to increase the attractiveness of sustainable transportation modes including walking, cycling and public transportation as alternatives to travel by automobile. In other words, TDM policies aim to maximize efficiency of existing transportation system by increasing the number of passengers in a vehicle, or by influencing the time of, or need to, travel. TDM instruments rely on incentive and disincentive mechanism to accomplish these types of behavioral change by making unsustainable modes less attractive and sustainable modes more attractive. TDM policies may also be classified as push and pull policies or hard and soft policies with respect to incentives and disincentives.

Among many different categorization of TDM measures such as 'physical and behavioral' or 'push and pull' or 'hard and soft' [104], we have used 'hard' in similar meaning with 'push' and 'soft' in similar meaning with 'pull' categories, which were defined by StegVlek in 1997 [105]. 'Push' (hard) policies aim to decrease attractiveness of car by economic disincentives, laws and regulations, as well as modifying the objective physical environment. Examples for this type of policies are road tolls, congestion charging, traffic calming, increased prices of fuel and vehicle ownership, and reduction of road capacity. 'Pull' (soft) policies aim to increase benefits from using other modes of travel more than car, influence individual's awareness of the problems related to cars, and increase their knowledge for more sustainable modes of travel as alternative to car by providing economic incentives, information, education, public campaigns as well as improving physical infrastructure and service levels of sustainable modes [105, 106]. Because of resulting high public opposition, being politically unfeasible and having only short-term effects, previous researches show that hard policies, that enforce change, alone do not lead to meet reduced car use targets in long-terms [107]. To illustrate this, Mogridge found that during the world oil crisis of the mid-1970s the substantial rise in fuel prices had only a marginal effect on car use in short term [108]. In long term, higher prices have lead people to purchase smaller and more economical cars and consequently lower petrol consumption.

Thus, transportation planners, scholars, and other stakeholders have started paying serious attention to applying âsoftâ policies to meet desired sustainable urban transportation objectives [109]. Mainstay of 'soft' policy applications are an economic paradigm âutility based theoryâ in which travelers are generally assumed to be rational decision makers, who make choices for their travel based on how much net utility they can get out of their journey [109, 110]. On the other hand, there are rationale advantages of car such as speed, comfort, flexibility, carrying capacity, however, there are also some subjective or emotional factors, which play significant role for charging travel behaviors through sustainable modes such as expressing feelings of power or superiority, or deriving enjoyment

Table 2.3: Different types of soft policy measurements [22]

Type of Measure	Explanation
1. Workplace travel plan	Targets primarily commuters to travel to work more sustainably
2. School travel plan	Targets children and their parents to organise the way to school more sustainable
3. Personalised travel planning	Encourages people through customized information to travel more sustainably
4. Public transportation information and marketing	Advertising campaigns and simplified ticket schemes
5. Travel awareness campaign	Increases awareness of problems resulting from transportation choice
6. Car club	Offers shared vehicles that have to be paid only when used
7. Car sharing / Car pooling	Where individuals share their private car for particular journeys
8. Teleworking	Working from home through remote working practices
9. Teleconferencing	Replaces business travel
10. Home shopping	Purchased goods are directly delivered to the customers' homes

from driving, expressing their personality through type and color of car [111]. These two important aspects, utility theory and rationale and emotional advantages of car form groundings of soft policies [22]. Cairns and Sloman et al. identified and defined different soft policy measures, and then grouped them into 10 different soft policy measures (see Table 2.3). The first five policy types (1-5 in Table 2.3, workplace travel plans, school travel plans, personalized travel planning, information and marketing, awareness campaigns) have been the most frequently implemented and evaluated to impact upon car use in the last decade. Although, there is lack of evidence for the last five categories (6-10 in Table 2.3) having remarkable impacts on reducing traffic levels at urban areas in recent years, they offer a great potential in the future to affect travelers' behaviors as technology evolves [112, 113]. To obtain favorable results from these measures, they should be combined in order to boost the effectiveness [114].

2.6.3 Workplace Travel Plan (WTP)

Nobody doubts that commuting to work by car accounts for vast majority of all car traffic in every mega-city, particularly at peak times. However, growing experience of employer travel planning programs from different countries such as the UK, Netherlands, the US, Australia etc. demonstrate that workplace travel plans offer great potential for sustainable urban transportation as they can be highly effective at cutting the number of cars driven to work totally or at peak times, through a combination of incentives for alternative sustainable travel modes [115]. From this point of view, a work place travel plan can be described as a package of measures developed by an organization or a company or in some cases a combination of organizations, companies, municipalities and governments to accomplish more sustainable travel as making getting to and from the workplace easier, faster, more inexpensive and less harmful for employees, and reducing dependence on private vehicles and parking space [112].

A well designed Workplace travel plan offers savings and benefits for operations and employees. On one hand, it delivers efficiencies to organizations or companies of any size due to reduced traffic at business sites so that it attracts more customers, eases transportation of goods and reduces parking needs of a workplace along with expenses associated to space provision. It can also have positive impact on corporate image from the point of social responsibility, improves an organization's position in the market, and reduces its carbon foot-prints. On the other hand, it offers happier and healthier life for employees because of walking, cycling and public transportation meaning more exercise and less stress.

Workplace travel plans can be implemented in a single site or a cluster of businesses such as a business park or locale or quarter. Measures would vary depending on the number of employees and stakeholders. However, main measures used in a typical workplace travel plan would include [116]:

- Discounts on public transportation,
- Increased and effective spending on public transportation infrastructure by offering new public bus or rail services to linking to the sites of interests such as business quarters,
- Providing all staff with public transportation information and available promotions and discounts,
- Offering personalized journey plans to staffs,
- Cycling and walking initiatives (secure cycle parking, promoting cycling and walking changing facilities, and showers),
- Co-ordinated car-sharing schemes and incentives,
- Management of workplace parking (parking restricted to essential users, parking charges, preferential car parking for sharers, parking 'cash out' for non-users),
- Encouraging teleworking and teleconferencing,

- Variations and working hour arrangements on the five day week, e.g. compressed working hours.

There are various implementation examples of workplace travel plans in different cities throughout the world with different success rates. There is a reasonable agreement in the literature based on the experiences from the UK, the Netherlands, and the US as to the travel reduction achievements of WTP are within the range of 18-20% reduction in the number of staff driving alone to workplace [117]. To illustrate this, California law requires employers who offer a free parking space for their employees to offer a cash allowance program for non-commuters. The law requires cash allowance programs must be at least equal to the cost of the parking space [118]. Shoup studied a total of 1,694 employees at eight (8) firms applying cash-allowance program to focus on the role of financial incentives with respect to traffic reduction objective [118]. According to the results, the number of workers driving alone to workplace has fallen by 17% after cash-allowance program. The cash allowance program has been praised due to its fairness and simplicity by both employers and employees. Another study in Bangalore, India, focused on the role of financial incentives contrast with current disincentive practices [119]. They conducted an experiment involved about 14,000 commuters over a six (6) months period in Bangalore to change commuters' behaviors to travel at off-peak times by deploying an incentive mechanism. The experiment aimed at to reduce traffic congestion, pollution levels, fuel consumption and commuting times while increasing travel comfort of commuters. The incentive mechanism awards commuters every day based on their arrival times and at the end of each week a monetary reward made depending on accrued credits of a commuter. The rewards are in the range about \$10 to \$240. According to the results, the incentive mechanism had a significant impact to encourage commuters to travel at off-peak times. For example, the number of commuters arriving in various pre-rush-hour periods (before 8 am) doubled. The average morning commute time per bus commuter, averaged over all bus commuters, dropped about 24%. With regards to these studies among many other successful workplace travel implementations, it can be concluded that workplace travel plans have significant impact to reduce traffic related problems especially in mega-cities.

2.6.4 School Travel Plans (STP)

In mega-cities, millions of students and their parents go from home to school in the mornings and return home in the afternoons every day during school terms. Substantial proportion of students are driven between home and school. This proportion has tended to increase steadily as motorization level of mega-cities increase at last decades. Research by Bradshaw and Atkins shows that factors influencing parents whether driving their children to school includes safety reasons (either related to traffic danger or personal safety), linked trips (if school on way to parents' work), parental choice of school (parents choose not to send their children to nearest school) and lack of information (regarding public transportation or dedicated school buses availability) [120]. Consequently, traffic congestion around schools has increased dramatically at peak times. Hence, an increasing number of local authorities and scholars focused at these trips to make them more sustainable as promoting walking and cycling for short distances, and public transportation or dedicated school buses for longer distances through developing school travel plans. In this respect, a school travel plan can be defined as a travel plan which aims to decrease problems related to school related-congestion and traffic and to support pupils who are already travelling by more sustainable means [116]. On the other hand, not only school travel plans are significant for reducing traffic related problems in mega-cities, but also they are helpful and crucial for children's health and well-being as it is desired for children to walk or cycle which helps them to increase their daily physical activity.

Well-designed school travel plans (STP) concentrate on measures to make school runs safer for walking and cycling together with awareness-raising education and campaigns, and incentives to walk or cycle such as cycle parking, fare cuts etc. A typical STP might include measurements [116]:

- Special walking or cycling days,
- Walking buses or cycle trains (see Figure 2.5),
- A program for pedestrian and cycling training for children,
- Dedicated school buses,
- Improvements to public transportation for children,
- Fare cuts,
- Traffic calming, pedestrian crossing and cycle lanes around schools,
- Offering lockers at schools.

Among many successful case studies all over the world, especially in the UK, Buckinghamshire County and Ipswich's Kensgrave High School have been chosen due to their inspiring practices towards sustainability [121]. Buckinghamshire County Council has been working on soft policy measures for more than 15 years. The council has created 'Go for Gold' incentive scheme to as a way encouraging pupils to use sustainable modes (walking, cycling, school buses, buses, car sharing) when traveling between home and school to increase their physical health as well as to decrease pollution and congestion

FIGURE 2.5: A Walking Bus [7]

around schools. In this scheme, pupils who use sustainable modes of traveling are rewarded with green, bronze, silver and finally gold stickers, which they can exchange for different small prizes such as a free activity at participating sports center, badges, pencils etc. 'Go for Gold' was an original idea, by using this scheme many schools has accomplished noteworthy levels of sustainable targets around school environment. For example, Holmer Green First School reduced car use from 62% to 26% or Chalfont St Giles Infant School Nursery reduced car use from 57% to 7% between 2002 and 2003 [122]. Another inspiring example is Kensgrave High School in Suffolk [121]. Despite it is located around one of the busiest road, they have increased the percentage of pupils cycling to school up to 57% compared to the country average of only 1% at secondary school levels. At Kensgrave, cycling has promoted by well-designed incentives such as minimizing the books which pupils have to carry, provision of lockers, providing secure cycle storage or off-road cycle routes and subways at busy places. As another result, the pupils demonstrated an impressive increase in successes in school sports owing to their fitness levels by cycling up to 12 mile round trip home to school every day [121]. Regarding these inspiring cases among many other successful school travel plan implementations, it can be concluded that school travel plans are critical to educate students about sustainability and to gain sustainable behaviors and practices as well as to reduce traffic related problems.

2.6.5 Personalized Travel Planning (PTP)

Recently, personalized marketing, also known as individualized marketing or one-to-one marketing has become one of the most practical strategies in the market. Basically, it means differentiating products to specific customers or customer segments according to his/her/their preferences rather than mass-marketing campaigns. It begins first identifying customers or smaller segments of them, then differentiating them according to their priorities and needs, following interacting them with the products or service and finally customizing the products or services to customers' individual needs. Personalized marketing strategies have been applied successfully in various fields with positive results as well as in the field of TDM under the name of personalized or individualized travel planning (PTP) at the household level and for all types of trips.

PTP is one of the most promising measures among soft policies. The assumption behind personalized travel planning is that drivers generally have limited and inaccurate information about alternative modes, and would like to switch or use more sustainable transportation modes if they had known the available services were better [112]. Herewith, various personalized information is provided to people who are interested in. The earliest personalized travel planning programs, if not the first, have been created by (1) Werner Brög and his company Socialdata based in Germany and (2) Steer Davies Gleave and his firm Steer Davies Gleace Consultancy based in the UK in 1980s [123]. Social data calls its approach IndiMark (individualized marketing), under the 'TravelSmart' brand and the approach has been applied in many European countries as well as in the UK, Australia and the US. On the other hand, Steer Davies Geleave named his approach as 'TravelBlending' and it has been implemented in the UK, Australia, Chile and other countries [123].

In a typical personalized travel planning application, first, all households within a target area are contacted to offer alternative travel modes, and classified in three main groups whether they are interested or they are already a user or not interested. After that, pre-surveys are conducted with interested customers to learn their current travel behaviors and sometimes (in travel blending applications) also asking them keeping travel diary for generally a week. After receiving individualized information from the travel diaries and pre-surveys, personalized information packages, which is designed to modify behaviors, have been offered to each participant [124]. A typical personalized information package may include ideal tools (ideas for changing current travel activities or time of activities), travel blending, personalized journey plans, public transportation schedules, brochures (dealing with saving money, reducing environmental impact, making travel less stressful), local activity guides, loan-a-bike, free public transportation tickets, and information regarding CO_2 emissions their car produced, wasted time in traffic, how much money they spent etc [112]. After a participant received his/her customized information package, participant is asked to keep post-travel diary for identifying change in travel behavior to facilitate feedback to participant and monitors program's total impact.

There are various successful implementations of personalized travel planning under TDM concept in the world from European countries like Germany, Sweden and the U.K. to Canada, from Australia to the US. Most of these implementations summarized in Table 2.4 which includes a number of projects and their locations, target population and their success rate according to car reduction rates. As mentioned before, the first significant personalized travel planning implementations were in Germany and spreads out to Europe, then followed by Australia and next applied in the U.S and the other countries. The first significant milestone in Personalized Travel Planning experiment was implemented in 1991 in Kassel, Germany by SocialData which was aiming to increase public transportation usage [125]. After potential users determined, they were contacted directly and provided special information for available public transportation with regards to their requirements to motivate them to switch their travel behaviors. The result were extremely promising for future travel management; the use of public transportation among the potential users nearly doubled after the implementation.

Another significant implementation of individualized marketing was in South Perth in Australia [126]. Before SocialData was contracted by Department of Transport In Perth to implement first personalized marketing pilot program, car use rates either a car driver or a passenger in Perth metropolitan region was as high as about 80% of all personal trips, despite of that the city provides wide variety of travel options with an extensive network of walkways, cycle ways and public transportation services [125]. The pilot project in 1997 carried out by SocialData in city of South perth covered 380 households and results were impressive; car as driver trips went down by 10% and at the same time walking increased by 16%, cycling by 91% and public transportation by 21% [127]. Following, the IndiMark by SocialData implemented the first-large-scale application in the city of South Perth involved about 15.000 households. This project was more significant compared to its European predecessors because of promoting not only public transportation but also walking and cycling modes. The results even exceeded projections; car as driver trips decreased by 14% at the same time walking increased by %35, cycling by 61% and public transportation by 15% [125]. The South-Perth large-scale- project has led the city of Perth to establish its own program TravelSmart Household program (TSHH) and inspired many other significant personalized travel planning programs in many cities all over the world (see Table 2.4) including the biggest single project ever realized in Brisbane in Australia with 180.000 people involved [23]. These results indicated that personalized travel planning programs were very successful in motivating people to change their travel behaviors into sustainable ways. However, it is for sure that the success of all these

Table 2.4: TravelSmart in Australia, Europe and North America [23]

	Projects	Locations	Target population (People)	Car reduction (%)
Perth	24	1	408,500	-11
Other Australia	10	4	338,800	-12
UK	24	12	304,800	-12
Other Europe	7	6	47,000	-13
USA	12	9	47,500	-8
Canada	6	1	4,000	-10

programs largely depends on the quality of alternative modes or opportunities offered to people.

2.6.6 Marketing, Information and Travel Awareness (MITA)

Since the second half of 19th century, marketing has gained a significant place as a distinct discipline within business field, with its own issues, principles and terminology [128]. Marketing, information and travel awareness applications based on targeted marketing techniques providing advice and information for alternative transportation modes, and increasing public awareness for problems resulted from travel choices through campaigns. At the last decades, the concept of de-marketing emerged as a particular specialism in marketing field. While conventional marketing practices based on encouragement of demand for a product or service, on the other hand, de-marketing concept based on discouragement of demand for a product or service [128]. Both marketing and de-marketing applications in the transportation field is as old as Second World War. For example, an awareness campaign generated by the UK government during Second World War was used to remind people to save fuels and let trains to transport more goods and soldiers (see Figure 2.6). Marketing applications in transportation field can be easily separated into two categories. First category is mainly focused on marketing of alternative transportation modes in substitution for automobile, while the second category consists of de-marketing applications for discouraging people for car usage. Applications from both categories reported evidence of reductions in car usage [112].

Likewise personalized marketing, but in relatively wider scope, improving information about traffic problem and availability of alternative sustainable modes promises note-worthy potential to reduce demand for car usage. The types of initiatives to promote these sustainable modes include: journey planning websites including links to public transportation information; simplified ticket availability; more technologically advanced initiatives such as i-Kiosks and the ability to access travel information anytime via mobile phones; road safety initiatives to encourage more people to walk and cycle; organized events for walk and cycle rides for health groups; and cycle and walking maps [129]. On

FIGURE 2.6: 'Is Your Journey Really Necessary' the UK awareness campaign during Second World War [8]

the other hand, travel awareness campaigns aimed at improving general public awareness of the economical, ecological and health problems resulted from transportation choices, what can be done to solve these problems in other words de-marketing of car and to win support for other soft policy initiatives. Travel awareness campaigns involve a wide range of media tools such as newsletters, large display boards, posters, fliers, attractive leaflets, promotional events, radio and TV ads and programs, social media promotions etc. Many of campaigns focus more on positive health and ecological benefits from alternative transportation modes rather than economic benefits. For example, in Darlington in the UK [130], the branding of Local Motion campaign was released around 2005 to increase public awareness for traffic congestion problem and promoting alternative transportation modes. The motto of Local Motion is 'Think it, change it, do it' and one of the main slogans was "Low cost, low stress, low fat. . . Do the Local Motion". The campaign benefited from various marketing techniques such as pro-bike organizations where some celebrities such as Kylie Minogue took part, or social media accounts, advertisements, free bus time tables, cycling and walking maps etc. Although it is really hard to measure effect of the campaign alone for cutting traffic demand, it has shown remarkable success in both increasing usage of alternative modes and decreasing traffic congestion.

2.6.7 Car Clubs Car Co-operatives or Car Sharing Schemes (CC-CS)

Car clubs (in the UK) or US name 'car sharing' is a model of car rental where people rent cars for short period of time by the minute, by the hour as well as by the day [131]. Car clubs also differ from traditional car rentals in some points which are: 7/24 renting is available; reservation, pick up and return is all self-service; fuel costs included in the rates; users are members and pre-approved to drive; the locations of vehicles are very easy to reach by public transportation, walking and cycling; reservation can be made by phone, websites, mobile applications or even text messages depending on company. Car clubs required membership with fees from $30 to $200 annually and charge by time used and distance travelled [9]. They are mostly attractive to people whose main travel modes are public transportation, walking and cycling and they only need car occasionally. Car clubs are also an alternative for owning second car for households with more than one driver. The members of car clubs use car for various purposes but rarely for commuting to work for about %2 percent (See Figure 2.7).

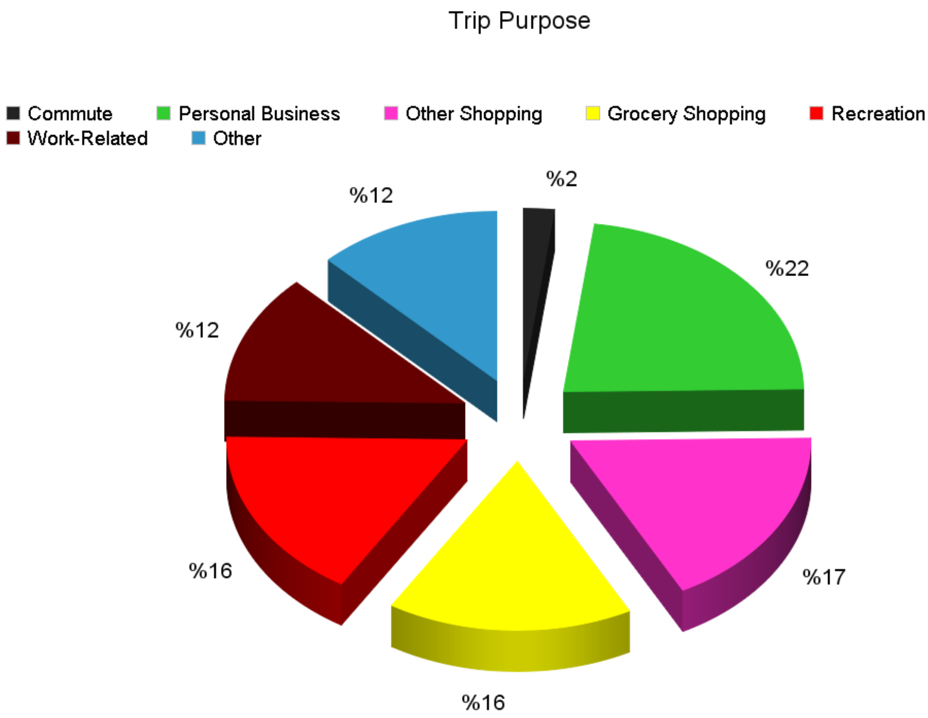

FIGURE 2.7: Trip purposes of Car-Club members [9]

The first known trial of car club idea was SEFAGE ('Selbstfahrgemeinschaft / self-riding community') in Zurich, Switzerland in 1948, which still exists today and its members were people who could not afford to purchase a car decided to share one [132]. Car clubs were limited at the beginning, but after 1990s it has grown rapidly and spread out to whole Europe and North America and following other countries throughout world. Car clubs may be operated by a commercial business, by non-profit organizations or by government itself. In the car club market, there are specialized companies for car share such as Zipcar, Autolib, City car club etc. and traditional car rental companies' car clubs like Hertz on demand by Hertz, Avis on location by Avis etc. and global car manufacturers' car clubs such as Daimler's Car2Go or BMW's DriveNow. Today, there are more than one thousand world cities where car clubs are available with around 2,5 million members and expected to surpass 12 million members by 2020 [133]. In addition, global car club market is now as big as $ 1 billion in 2013 and expected to reach about $ 6 billion by 2020 [134].

Car clubs can provide noteworthy economic, environmental, social benefits by its potential. It has the potential to reduce the rates of car owning and car use. According to a long term study on City CarShare members by Robert Cervero from University of California, Berkeley, 29% of car share members sold their personal cars and some delayed purchasing one to four years after the introduction of a car club, City CarShare, in San Francisco and Bay Area in California [135]. Because car clubs offer less car intensive means of urban transport by leading its members to make only necessary trips and increase usage of alternative transportation modes, it has the potential to reduce car owning rates at an estimated rate of that one rental car can take the place of 15 owned vehicles [136]. According to Sloman, in the longer term, growth of car clubs might reduce national car travel demand by 1.6 per cent [115].

2.6.8 Teleworking (Telecommuting, Teleconferencing, and Shopping from Home)

New developments within the fields of computer and telecommunication technology in recent years, -including computer networks and data systems, telephone, fax and scanner machines, electronic mail, online payment, online calling, websites, video connections etc.- offer new work and social habits to people, especially workers, so they can work or shop or communicate socially wherever these tools are available including home. These opportunities have led many companies, organizations and government agencies to adopt these technologies for improving services, reducing costs, reducing vehicle trips, or to achieve other objectives. In this manner, a general term, teleworking, has been defined as use of telecommunications to replace physical travel [137]. Specific examples of teleworking are as follows [137]:

- **Telecommuting:** working at home or at an alternate location like satellite office and communicating with usual workplace using telecommunications tools, instead of physically traveling to a more distant work-site for one or multiple days a week or full-time [138]. This is particularly appropriate for workers in the fields of research, accounting, editing, software development and design.

- **Satellite office or local work center:** Neighborhoods work centers full equipped with appropriate telecommunication tool can serve employees of single or multiple firms to a variety of businesses, reducing the need to travel to a central office.
- **Video-conferencing and video presentations:** Replacing physical meetings by the use of live video connections.
- **Distance Learning:** Replacing physical meetings for classes and projects in Colleges and Universities by the help of telecommunication tools.
- **Tele shopping or Internet-shopping:** Electronic shopping via internet. Customers purchase goods online with direct delivery to them instead of purchasing and transporting from a store.
- **Online-Banking:** Electronic transactions via internet.
- **Electronic Government:** Replacing physical visits to government office for many services by telecommunication tools such as websites.
- **Internet Business-to-Business (B2B):** Electronic interactions between businesses such as bidding, sales and planning.

Since it is certain that most of the travel activities are for commuting to work and shopping, teleworking can provide some economic, environmental, social benefits. It has noteworthy potential to reduce a significant proportion of peak-time commuting so that decreasing total vehicle travelled. Therefore, it may provide social opportunities to teleworkers such as spending time with their children or conducting other activities at home while working. For example, Marshall and Bannister reviewed a range of travel reduction strategies including teleworking in Netherlands [139]. The teleworking experiments were analyzed and then found that teleworkers reduced the total number of trips by 10 to 17% and total distance travelled by 14% to 16%. Mokhtarian proposed a model for examining current state and forecasting the demand [138]. She has estimated that 6,1% of the California workforce may currently telecommute 1.2 days a week on average, with the result that 1,5% of the workforce may be telecommuting on any given day. Based on American Survey Data, teleworking grew nearly 80% from 2005 (for profit organizations 70%, non-profit organizations 88%, local government 62%, state government 122%, and federal government 421%) [140]. Also, 2,6% of the U.S. employee workforce (3,3 million people, not including the self-employed or unpaid volunteers) considered home as their primary place of work according to the survey (3,3% of federal employees, 2,9% of private sector non-for profit employees, 2,6% private sector for-profit employees, 2,4% of state government workers, 1,2% of local government workers). Likewise, E-commerce market has been also growing dramatically. In 2013, e-commerce sales worldwide reached $1,251 trillion and expected to reach $2,357 trillion by 2017 [141].

On one hand, teleworking has many advantages such as cost-efficiency for both employee and employer due to less cost for traveling and office space; increased work efficiency due to flexible working and better working atmosphere, increased productivity because of no time for traveling, less stressed employees because of lack of commuting stress etc. On the other hand, there are some disadvantages as well such as less contact with co-workers, less access to office equipment, discipline problem, initial start-up costs like laptops, cell phones etc. required for teleworking, and trust issues. As many consider teleworking is the future of work like Forbes magazine due to its benefits [142] there, however, are some challenges to overcome before taking advantage of teleworking.

2.7 Case Study of Istanbul

2.7.1 Road Network and Motorization in Istanbul

Istanbul, Europe's easternmost or Asia's westernmost city (see Figure 2.8), is one of the most important gateway for trade routes between Europe and Asia from past to present. It is surrounded by two important highways (the TEM and D-100) on a total length of 130 km and provide mobility between regions [143]. Trans European Motorway (TEM), which is also known as O-2 (see Figure 2.9), begins from European borders of Turkey in north west, passes through Istanbul by Fatih Sultan Mehmet (FSM) Bridge and extend all the way to Asian borders in east and to Middle Eastern borders in south east. D-100 highway, also known as E-5 and O-1 (see Figure 2.9), was the former highway providing access between Europe and Asia before TEM and connected by Boğaziçi (Bosporus) Bridge. However, its role is now more of providing inter-regional access in Istanbul. These two highways connect the European side and Asian side of Istanbul, the two international airports, the three main ports, important business districts and provide access to the sub centers of Istanbul. Besides these, there are extensive road network surrounding Istanbul with main arterials, urban streets, beltways, boulevards, avenues etc. According to Istanbul Metropolitan Area Urban Transportation Master Plan (IUAP), total road network in Istanbul Metropolitan Area is on a length of 29702 km and length of total main roads is 2833 km (see Figure 2.9) [24].

There are many bridges in Istanbul; however, only two of them provide access between European and Asian side of the city. First of these two bridges is Bosporus Bridge,

FIGURE 2.8: Political map of Turkey and location of Istanbul [10]

also known as First Bridge, whose construction was completed in the year of 1973. The bridge highway has a total width of 8 lanes including two emergency lanes and a total length of 1560 meters. Its capacity is 130.000 vehicles per day and located in the south part of Bosporus canal. The other bridge is Fatih Sultan Mehmet (FSM) bridge, which is also known as second bridge, was built in 1988 and located in middle of the canal. FSM is very important for coaches and transportation of cargos by big trucks because it is a part of TEM. Its planned capacity, length and width is very similar to first bridge as well as its shape. Furthermore, these two bridges on the Bosporus are one-sided toll roads. Although their total capacity is approximately 250.000 vehicles per day, total of 420.000 vehicles uses these bridges every day to pass other side of Istanbul [1]. Besides, the proportion of road transportation in around 20 million trips per day is %85 [16, 24]. Government recently announced constructing a new tunnel under Bosporus canal and 3th bridge for solving these over capacity problems by supplying more. The tunnel, which is also known as Eurasia Tunnel, will be located south side of first bridge and will provide access between historical peninsula in European side and Kadıkoy in Asian side. While the 3th bridge, named as Yavuz Sultan Selim Bridge, will be located on the northern side of Istanbul. These two newly announced projects are under construction and planned to be completed in 2015 [144].

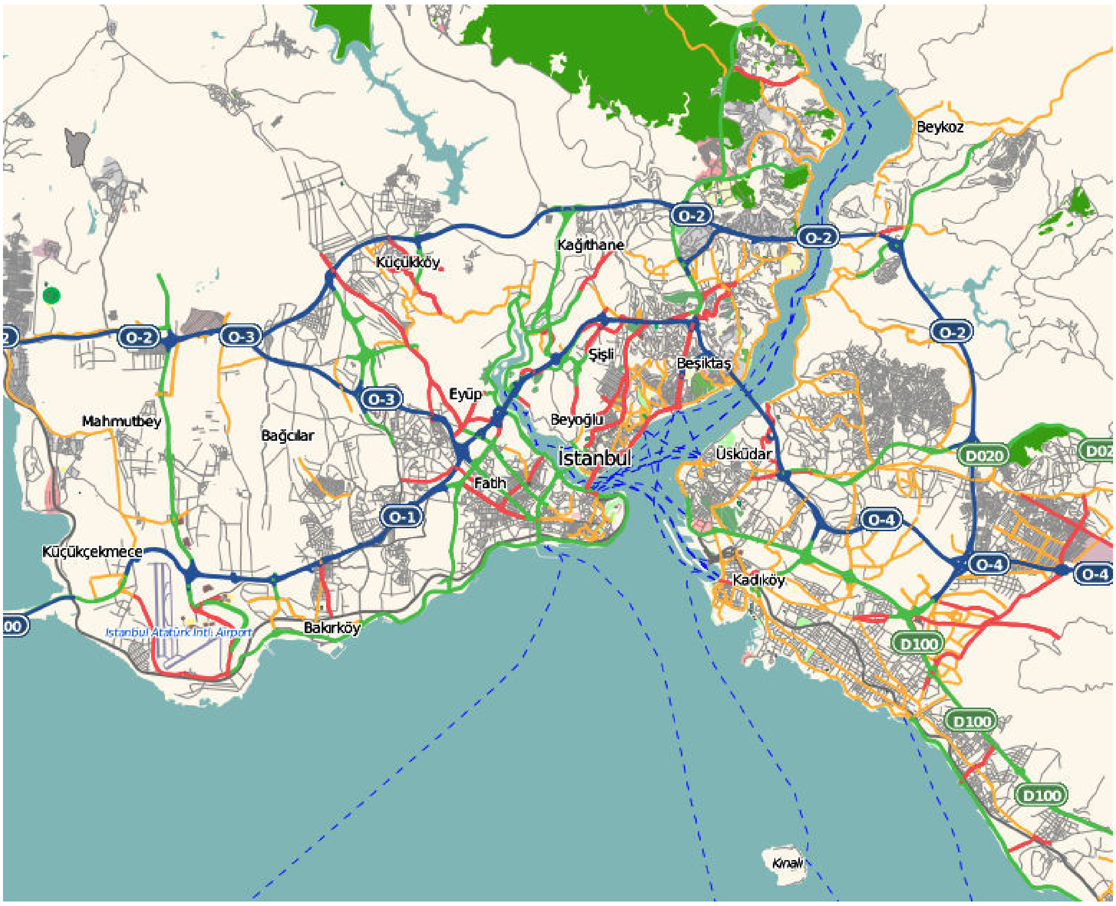

FIGURE 2.9: Road map of Istanbul [11]

Likewise other mega-cities in developing countries, Istanbul has faced rapid motorization in last decades in conjunction with population explosion and economic growth. The number of registered vehicles in 1980 in Istanbul was 200.000, it has dramatically increased to 1,25 million in 2000, while, population of Istanbul has increased from 2,7 million in 1980 to 8,8 million in 2000 [12]. As compared with other mega-cities in developed world (400-500 vehicles per 1000 population), motorization rate is still low in Istanbul where there are 232 vehicles (152 out of 232 are cars) registered for 1000 people [13]. However, trend of motorization rates in last 10 years is alarming. There were 2,1 million vehicles registered in Istanbul in 2005, however, it dramatically increased to 3,3 million in 2014 with the rate of %56. At the same era, population has increased with the rate of %20 from 11,7 million in 2005 to 14,1 million in 2014 (see Figure 2.10). According to projections of IUAP; population will increase to 17,2 million, number of vehicles in the city will increase to 4,3 million, and number of vehicles per 1000 population will increase to 252 in 2023. In addition to these estimates, it is also expected that the percentage of car owning households will increase from %35 in 2006 to %65 in the year 2023 [24].

There are two online ITS systems available in Istanbul. They are offered by Istanbul Metropolitan Municipality (IMM) and Yandex to inform public regarding current traffic

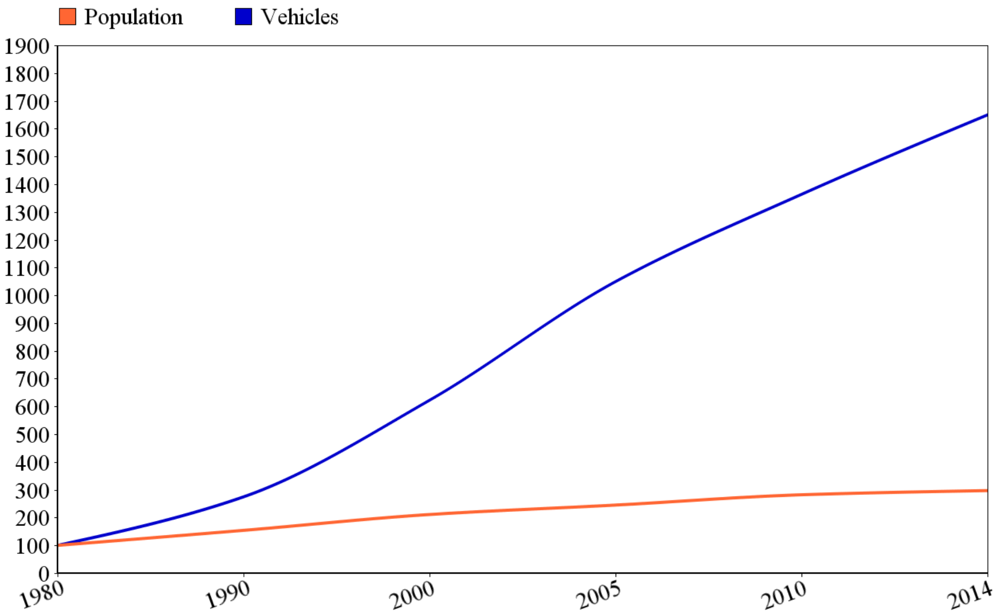

FIGURE 2.10: Population and motorization growth in Istanbul between 1980-2014 (1980=100) [12, 13]

congestion situation and provide estimations for a specific time in any day by using past data of available in Istanbul (See Figure 2.11). Both of these services offer website and mobile application versions to millions of residents of Istanbul. For example, IMM mobile application (IBB cep trafik) has been downloaded by more than millions at smartphones. IMM service is based on data of traffic sensors located at main roads and principals roads and it is published real time, while Yandex traffic service is based on the data of GPS sensors located in thousands of cars in Istanbul.

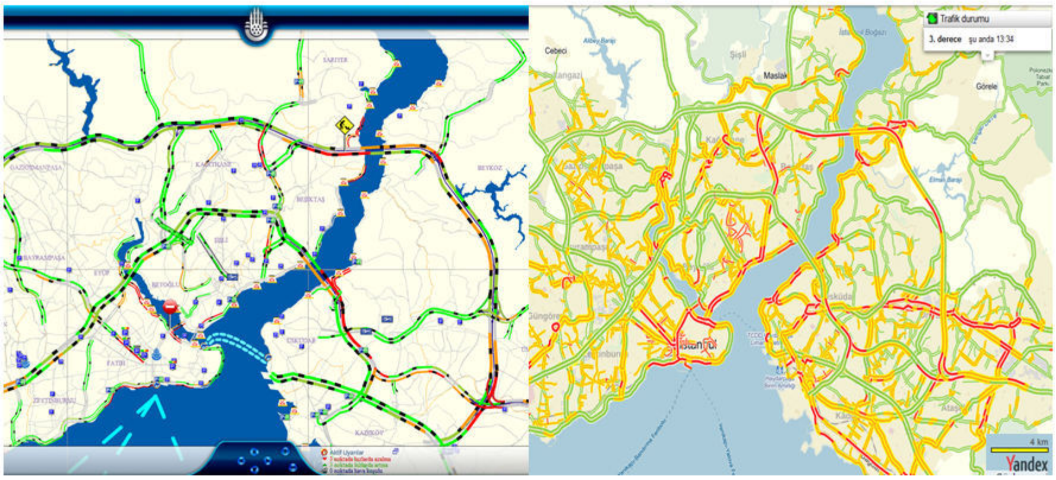

FIGURE 2.11: IMM and Yandex traffic congestion maps, respectively [14, 15]

2.7.2 Public Transportation in Istanbul

Although public transportation has difficulties to keep up with the growth of urbanization and motorization, a wide variety of public transportation (PT) modes are available in Istanbul. These can be divided into three categories; road based modes (1), rail based modes (2) and sea based modes (3). Road based modes represent 84% of total passenger of Public Transportation per day, while railway systems are represented by %14 and sea lines by %2 (See Figure 2.12).

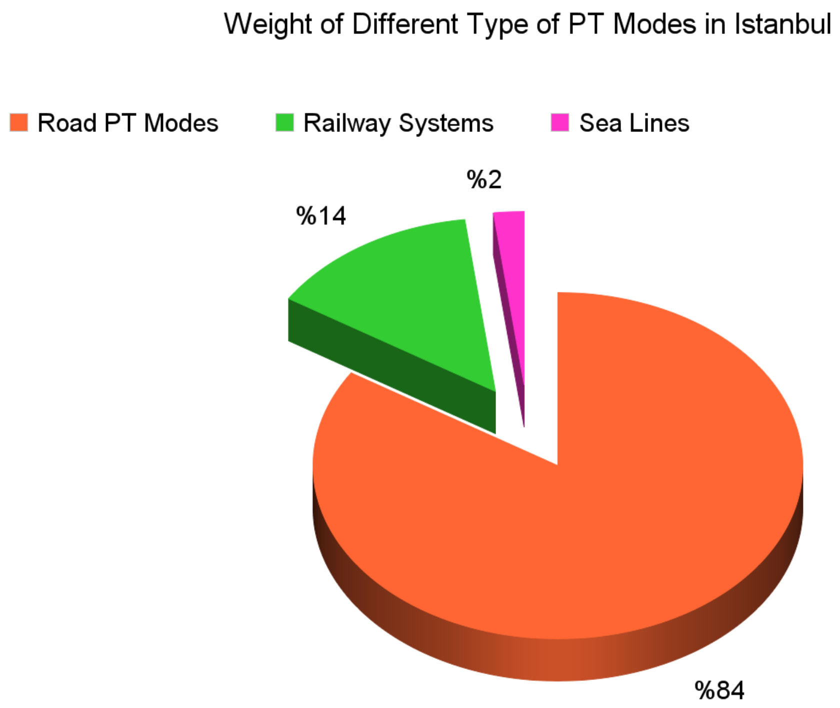

FIGURE 2.12: Weight of different type of PT modes in Istanbul [16]

Road based modes are buses, a BRT line (Metrobüs), minibuses, company and school shuttles, shared taxis (Dolmuş), and taxis. Bus fleets owned by municipality (IETT), by private organization (ÖHO) and by semi-private association (OAŞ), together with privately owned minibuses form the main body of road based PT with the share of %54 in all road based PT (see Figure 2.13). Shared taxis (dolmuş) are a type of collective taxi with the capacity of 8 people and fixed routes but free stops. Buses, minibuses and shared taxis play a key role in commuting patterns in Istanbul, which has the highest share in all daily motorized trips by %40,8 [12], while they all together provide service to average 5,5 million passengers per day [16]. There are official approximately 18000 taxis in Istanbul owned by private or cooperatives and provide service to 1 million passengers daily [24]. Dedicated company and school shuttles are also widely used in Istanbul and provide service daily to 2,4 million of employees and student [16]. Companies generally offer free shuttle service to their employees which contribute to reduce car commuting, while school shuttles are generally charged monthly by distance travelled. Besides these modes, a Sustainable Transport Award winning BRT line (metrobüs) was implemented in 2007/2008 and provides service to almost 1 million passengers per day with a share of %8 in total passengers of road based PT (see Figure 2.13). Today it is operating on a distance of 51 km with 6 different routes and 44 stations by 535 high quality buses. It links western suburbs and some busy districts at the entrance of Bosporus in Asian side. It has been implemented onto the center lanes of E-5 highways and across the first bridge. Because of its speed (maximum of 60km/h) and running on one of the busiest motorways, it has successfully reduced travel times and increased PT use [16].

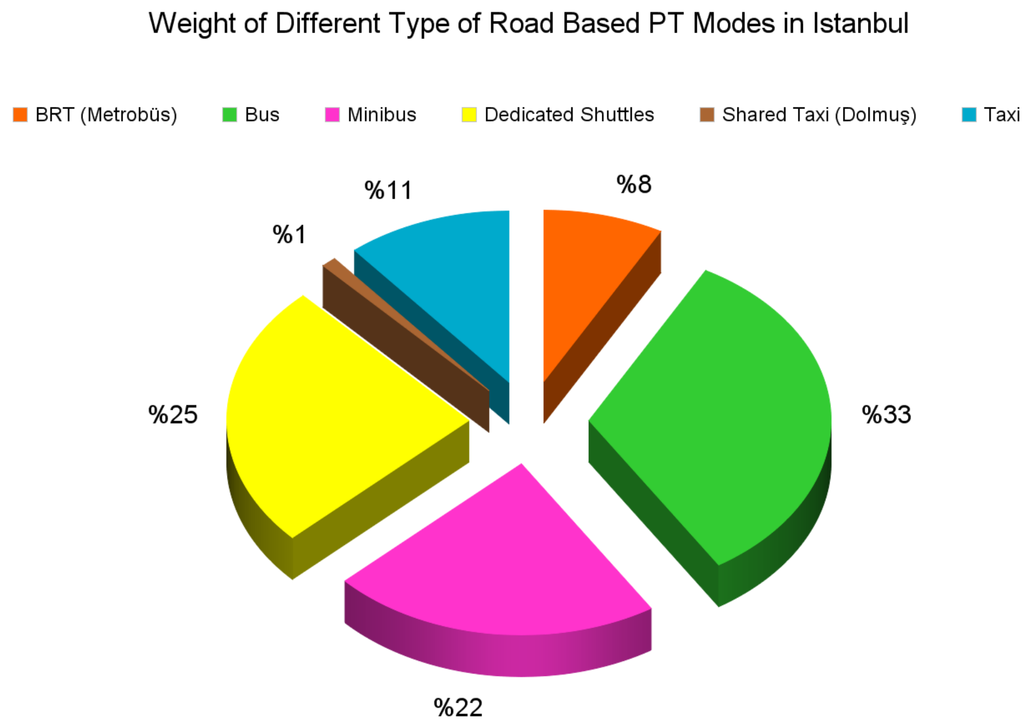

FIGURE 2.13: Weight of different road based PT modes in Istanbul [16]

Although Istanbul has one of the earliest underground systems (Historical funicular-1875), railway investments were fairly low because of natural constraints on the construction of railways due to being a hill city. There were only 45 km of urban rail system and about 75 km commuter train rail line in service before 2004. The Municipality has recognized the need for better public transportation system to keep pace with high urbanization and motorization rates and started to focus on rail transit investments after 2004. Commuter train rail line, which provides service to both suburban line and intercity railway, begins in Halkalı and end in Sirkeci Station in European Side, while it begins in Gebze and end in Haydarpaşa Station in the Asian Side. Main problems of these lines were inadequate service quality and lack of rail connections between two stations. Therefore, one of the most significant project in the city history, the Marmaray Project, has been launched. The project can be divided into two part. First part is crossing Bosporus through an immersed tunnel with 4 new underground stations, while second part consists of rebuilding or refurbishing 37 existing above ground stations. First part of the Marmaray Project was completed on 29 October 2013, while the second part has being completed in sections. As the date of 2013, length of urban rail system (metro, LRT, tramway, funicular, and cable car) has increased from 45 km to 141 km. New rail transportation projects are currently underway to extent existing network. After completion of these scheduled projects, the total system length is expected to increase to 400 km, including 75 km renewed commuter train rail line by 2019 (see Figure 2.14).

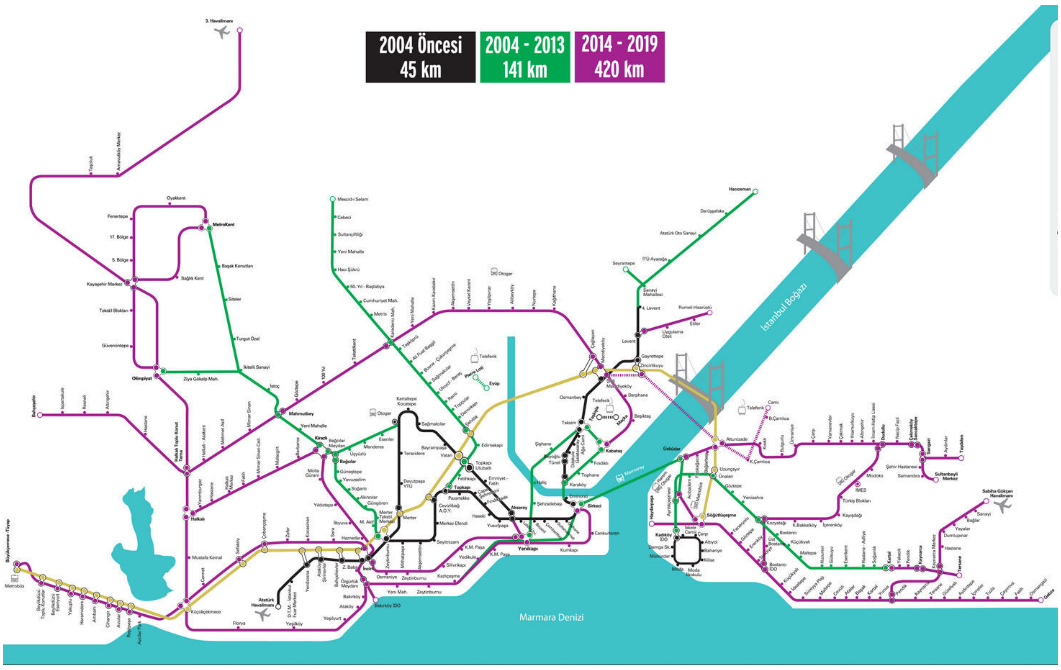

FIGURE 2.14: Urban railway network before 2004, 2004-2013, and 2014-2019 [17]

There is variety of sea lines available as part of public transportation including small-to medium sized ferry-boats, sea-buses and water-taxis operated by the IMM, private and semi-private organizations. The sea lines link the European and Asian sides of Istanbul in many points along the Bosporus canal, as well as the centers of Istanbul coast off the Marmara Sea. Although the share of sea transportation is limited compared to road and rail based PT modes, they play an important role in connecting two sides of the city by carrying 265 thousands sea commuting passengers daily [16].

In all public transportation modes except minibuses, shared taxis and taxis, a contactless payment card which is called as Istanbulkart is used for fare payment in Istanbul. It was introduced in 2009 to replace cash and an integrated electronic ticket system in already use. It has four types: (1) anonymous card for full fare payment, (2) blue card for monthly discounted use, (3) personalized reduced-fare card for students and teachers; (4) free ride card for handicapped persons, seniors, veterans, national athletes, and employees with specific duties [16].

Based on the 2006 Household Travel Survey conducted by the Istanbul Metropolitan Planning and Urban Design Center (IMP) in Istanbul, has estimated the change in modal split of urban motorized travel in the period of 1987 to 2006 which is shown in Figure 2.15 [12]. According to the figure, it can be seen that the share of car has risen from %19,3 in 1987 to %26,3 in 2006 together with Company/School shuttles which has increased from 10,4 in 1987 to 21,5 in 2006. On the other hand, the share of buses has dropped from %35,2 in 1987 to 24,1 in 2006 together with respectable decreased rate of taxi, shared taxi and minibuses. Share of railway and sea lines range at a low level between %2 and %5.

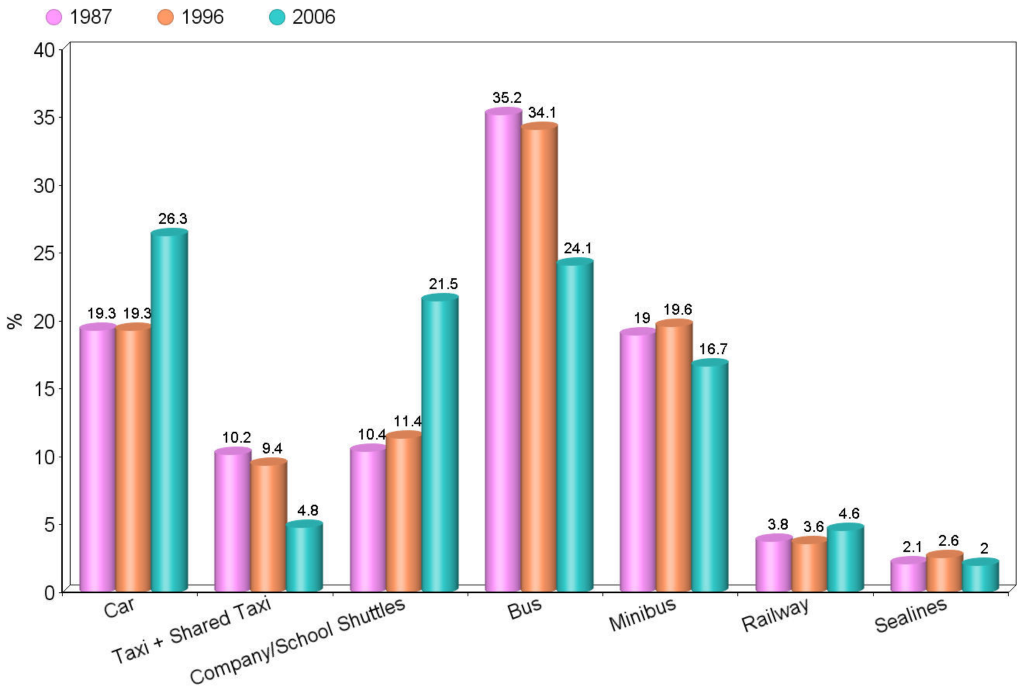

Figure 2.15: Modal split of urban motorized travel in the period of 1987 to 2006 [12]

Based on the 2006 Household Travel Survey conducted among approximately 70.000 households in Istanbul, the trip composition by purpose were found out in Istanbul which are shown in Table 4.1. According to the results, HBW (home based work) trips has the largest share of total trips by %53, while HBS (home based school) has the share of %15, HBO (home based other) has the share of %24 and NHB (non-home based) trips has the share of %8. It should be noted that HBW, HBS and HBO trips are two-way trips which means they include "return to home" as well. Besides, if the share of NHB is distributed to HBW, HBS and HBO proportionally, shares of HBW, HBS and HBO became %58, %16 and %26, respectively.

TABLE 2.5: Trip composition by purpose in Istanbul[24]

Trip purpose	Percentage	Percentages after distribution of NHB
Home Based Work (HBW)	53	58
Home Based School (HBS)	15	16
Home Based Other (HBO)	24	26
Non Home Based (NHB)	8	-

2.7.3 Comparisons of Istanbul and Different Mega-Cities on Various Indicators

As one might expect that all mega-cities share similarities due to extreme globalization trends, however, each city draw different patterns of urbanization and motorization with diverse spatial, economical, and social characteristics that result in specific urban experience for each city. A preliminary assessment and comparisons of various world cities on different key indicators is important to get the bottom of this urban experience. New York City from North America, Mexico City from Central America, Sao Paulo from South America, Shanghai and Singapore from Asia, London and Barcelona from Europe and finally Johannesburg from Africa have been selected in comparisons to Istanbul. The selection has been made due to representation of all parts of the world and each city sharing different spatial, economic and social characteristics. First, they have been compared on population growth, central area density, and their GDP (see Table 2.6). The range of population of these nine cities vary from 3,2 million (Barcelona) to 24,2 million (Shanghai). Istanbul (298,6%) and Johannesburg (285,4%) has faced the highest population increase since 1980, while the lowest increase is 105,5% in Barcelona. Patterns of central area densities also differ significantly. The cities representing highest densities are Shanghai (24.673 people per km^2) and Istanbul (20.116 people km^2) which nearly tripled London (7.805 people per km^2), Barcelona (7.866 people per km^2) and Singapore (7.418 people per km^2). On the other hand, the city indicating lowest central area density, which might be considered as being more dangerous places to live, is Johannesburg (2.270 people per km^2). Despite of New York City ($1.210 billion) having the highest weight in terms of GDP, its share in the US GDP is only %7,5 which is the second lowest in the nine cities. Cities contributing most in country GDP are Istanbul ($ 301,1 billion) with percentage of 38,1, Mexico City ($411,4 billion) with share of %34,7 and London ($731,2 billion) with contribution of %29,6.

The uncontrolled growth depicted in the previous section has led to a growing traffic congestion problem in Istanbul, similar to many other big cities of the world. The congestion problem severely affects economy, environment and social life in Istanbul. As mentioned in previous sections, the number of vehicles in Istanbul has increased in a more rapid trend than the population, thanks to the economic developments. The number of

Table 2.6: General comparisons of various cities [25–28]

City	Population in 1980 (million)	Current Population (million)	Population increase since 1980 (%)	Density (people per km^2)	GDP (billion $)	% Share in Country GDP
Istanbul	4.74	14.16	298,6	20.116	301,1	38,1
New York City	7.07	8.40	118,9	15.361	1.210,0	7,5
Mexico City	13.88	21.17	152,7	12.541	411.4	34,7
Sao Paulo	12.49	20.82	166,6	10.299	473,0	21,0
Shanghai	11.73	24.15	205,7	24.673	516.5	6,2
London	7.74	9.78	126,4	7.805	731,2	29,6
Barcelona	3.07	3.23	105,5	7.866	171,0	12,9
Johannesburg	1.55	4.43	285,4	2.270	76,0	19,8
Singapore	2.41	5.31	220,1	7.418	327,2	100,0

automobiles in Istanbul has experienced an 8-fold increase since 1980, compared to 5-fold increase in the population [5]. Although the number of cars per thousand population is significantly lower than the most of the other large world cities [5], the scope of congestion problem has increased in the last years. Table 2.7 shows a comparison of congestion index, which is calculated as follows [54]:

$$congestion = \frac{t_{normal} - t_{free}}{t_{free}}$$

Where t_{free} is the amount of time spent when the roads are free (e.g., during night), and t_{normal} is the amount of time spent during a usual scenario (e.g., averaged over a large number of times sampled from various instants) over a predefined route. The higher values of congestion means higher difference between t_{free} and t_{normal}. The congestion index, therefore, gives a good estimate of the degree of congestion on a normalized scale. Looking at Table 2.7, it can be seen that Istanbul has the highest congestion index, compared to the other world mega-cities. Strikingly, number of cars per 1,000 residents in Istanbul is lower than all the cities given in Table 2.7, except Shanghai and Singapore. The number of cars per 1,000 residents for these cities is also provided in Table 2.7. Infrastructure comparison of these cities is made on the indicators of total metro network and total road network. While cities having the longest road network are New York City (56516 km), Mexico City (52749 km) and London (47287), they also have the longest railway networks, which are London (402 km), New York City (373), and Mexico City (226,5 km), except Shanghai with total road network of 20082 km but

Table 2.7: Infrastructure, quality of life and congestion related indicators for various cities [25, 29? –32]

City	Mercer Life Quality Rank.	Congestion Index	Car Ownership per 1,000 residents	Total Metro Network (km)	Total Road Network (km)
Istanbul	117	0,62	152	141	32.535
New York City	44	0,26	215	373	56.516
Mexico City	120	0,54	360	226.5	52.749
Sao Paulo	115	0,46	368	74.8	28.956
Shanghai	95	0,38	73	538	20.082
London	38	0,34	345	402	47.287
Barcelona	40	0,25	470	102.6	4.551
Johannesburg	94	0,31	206	NA	2.280
Singapore	25	NA	120	152.9	NA

538km rail network. On the other hand, Istanbul is in the mid-range on both indicator with total road network of 32.535 km and 142 km total railway network. The unexpected relationship between the congestion index, road and rail network and the number of cars compared to the other cities implies mistakes related to the management of the traffic. It can be revealed that the congestion problem can get aggravated in forthcoming years, due to the fact that Istanbul has reached its natural limits in terms of roads available and building new roads excited people to use cars more than ever, diminishing its effect. It can be also shown that mitigation of the flaws related to the management could ameliorate the congestion problem in Istanbul. The comparison of the cities on quality life is also significant to analyze social welfare and life satisfactions of individuals and societies in those cities. Mercer life quality index has been used to evaluate the cities (See Table 2.7). The index consists of evaluating cities on more than 39 factors including political, social, economic environment, education, health and sanitation, natural environment, housing, consumer goods etc. which is determined according to surveys conducted in 420 different cities all over the world [145]. The index reveals that the most livable cities among these nine cities are Singapore (ranked as 25th), London (38th), Barcelona (40th) and New York City (44th), while the worst livable cities are Mexico City (120th), Istanbul (117th) and Sao Paulo (115th), respectively.

Table 2.8 reveals purchasing power of minimum wage in the cities according to different mobility related indicators, while it also provides comparisons of prices of an average car, gasoline, and one way metro ticket. New York City has the highest minimum wage $1.400, while Johannesburg has the lowest $174. If one looks at the comparisons according to prices of an average brand new car (Volkswagen Gold 1.4 90kw or equivalent new car), gasoline and one way metro ticket price, it can be seen that Mexico city has

Table 2.8: Purchasing power of minimum wage in various cities by mobility related indicators [25, 30, 33]

City	Minimum Wage ($)	VW Golf or Eq. Car Price ($)	Gasoline ($ per lt)	Metro Ticket Price ($)	Car price/ Min. Wage	Min. wage/ Gasoline	Minimum wage/ Metro Ticket
Istanbul	393,00	24.123	2,29	0,99	61	172	397
New York City	1.400,00	23.000	1,05	2,67	16	1.333	524
Mexico City	130,00	17.982	0,92	0,38	138	141	342
Sao Paulo	310,00	23.914	1,25	1,38	77	248	225
Shanghai	295,00	25.175	1,30	0,57	85	227	518
London	1.925,00	26.895	2,33	4,71	14	826	409
Barcelona	620,00	25.462	1,97	2,67	41	315	232
Johannesburg	174,00	20.496	1,25	0,02	118	139	8.700
Singapore	1.000,00	111.865	1,71	1,44	112	585	694

the lowest cost for purchasing a new car (14.982 $), the lowest gasoline price of $0,92, and the second lowest metro ticket price $0,38. On the other hand, London has the most expensive gasoline ($2,33) and metro ticket price (4,71) in addition to having the second highest cost of purchasing a new car ($26.895) after Singapore having the cost of $111.865 for a new car. However, comparisons only between prices are inadequate to draw objective comparisons between cities on mobility related indicators, therefore, purchasing power of minimum wage in different cities have also been provided in Table 2.8. For example, one can purchase a new car in 138 months in Mexico City, or 141 liters of gasoline, or 342 one way metro ticket by related minimum wage in the city, while in London a new car can be purchased in 14 months by minimum wage or 826 liters of gasoline or 409 one way metro tickets can be purchased by related minimum wage. On the other hand, it can be seen that one can purchase a new car in 61 months, or 172 liters of gasoline, or 397 one way metro tickets.

Table 4.1, Table 2.7 and Table 2.8 provide a summary of Istanbul's traffic related and demographic indicators in comparison with the other mega-cities. It is noteworthy that Istanbul has the highest share in country GDP (with the exception of Singapore, which is also a country) among the given cities and third highest population, which further increases the scope and the importance of the traffic problem because of increasing levels of motorization and urbanization.

Chapter 3

Methodology

Since objectives of these study are making reasonably accurate projections on Istanbul traffic congestion and estimating potentials of TDM policies for decreasing congestion levels in Istanbul, the methodology can be divided into two phases after a comprehensive review and analysis of literature as summarized in the previous chapters: (1) understanding the utility of a simulation tool for studying various scenarios and making projections on traffic congestion in a busy business quarter of Istanbul (Altunizade); (2) a survey study for assessing traffic congestion perceptions of Istanbul's residents and estimating potentials of TDM policies according to the survey results.

3.1 Simulation Modeling

Simulation technique, which is widely used in various fields as well as in transportation, is an useful tool for different traffic operations to assess traffic performance or to measure the effectiveness of different alternatives of transportation engineering [146]. In this study, as discussed in previous sections regarding current traffic conditions in addition to increasing level of urbanization and motorization trends in Istanbul, it is needed to use a simulation tool to capture the current conditions of Istanbul traffic congestion for making further projections for the year of 2023 and to evaluate the effect and potential of assessed TDM policies on decreasing traffic congestion levels. Many simulation software packages have been developed through out years both for academic or commercial use as well as simulators used for general purposes like ARENA, or object oriented software tools like MODSIM III, or applications oriented simulators like Automod for manufacturing, SIMPROCESS for business, MedModel for Health Care [147].

Similarly, there are several simulations tools available for different purposes in the field of transportation. The traffic simulation models can be classified into three categories [148, 149]: (1) microscopic models, which focus on dynamics and characteristics of individual vehicles in relatively small areas as well as interactions between vehicles by using car-following and lane changing algorithms to provide very detailed information regarding traffic performance of a system; (2) macroscopic models, which are used in a relatively large network representing the traffic with main properties such as flow, density, and speed, therefore, provide less detailed information compared to microscopic models; (3) mesoscopic models, which consider main properties of the traffic flow (flow, density, and speed) and evaluates interactions and relationships between them. Mesoscopic models can be considered as in between microscopic and macroscopic models. In this study, a microscopic simulation tool is planned to use to capture the current traffic congestion conditions in Istanbul as well as for making projections under different scenarios due to their ability to simulate more advanced conditions of traffic and provide more detailed information on traffic performance like average travel time, average delay, capacity, speed etc.

A microscopic traffic simulation tool is described as "tool that models individual vehicle movements based on car-following and lane-changing theories on a second-by-second basis for the purpose of assessing the traffic" [148]. There are many microscopic traffic simulation software packages available in the market. The most popular of those packages are Aimsum (Spain), CORSIM (USA), MITSIMLab (USA), Paramics (UK), and PTV VISSIM (Germany). Among these software tools, MITSIMLab developed by Massachusetts Institute of Technology is the only one for research use, while the rest is all for commercial use. In this study, PTV VISSIM 6.0 version was used for simulation due to its advantage over the others as it is based on 'physco-phsycal' driver behavior model [150].

3.1.1 A Brief Description of PTV-VISSIM

PTV-VISSIM is a microscopic, time-step, and behavior-based simulation model which is developed to model traffic operations and analyze traffic performance in a small area of urban network for detailed operational analysis or to lager areas including freeway and arterial corridors [151]. It was originally developed at the University of Karlsruhe, Germany, but its commercial versions are available since 1993 by PTV Transworld AG. The software can be used to analyze traffic and transit operations under various constraints such as lane configuration, traffic composition, bus stops, traffic signals etc., making it a useful tool for assessing traffic performance on several indicators such as delay, average travel speed, average travel time and evaluating different alternatives under various scenarios. Therefore, it helps decision makers, transportation planner or traffic engineers to make well-informed and more reasonable decisions.

As mentioned above that VISSIM has advantage compared to the other models as it is based on 'physco-phsycal' driver behavior model instead of using constant speeds and deterministic car following logic [152]. The model was originally formulated in 1974 and reproduced in 1999 by Rainer Wiedemann [153]. This model can be described in four (4) states [153]: (1) free driving - which means vehicles in VISSIM proceed at her/his desired speed if there are no obstacles in front; (2) approaching - which means if the vehicle hindered by a slow moving vehicle, it brakes and decelerate within a desired gap to correspond with the vehicle in front; (3) following - which means when following a vehicle in front, the driver maintain his/her speed in a reasonable distance; (4) breaking - which means if the vehicle in front decelerates, then the vehicle behind also must decelerate. The lane change logic also shows similar characteristics: (1) free lane changing - when desired speed of the vehicle behind is higher than the vehicle in front, it overtakes to reach its desired speed if there is no other obstacles; (2) necessary lane changing - if driver needs to change lanes in order to follow a route, he/she changes lane. Therefore, it can be considered as one of the best available micro-simulation tool for representing 'real world' data by capturing the real operations of vehicles' following and lane changing behaviors.

To establish a network model in VISSIM, type of necessary data can be divided into two categories [152]: (1) static data, (2) dynamic data. Static data represents the road network, links with start and end points, characteristics of lanes, connectors, nodes, edges, speed limits, location of stop signs and signal timing plans etc. While dynamic data represents traffic volumes entering the network for all links, traffic volumes entering for different turn directions at each intersection etc. Therefore, a representative district (Altunizade business district in the Asian side) reflecting conditions of Istanbul traffic congestion has been chosen in order to evaluate and to make further projections. The required data both static and dynamic has been collected by field studies in the representative district.

3.1.2 Selected Network: Altunizade District

Altunizade district, as shown on Figure 3.1, is located in the Asian Anatolian side of Istanbul as part of a historical town of Üsküdar. It provides connections between Üsküdar and other Asian side towns and the European Side as one of main arterial roads of the First bridge passes through the district. It also serves as an important commercial center where branches of many banks, numerous franchised stores of local and global brands, and one of the first shopping malls in Istanbul (Capitol) as well as some local shops are located. There are also four different university campuses, two hospitals and a great number of residential buildings in the area. The selected road network (in the area of about 1km*1km) covers various type of roads including linking roads, arterials and local streets. Since it consists of various roads, education buildings, hospitals, residential buildings and also serves as a commercial district, it can be considered as a typical representation of Istanbul in terms of urban network with large traffic flows.

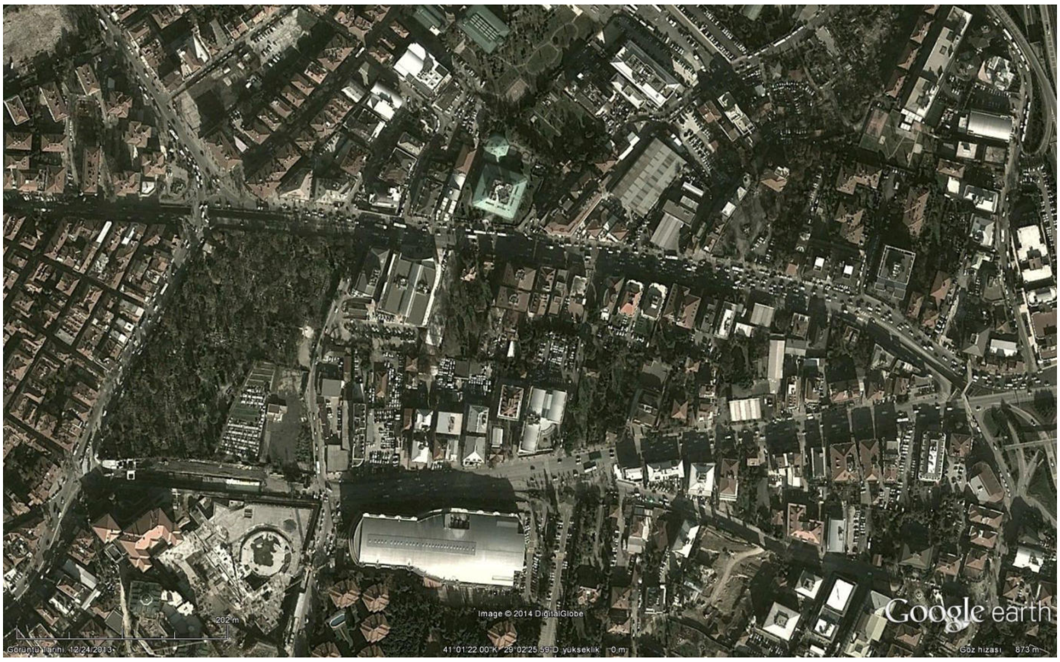

FIGURE 3.1: Study area in Altunizade District obtained from Google Earth

3.1.3 Modeling Network

The first thing to start modeling the network after selecting the district is to gather data for the location and lengths of the links, the connectors locations, their topological relationship with links, the number of lanes and their widths, so that the traffic performance (speed, travel time, delay etc.) are not affected by these basic facts. Thanks to the user friendly interface of VISSIM, it is easy to input these kinds of data into the model by obtaining an aerial image from Google Earth just after conducting a small field study in the district regarding the properties of links, connectors and lanes (see Figure 3.1). This can be done by using a scaled background graphic and setting the scale in VISSIM with respect to the obtained image.

The next thing to do is gathering static data, which represents the road network, links with start and end points, characteristics of lanes, connectors, nodes, and edges, as well as speed limits, location of stop signs and signals etc. After this stage, one can start to create the network onto scaled background image according to the collected data so far. Several link types defined in order to control driving behavior or characteristics of links such as length, urban or highway, number of lanes on each link etc. Then, characteristics of lanes are defined including the width of each lane. The representation of intersections between links is required to use connectors that serve to join two links. Therefore, the intersections are placed into the network. The next step is to determine where to place stop signs and signals. After placing stop signs and signals, determinations of desired speeds and reduced speed areas in the network have been entered into the model. The next step is to determine whether the traffic signals time is built-in fixed time or dynamic. In the whole network, there are only two semi-dynamic signal heads, the rest are fixed time. The semi-dynamic signal heads are determined in a fixed time range when pedestrian are present, the red light goes on and stop the traffic flow if the minimum time of fixed time range is reached if no pedestrians wait for the minimum fixed time. The signal heads time interval data are collected by field study in different hours of day and different days. For the semi-dynamic signal head, the data also collected but the mid-range times are used, which means if red time of a signal head is in the range of 90 sec and 130 sec, the time is determined as 110 sec. The signal timing plans are entered into model according to these field surveys. There are several non-signalized intersections required determination of priority rules. Thus, the last thing was to input priority rules into the model. After this stage, the static inputs of the network have been completed. Figure 3.2 is a snapshot of the network including links, connectors, reduced speed areas, stop signs etc. with and without background image.

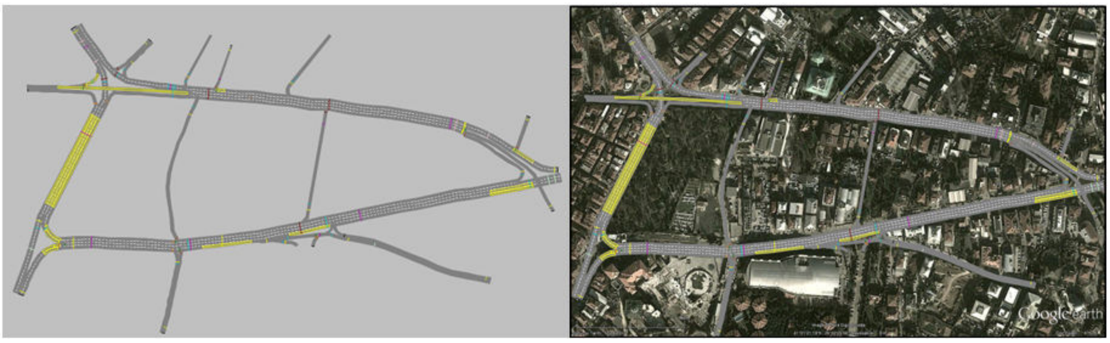

Figure 3.2: A snapshot of the network with and without the background image

After the process of static data input, the next phase is dynamic data input, which includes routes, vehicle types, traffic volumes entering the network for all links, and traffic volumes entering for different turn directions at each intersection. The first thing to decide was vehicle types whether car, truck, bus, tram, bike, and pedestrian. Typical urbanized vehicles (car, truck, and bus) are selected, accordingly. For the routes, fixed routes option is selected in VISSIM, which are fixed sequence of links and connectors. Data for traffic volumes in all links and turn directions at intersections are collected by field study in the district. First, the links where traffic volumes enter the system and the turn directions at intersections where the traffic volume separated into different routes have been determined. There are 11 links and 10 different intersections in the system.

Traffic volume varies with the fluctuations in different factors (e.g. due to day of the week, time of the day, seasonal effects, incidents, road works, weather conditions etc.). Therefore, the data collection methodology for traffic volumes is designed according to eliminate effects of these factors at minimum. First, traffic volumes are measured in different days of the week and different hours of the days to find out which days and what times the peak times occurred. According to these results, Mondays and Fridays reflect biased data because of being the beginning of week and end of weekdays, therefore, Tuesday, Wednesday, and Thursday have been selected as field days. Likewise, measurements of traffic volume in a day reflect that the peak times occurred in the district between 5.00 pm and 7.30 pm. The measurements of traffic volumes were performed during school time in two different weeks in the days of Tuesday, Wednesday, and Thursday between 4.30 and 7.30 pm. Then, the measurements of 11 links and 10 intersections were performed. Finally, the simulation model of the network became ready for the first runs after the traffic volumes were assigned into model in VISSIM.

3.1.4 Validation of the Model and Experimental Procedure

The network was simulated for a period of 3900 seconds (1 hour and 300 seconds) for each run. The first 300 seconds of every run is considered as warm-up period and were not used in analysis phase. Travel time measurements are performed on selected routes. Delay is calculated by VISSIM according to subtracting theoretical (ideal) travel time from the actual travel time. For the validation of the model, firstly, several measurements were performed in real life by different drivers for finding travel times on specified routes at peak times to get actual travel time as well as at night times to get ideal travel times to calculate delay. Then, the model has been run for multiple times with random seeds to compare with real life data. According to results, there were significant difference between simulation results and real life results in terms of delay and travel times. The reason for this difference is considered to be lack of PT stops. Then, the model is updated by using reduced speed areas on PT stops to eliminate PT stops effects on traffic flow. A hypothesis testing was developed claiming that there are no significant difference between real time values and simulations values in terms of travel times (see Appendix A). Finally, it can be said that the last version of the model was good enough to capture real time traffic flow in the district.

The experimental procedure needs to be determined according to scenarios, delay, travel time, and number of runs. VISSIM calculates delay by subtracting ideal time and actual travel time. Since ideal time is calculated according to the situation of no other vehicles and/or no signal controls or other reasons for stops, the model was run with very low traffic volumes in order to capture night time travel times to use as ideal time, which considers signal controls as well, to compare with actual time. On the other hand, the number of simulation runs needs to be determined to obtain sufficient data from the model. Therefore, 30 simulation runs were performed as pilot experiment. The minimum number of runs were determined by the following formula [154]:

$$n = \left(\frac{t_1 - \frac{\alpha}{2} \sigma_d}{\epsilon^d} \right)^2 \tag{3.1}$$

where

- n: the required minimum number of simulation runs
- $t_1 - \frac{\alpha}{2}$: t-distribution with the confidence level of 1 - α, where $\alpha = 0,05$ is selected in our experiment
- σ_d: the standard deviation of travel times (the standard deviation of our pilot experiment runs is used as sample standard deviation)
- ϵ_d: the accepted error ($\epsilon_d = \mu_d * 0.05$ is used where μ_d is the mean travel time of pilot experiment runs)

The required number of simulation runs was found as 3 by applying Equation 3.1. However, to get more sufficient results, the simulation model was run 5 times for each case. As a result, the simulation model of the selected network is ready to make future projections regarding Istanbul traffic congestion in terms of delay (see Figure 3.3).

3.2 Survey Study

To assess the potential effect of TDM policies, a survey study has been conducted. Surveys are often a useful way of capturing demographical variables by following a sampling approach. In a survey, data are collected from a population by using methods such as questionnaires. It is oftentimes used for fields such as marketing research, psychology or sociology. Surveys have been used extensively in the form of questionnaires to assess the potential effect of traffic measures as well [138, 155].

A set of representative sample allows one to draw conclusions about the larger population from which the samples are drawn. This makes it feasible to infer the variables related to the population where questing each and every individual is impractical. However, one should be careful while using surveys as a tool of inference. For example, conducting surveys over a very small number of people with respect to the population size may

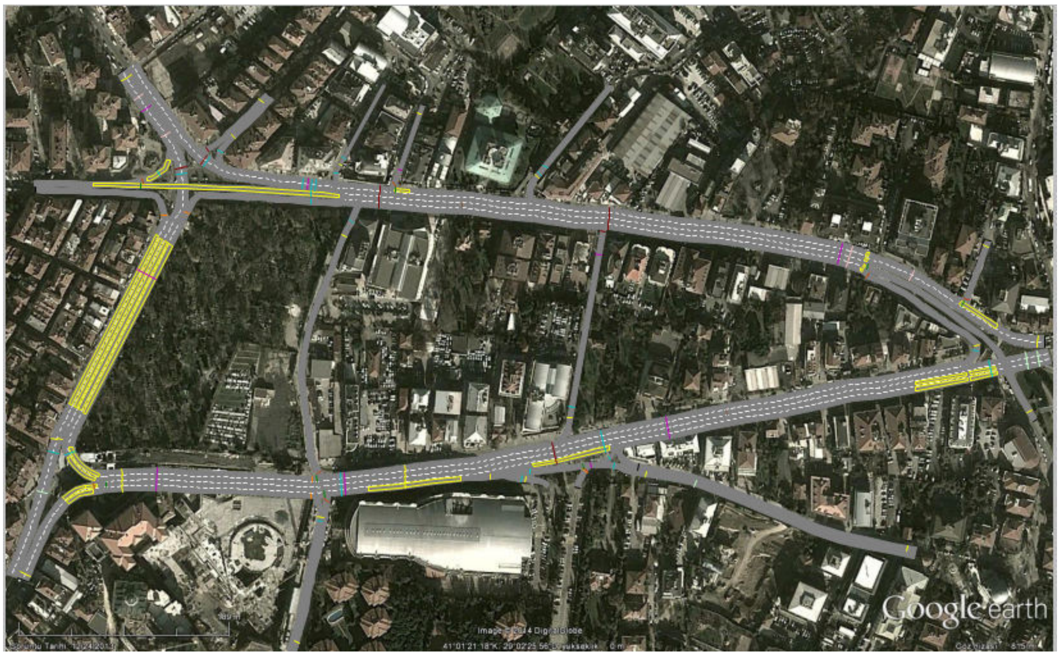

Figure 3.3: Updated version of the model

result in erroneous data. Moreover, choosing subjects that does not represent the general population (e.g., people that do not follow the same gender, age, occupation distribution as the general population) may result in a deviated results. Determining a number for the sampling size is related to three variables: Population size, margin of error and confidence level. Using 15 million as the population size, 3% as the margin of error and 95% as the confidence level, the number of respondents needed is determined to be around 1000.

In the context of our study, since surveying over near 15 million people in Istanbul would be impractical, 152 people are surveyed considering the scope and time limitations. This is significantly lower than the number stated above, and it is needed to be validated for further use. To this end, representativeness of chosen 152 people is validated by asking questions that aim to capture the distribution of the chosen population that in terms of variables that are relevant to the representativeness (e.g. age, sex, type of population, district etc.). The results reveal that the data obtained as a result of study is representative, hence suitable for determining the potentials for traffic measures, as it will be presented in the result section.

3.2.1 The Survey

The survey was conducted among the inhabitants of Altunizade, Üskudar, Istanbul. The questionnaire, which consists of 45 questions, was distributed as hard copy to 152 respondents who submitted the questionnaires back. The questions can be roughly divided into three subcategories: (i) Demographic questions such as the age group, gender, level of education, income and type of population (working or not), which aim to determine the representativeness of the respondents with respect to the general population; (ii) Questions that aim to determine potential effects of certain traffic measures by evaluating their level of applicability for people; (iii) Questions that aim to determine willingness, i.e., the level of consciousness and determinedness among people to solve traffic problem.

Since the survey was conducted in-person and in hard copy, the response rate was close to 100%. Only a few surveys were eliminated since they lack answers in many of the questions.

3.2.2 The Need for Calculating the Potential Effects

It is relatively straightforward to foresee that traffic measures will have positive effect on traffic by reducing traffic congestion. However, the extent to which these measures will be effective is of interest to determine measure or measures to be applied. To this end, we present a strategy for calculating the potential effects by using the type II and type III questions described above. Our method also includes a best-case and worst-case prediction, in which the minimal effects and the maximals are predicted, respectively. Our approach has similarities with the work of Mokhtarian [138], which aimed estimating the potential impacts of telecommuting on travel. Although both methods have similarities, since our work is concerned with a different problem, we find it unnecessary to follow the same notation.

3.2.3 Distribution of Questions

In the study, potentials are calculated for six different types of traffic measures. These are: (1) Workplace Travel Planning (WTP), (2) School Travel Planning (STP), (3) Personalized Travel Planning (PTP), (4) Marketing, Information and Travel Awareness (MITA), (5) Car Clubs and Car Sharing (CCCS), and (6) Online Shopping (OS). The distribution of questions in the survey with respect to the measures are given in Table 3.1.

For each traffic measure, the associated questions are asked to determine the applicability of the measure. In addition to the question numbers given above, questions 25 and 26 were asked to determine the willingness score, hence constituted the type III questions. The remaining questions (i.e., question number 1-12, 14-16 and 18-21) are used to determine the representativeness of the group and for statistical purposes. The list of questions asked are given in Appendix B.

Table 3.1: Distribution of survey questions with respect to the traffic measurements

Policy	Question Number
Workplace Travel Planning (WTP)	29, 30, 31, 32, 33, 40, 41
School Travel Planning (STP)	36, 37, 38, 39, 40
Personalized Travel Planning (PTP)	23, 27, 42
Marketing, Information and Travel Awareness (MITA)	17
Car Clubs, (CC)	13
Online Shopping (OS)	44, 45

3.2.4 Potential Effect Calculation

After the survey results are gathered, the potential effects are calculated for each measure. The method for calculating measures are given as follows. For multiple choice answers, the respondents' answers are first enumerated with integer values, depending the number of possible answers in each questions. For example, consider the example question given below:

"I think that the traffic problem requires immediate solutions." Do you agree?

- I definitely agree - 3 (normalized 1)
- I agree - 2 (normalized 0.67)
- I disagree - 1 (normalized 0.33)
- I definitely disagree - 0 (normalized 0)

In this question, the choices are enumerated by using integers 3,2,1 and 0, respectively. To incorporate the choices in a more meaningful way, the values are normalized, i.e., all the values are divided by the largest value, resulting in 1, 0.67, 0.33 and 0 in this case.

After the normalized values are obtained for each answer of each respondent, these values are used for calculating the overall effects of the measures: For each measure, the mean normalized values for associated answers are averaged, and that number is used to quantify the potential effect. For each measure, we define an effect variable, e_i, which is defined as follows in Equation 3.2:

$$e_i = f_i.p_i.w_i, \tag{3.2}$$

where e_i is the effect variable associated with i'th measure (where i ranges from 1 to 6 (i.e., the number of measures)). The variables that are used while calculating e_i is given in Table 3.2.

TABLE 3.2: Variables used while calculating e_i

Symbol	Variable Name	Explanation
f	Fraction	Fraction of trips by purpose
p	Potential Effect	Potential effect determined from the survey
w	Willingness	Willingness potential determined from the survey

For example, when the potential for personalized travel planning is to be calculated, the normalized quantified values for each answer was calculated for each associated question (i.e., questions 27, 42 and 23). Looking at Appendix B, it can be seen that the question 27 has five possible answers, ranging from 'very strong' to 'very weak'. These answers could be quantified by using integers from 4 to 0, which can be then normalized to have a range between 0 and 1. Let μ_{27} be the averaged out responses for 27th question over all respondents. μ_{27} is calculated as follows:

$$\mu_{27} = \frac{1}{152} \sum_{i=1}^{152} r_i^{27}, \tag{3.3}$$

where r_i^{27} is the answer given to the 27th question by the i-th respondent. In this example, μ_{23} and μ_{42} are calculated in a similar fashion to μ_{27}, which are then combined to calculate the potential effect of the PTP measure:

$$p_i = \frac{\mu_{23} + \mu_{27} + \mu_{42}}{3} \tag{3.4}$$

Fraction of trips by purpose was given in the Second Chapter in Table 4.1. The details of the calculation for willingness based on various scenarios is provided in next section. After all the variables are obtained through the relevant calculations, the overall effect, which is denoted as E, is calculated as follows:

$$E = \sum_{i=1}^{n} e_i. \tag{3.5}$$

The E value provides the overall effect introduced by the traffic measures. To convert this effect into a percentage representation, a suitable weight should be found. To this end, it can be argued that the effect of each policy types correlates each other with exception of WTP and STP. Because, WTP and STP only effects the trips regarding homed based work and home based school trips, while the other policies (PTP, MITA, CC and OS) effects all types of trips (Home based work, home based school, and home based others). For this reason, it is very difficult to measure compound effects between each policy. Therefore, WTP and STP were taken into consideration when determining overall effects of TDM policies to decrease traffic congestion levels. The other policies were considered as the policies that triggers the overall effects of WTP and STP. As a result, the E value only includes WTP and STP overall effects which is used as input for simulation modeling. Since it does not take into account the other measurements besides WTP and STP, it can be said that our model captures the worst case potential effect. If the other measurements can be combined with these measurements (WTP and STP), the overall effect would be even larger than the overall effect estimated by our model. Therefore, it does not mean that our model is not well enough to estimate potentials of TDM measurements as it gives and estimates the lower-bound for overall potential.

3.2.5 Generating Scenarios

As stated above, the willingness score is used to quantify the level of consciousness and determinedness among people to solve and/or to contribute towards the solution of the traffic congestion problem(s). Hence, since the people are the main subject of traffic awareness and measures, willingness of people can be used to generate a best-case and worst-case scenario. To this end, we use the results of questions associated with willingness to determine these estimates. For the worst-case estimate, we use the average percentage of people who responded to willingness questions as "I definitely agree". For the average case estimate, we use the average percentage of people who responded as "I definitely agree" and "I agree". Finally, for the best case scenario, we use all percentages except "I definitely disagree".

Chapter 4

Results

4.1 Representativeness of Respondents

A total of 152 respondents were included in the survey study. The respondents generally constitute a representative sampling in terms of age groups, level of education, and districts. The age distribution of the participants is given in Figure 4.1. The education status of the participants is provided in Figure 4.2. The participants are selected from around 30 different counties of Istanbul, creating an overarching study. Sixty four percent of the respondents were male, which may seem not representative at first sight, but actually provides a better representation of the drivers in Istanbul. Besides, more than 80 percent of the participants had an income lower than 4000TL, which can be also considered as representative of the larger population.

4.2 Traffic Perceptions of Residents in Istanbul

As a part of our study, traffic perception of the inhabitants of Istanbul is studied. The results suggest that the traffic congestion problem is significantly perceivable among the inhabitants of Istanbul. Sixty percent of respondents feel stressed either every time or every day they travel between home and work place/school. People who report that they almost never experience stress is only 12%. Traffic congestion and the transportation problem is considered as the most crucial problem of the people of Istanbul, ranking ahead of 'cost of living' and 'cost of housing'.

A noteworthy result of the survey study is that respondents ranked the human factor as the second most responsible factor in traffic problems behind the metropolitan municipality. This suggests that people are aware of the fact that human factor is one of

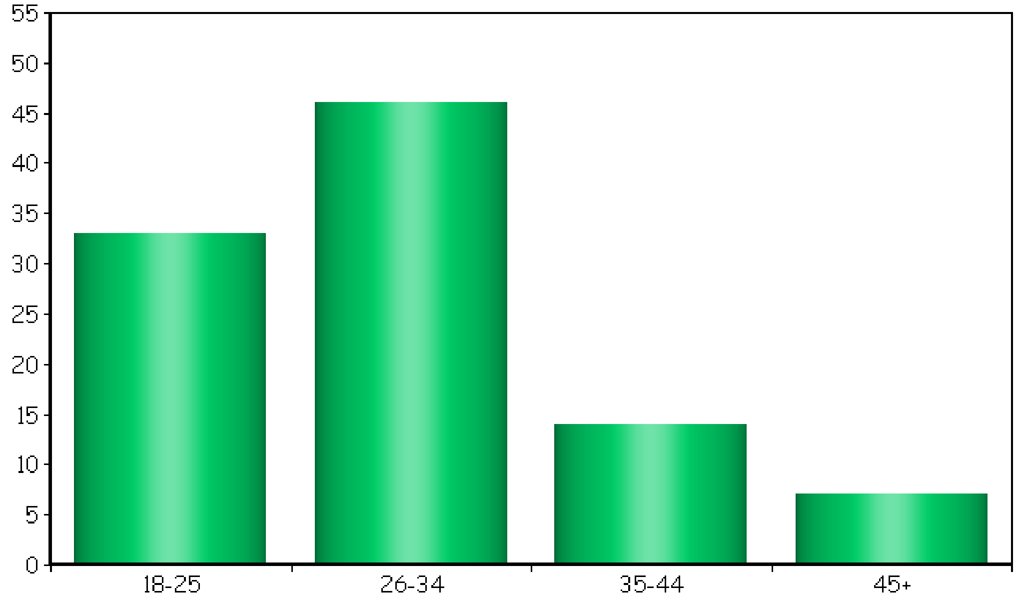

FIGURE 4.1: Distribution of respondents with respect to age groups (%)

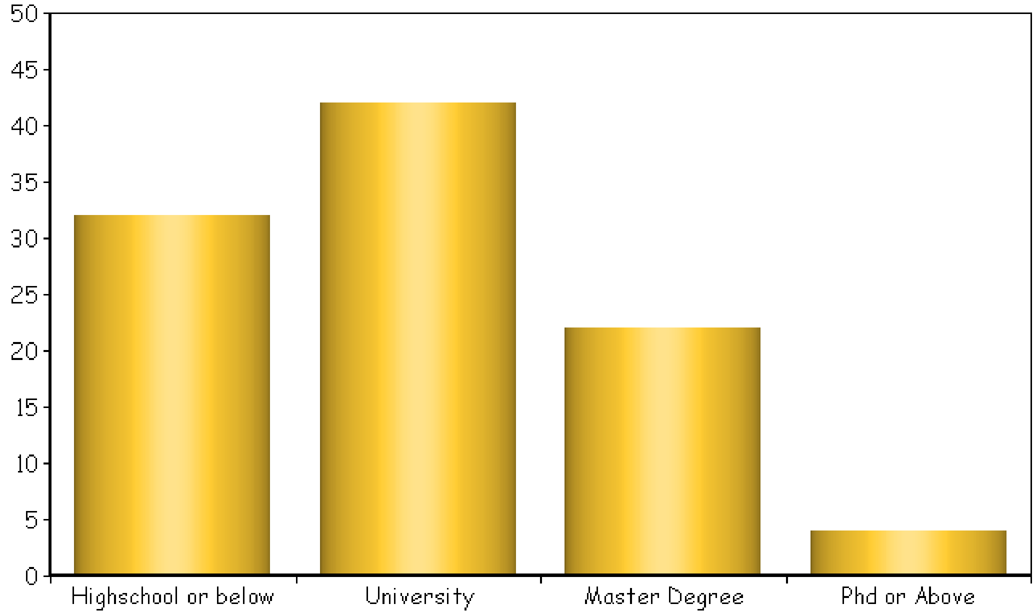

FIGURE 4.2: Education level of respondents (%)

the main responsible parties and stakeholders of the traffic problem, increasing the possibility of traffic measures to be adapted by people. Another valuable outcome of the survey study is that expenditures on public transport are perceived as the most effective solution for solving the transportation problems of the city. Given the inhabitants' relative unawareness of the soft traffic measures, this is promising as an indicator of people's willingness to take part in the solution. The second most effective solution according to the respondents is change of travel times and means to reduce congestion without changing the existing infrastructure. This is just a restatement of the soft measures,

TABLE 4.1: Trip composition by purpose in Istanbul

Trip Purpose	%	% after distribution of NHB (fi)
Home Based Work (HBW)	53	58
Home Based School (HBS)	15	16
Home Based Other (HBO)	24	26
Non Home Based (NHB)	9	-

TABLE 4.2: Potential effects for the policies

Policy	Potential Effect (p_i)
Workplace Travel Plans	0.67
School Travel Plans	0.81
Personalized Travel Planning	0.37
Marketing, Information and Travel Awareness	0.27
Car Clubs, Car Sharing	0.28
Online Shopping	0.28

and well accepted by the respondents. The biggest concern of the respondents about public transport is public transport being overcrowded and uncomfortable. This can be considered as an opportunity by the relevant authorities to improve the quality of service in public transportation to reduce traffic problems.

All in all, responses from survey related to the traffic perception suggests that the residents of Istanbul are aware about the significance and degree of traffic issues, its relative importance compared to other problems are faced in the urban life in Istanbul, and more importantly, they accept the fact that they are part of the problem, hence their cooperation is a must for a comprehensive and permanent solution. Furthermore, they think that actively and positively altering the peopleâs choices without costly infrastructure investments is one of the more important policies in bringing long-term, permanent and inexpensive solutions to the traffic problem. To sum up, it can be said that all these findings implies the great potential that the soft policies possess.

4.3 Calculating Potential Effects

By using the responses of 152 participants, the potential effects were calculated for six different measures, using the method described in the previous section. Table 4.1 shows the fraction of trip purposes (f_i) while Table 4.2 shows potential effects of the measures (p_i).

As stated in the methodology section, the potential effects are used in calculating the e_i values, and hence the E value, which denotes the overall effect of the measures. Using

TABLE 4.3: e_i values of all measurements for the worst and the best case scenarios

Policy	e_i in worst case	e_i in best case
Workplace Travel Plans	0.17	0.29
School Travel Plans	0.06	0.10
Personalized Travel Planning	0.04	0.07
Marketing, Information and Travel Awareness	0.11	0.20
Car Clubs, Car Sharing	0.03	0.06
Online Shopping	0.03	0.03

TABLE 4.4: % Predictions of overall effects

Policy	% Prediction for worst case	% Prediction for best case
Workplace Travel Plans	17	29
School Travel Plans	6	10
Total	23	39

the method derived in the methodology section, the e_i values are calculated as follows (see Table 4.3:

After having e_i values, using the method that we described in the methodology section, we convert from e_i values of WTP and STP to actual percentages for worst and the best cases. Our final predictions for overall effect of TDM policies for decreasing traffic congestion levels are given in Table 4.4.

4.3.1 Congestion Levels in Istanbul and Future Projections under Different Scenarios

As mentioned earlier, congestion level is calculated as "the average percentage increase in travel time during period of peak congestion, compared with when roads were running freely". According to this, a base simulation has been run which was used as the ideal time of a network without congestion (usually taken as the night time). Then, simulation has been run for second time to estimate current congestion levels of Altunizade district in 2014. This ideal time was then used as a base level for comparing with current congestion level in 2014. This ensures that the congestion level of the district at peak times decently represents Istanbul's congestion levels in general. In other words, it is used for validation of the model. Tom-Tom congestion level of Istanbul at evening peak times in 2013 is 127%. Table 4.5 shows the results of the base simulation run and the year of 2014 simulation run, so that it can be seen that the model captures the real time traffic congestion levels of Istanbul as well as it ensures that Altunizade district represents Istanbul averagely. There might be some discussion on regarding the difference between Tom-Tom congestion level of 127% in Istanbul and simulation congestion level (131%), it can be said that the difference might have occurred due to difference between school

Table 4.5: Validation of the model

	Base simulation run	The year of 2014 run
Number of Runs	10	10
Average Travel Time (all)	135 sim sec.	311 sim sec.
Congestion Level (%)	0	131

Table 4.6: Congestion levels (%) of Istanbul under different scenarios

Year	As Usual Scenario	Worst Scenario	Best Scenario
2014	131	122	108
2018	146	129	115
2023	159	139	127

time congestion level (simulation run) and average congestion level which averages school time and summer-time (Tom-Tom congestion level). After ensuring representativeness of simulation model, the simulation model has been run for different scenarios in 2014, 2018, and 2023. Table 4.6 shows congestion levels (%) of different scenarios in respective years.

As mentioned earlier chapters, the main problems associated with increasing urban traffic and congestion have very real economical, environmental, and social consequences. For example, economic efficiency, air pollution, equity, energy consumption, loss of 'urban space', severance, noise etc. To illustrate this for the case of Istanbul, approximately 54 % of households in Istanbul have no access to a car - in other words - they pay the price of traffic without enjoying mobility benefits offered by car ownership [2, 13]. This means a threat for equity. Traffic is also deadly for the residents of Istanbul due to traffic accidents. For example, over 50.000 traffic accidents resulted 232 deaths and over 21.000 residents were injured in the year of 2012 [156] and this figure is pretty much same every year. Furthermore, traffic congestion, pollution and accidents result in significant direct and indirect costs which decrease economic efficiency and competitiveness of the city. In Istanbul, residents spent on average approximately 100 minutes a day travelling to and from work, which adds up to three working days a month [157]. In other respects, an average Istanbulite's commuting from work to home in the evening peak takes 2,5 times than free-flow time which means 20-minute commuting time of a driver in this period results in 10-hour loss a month [158]. According to a study within the Ministry of Development, traffic congestion in Istanbul costs 2,7 billion $ in the year of 2010 with respect to direct costs of travel time, the capital cost of vehicles and pollution [159].

In the light of aforementioned facts and projected congestion levels within the scope of this thesis, it can be estimated that traffic congestion related problems within the city tend to become worse as it is projected that it will increase from % 131 in the year of 2014 to % 159 with a approximate rate of % 22. In a roughly estimation, the cost of traffic congestion within the city will increase to 3,3 billion $ in the year of 2023 with an increase of 0,6 billion $. However, application of TDM measures offers significant potential to alleviate traffic congestion related problems in the city. Under the worst scenario, the application of TDM measures could decrease the expected congestion level %159 for the year 2023 to %139 which means reducing approximately 200 million $ in the cost. It also might offer potential for the year of 2023 even to decrease under the levels of 2014 from %131 to %127 under the best scenario. This means there might be 90 million $ fall in the cost of traffic congestion for the year of 2023 comparing to the year of 2014. Of course, these estimations do not consider the indirect costs such as fatalities and injuries related to traffic accidents, equity problems, public health issues resulted from increasing air pollution, noise and vibration, or decreasing quality of urban life due to parked cars and other infrastructure related visual intrusion or severance of communities because of congested urban roads which can have a social cost. By adding this costs into the problem, the traffic congestion problems get even worse, but at the same time, potential of TDM measures also increases for alleviating associated problems.

Chapter 5

Conclusion

As a summary, this thesis focuses on the question how worse would current traffic congestion levels of Istanbul become in the following years and what can be done to alleviate this problem in the sense of achieving sustainable urban transportation. A brief recap of sustainability, sustainable development, urbanization, motorization and sustainable urban transportation concepts summarized in the earlier chapters which helped to understand and to form a framework for this study. Travel demand management (TDM) policies, which canalize people for social behavioral change, have been widely searched and discussed within this framework. Afterwards, a survey was designed to reveal traffic perceptions of Istanbul's residents as well as their responses to these policies for estimating potentials of TDM measures to alleviate congestion effects in the city. In parallel with survey, a micro-simulation tool (VISSIM 6.0) has been used to capture the current congestion levels in the city to make further projections under different scenarios according to the responses of residents obtained from survey results. Finally, some of the shortcomings of this research experience and possible future work will be highlighted.

On one hand, transportation of goods and people is vital for economic development and social life. On the other hand its negative effects (i.e. congestion, delays, air pollution, noise, environmental degradation etc.) risk economic development, social well-being, and most importantly sustainability of our world. Since it is known that building more roads makes driving more attractive and automobiles are unsustainable mode of mobility, it is significant to change our travel modes towards more sustainable modes like public transportation, walking and cycling to mitigate this effects, especially, resulted from traffic congestion. Besides, increasing urbanization and motorization rates makes the problem much more complicated, so that it requires urgent, extensive, and widely participative approach to take actions. In this sense, TDM policies were brought up to use existing infrastructure more efficiently, to canalize people for social behavioral change towards the sustainable modes, and to alleviate unnecessary travel demand. A deeper understanding of the residents' travel patterns, their perceptions of the traffic congestion, and their willingness for change helped us to develop appropriate strategies with the potential to influence travel patterns of people towards more sustainable modes.

As the economic, financial, cultural, and industrial center of Turkey as well as a widely used trade route due to its geo-political prominence, Istanbul's traffic congestion problem is alarming. Investments on road network and public transportation network do not keep up pace with increasing traffic demand due to the increasing urbanization and motorization levels, especially during the last decade. Furthermore, the result – based on the comparisons of Istanbul with various world mega-cities as part of this study – indicates possible gaps in management level especially for TDM measurements. Therefore, a micro simulation modeling of a representative district has been modeled to capture the current traffic congestion level in Istanbul for making further projections to estimate how badly it will become in the years of 2018 and 2023. Since the TDM measures are very new to the city, it might offer great potential to mitigate congestion levels. In this manner, survey methodology has been used to reveal traffic perceptions of Istanbul's residents as well as their responses to these policies for estimating potentials of TDM measures. The questionnaire consists of 45 questions and it was handed to 152 participants who were selected representatively. The first part of the questionnaire consists of the questions to ensure the representativeness of the sample, while the second part tries to find out the traffic perceptions of the residents, and the last part focuses on their responses on different type of TDM measurements. After survey stage has been completed, the results suggest that our sample is representative for the population, and the traffic problem is significantly perceivable among the inhabitants of Istanbul. Furthermore, the questions related to TDM policies were converted into quantitative potentials as percentage to decrease congestion levels according to the obtained results. Therefore, it can be seen that TDM policies offer great potential. Then, different scenarios have been generated for the years of 2014, 2018 and 2023. Finally, the simulation model has been run for those scenarios by transferring the potential effects into the simulation model for estimating their effects on mitigating congestion levels in respective years.

Specifically, the most effective policy type to alleviate congestion levels in the city, especially at peak times, was found as Work place travel plans (WTP). It has the potential impact to decrease traffic levels with the percentage of %17 in the worst scenario and %29 in the best scenario. The reasons behind this might be: (1) employers in the city offer free parking to their employees, which means they punish their non-car commuter employees; (2) offering shuttle buses for long distance commuting which results in waste of time for employees and waste of transportation cost like fuel; (3) employers/state not placing emphasis on how long/by what mode employees commute to workplaces.On the other hand, School travel plans (STP) offer a potential impact of %6 in the worst case and %10 in the best case for decreasing traffic related problems in Istanbul. This might be because of: (1) poor traffic education and lack of cycling and walking trainings in school; (2) safety problems due to inadequate pavements and pavements in poor condition; (3) lack of traffic calming in the areas near schools. The other effective measurements are Personalized travel plans (PTP) and Marketing, information and travel awareness campaigns (MITA). These offer potential because: (1) there are people in the city find the public transportation very complicated which means they don't know very much about the routes of the buses, minibuses, trams etc. or sometimes a new line is opened in the city but some of the residents never hear about it for a long time if they had known they would possibly choose these modes; (2) there are people who think that automobile is not harmful to environment and public health. Furthermore, car clubs offer potential impact on traffic congestion problem since a noteworthy proportion of respondents drive annually under the limit of 15.000 km, this measurement can canalize the residents towards becoming members of car clubs with a qualified marketing and travel awareness campaigns. Lastly, as newly developing shopping habit in Istanbul, online shopping is taken as effective way by the respondents, since nearly all of the participants experience this shopping style at least couple times per year and they think that the reason behind this is mostly time lost due to travel and traffic stress.

Since WTP and STP is more applicable if it is supported by appropriate legislation, their total effect in the worst case and in the best case is taken into consideration while generating scenarios. The results of scenarios observed from simulation runs show that traffic congestion level in Istanbul will rise from %131 in 2014 to %146 in 2018 and %159 in 2023 if no such actions taken. If WTP and STP measurements are put into practice in widely consensus at the beginning and also supported by other measures in time, they have the potential to decrease traffic congestion levels from %131 to %122 in worst scenario and %108 in best scenario in 2014. Likely, congestion levels in 2018 can be reduced from %146 to %129 in worst case and %115 in best case while congestion levels in 2023 can be reduced from %159 to %139 in worst case and %127 in best case.

In other saying, traffic congestion in Istanbul costs 2,7 billion $ in the year of 2010 with respect to direct costs of travel time, the capital cost of vehicles and pollution. In a roughly estimation, the cost of traffic congestion within the city will increase to 3,3 billion $ in the year of 2023 with an increase of 0,6 billion $. However, application of TDM measures offers significant potential to alleviate traffic congestion related problems in the city. Under the worst case scenario, the application of TDM measures may have the potential to reduce 200 million $ in the expected cost of traffic congestion(3,3 billion $) for the year of 2023. It can be also seen that TDM measures may even decrease traffic congestion cost of the year of 2023 under the level of the year of 2014 with a 90 million

$ fall in the cost. In other words, the traffic congestion cost can be reduced from 2,7 billion $ in the year of 2014 to 2,6 billion $ in the year of 2023 which means it is not only possible to mitigate the increase in traffic congestion, but also it may become possible to decrease traffic congestion in the following years in comparison with current traffic congestion level.

The estimated potential of TDM measures for Istanbul also has potential to alleviate the other problems associated with increasing urban traffic and congestion such as air pollution, energy consumption, fatalities from traffic accidents, loss of 'urban space' due to increasing supply of transportation infrastructure for cars, noise or public heath issues because of traffic stress, noise, severance of communities, air pollution etc. These are also very critical issues for sustainability of the city with respect to economics, environment and social life. At the end, it can be seen that the current traffic congestion conditions in Istanbul tend to become worse year by year, but TDM policies offers noteworthy potential to try to keep up with this enormous growth at the same time. On the other hand since it encourage people for social behavioral change to more sustainable travel modes; it also contributes individual and public health by more exercising, environment by alleviating air pollution levels and effects results in climate change as well as economy by decreasing time lost and fuel lost due to delay.

One of the main shortcomings of this research might be the sample size of survey participants which may have been misguided us. Although survey is a very useful method for collecting data for different purposes regarding very large population, it might sometimes provide unfair data. Another shortcoming is the selected district representativeness. It may provide wrong data for us regarding future projections, but I believe that it estimates at least the minimum congestion level of Istanbul since taking into consideration that the congestion level increased from %119 in 2012 to %127 in 2013. The projections of 2023 is %159 compared to congestion level of the year 2013 can be seen as reasonable estimate.

This current study mainly focuses on the perceptions and willingness of the residents for social behavioral change with the help of TDM measurements through mitigating increasing urban traffic and congestion and the economical, environmental and social problems associated with it. Although, the results of this study offer valuable insights for future conditions of the traffic congestion and potentials of TDM measurements, it is not very accurate and valid to conclude that these measurements are very effective and applicable for the solution of urban transportation issues of Istanbul. Therefore, it is important to choose the most appropriate and applicable combination of TDM measurements and to adjust the selected combination for the city with supportive legislation, and then to begin application in a pilot program such as in a workplace, school, or a small neighborhood to attain the advantages, disadvantages and applicability of the selected measurements. Thus, more accurate potentials of TDM measurements can be attained according to the results of this pilot program. After this stage, these measurements can be applied to the widened areas and spread out the whole city. Through out the future research, the outcomes of current study help to pave the way for these future studies.

Appendix A

Hypothesis Testing

A hypothesis testing was developed claiming that there are no significant difference between real time observation values and simulation values in terms of travel times. The procedure involves following steps:

1. Computation of estimated minimum number of repetitions for testing the hypothesis.
2. Hypothesis testing for two samples.

A.1 Computation of Minimum Repetitions

The number of repetitions required can be computed according to the following equation [160]:

$$|\overline{x} - \overline{y}| > t_{(1-\frac{\alpha}{2};2n-2)} * S_p\sqrt{\frac{2}{n}}$$

where:

$|\overline{x} - \overline{y}|$:absolute value of the estimated difference between the mean values of the two samples

$S_p^2 = \frac{s_x^2+s_y^2}{2}$:pooled estimate of the standard deviation of the model run results for each alternative according to the standard deviations of the two samples

n = number of model repetitions required for each sample

t= t-statistic for a confidence level of 1 - α and 2n-2 degrees of freedom.

TABLE A.1: Minimum repetitions required for each sample in a desired confidence level

Minimum difference of means ($\frac{\lvert\overline{x}-\overline{y}\rvert}{S_p}$)	Desired Confidence	Minimum Repetitions Required
3,78	%95	3
3,78	%90	2

Before applying this formula, we have observed 30 repetitions for each sample, namely, real-time values and simulation values. Then, we have applied this formula to our samples after we have found the sample means and standard deviations. Therefore, we have estimated minimum required repetitions per sample which are shown on the table A.1 which is 3. Since we have observed 30 repetitions for each sample and this is more than 3, so it is not necessary to obtain more observations for testing the hypothesis.

A.2 Hypothesis Testing for Real System and Simulation

To determine whether simulation output provides sufficient evidence that simulation model captures real-time system, it is necessary to perform a statistical hypothesis test for to analyse if there are significant difference between the means of real-time values and simulation output. A null hypothesis is specified as " There really is no difference in the means of real-time system and simulation model." A statistic is computed for %95 level of confidence, and if the difference between the two means is less than that statistic, then the null hypothesis is accepted and it is concluded that there is insufficient evidence to prove that the simulation model does not capture real system [160].

Null Hypothesis:

H_0: $\mu_x - \mu_y = 0$

against

H_1: $\mu_x - \mu_y \neq 0$

where:

μ_x: mean travel time of real system

μ_y: mean travel time of simulation

This is a two-sided t-test with the following optimal rejection region for a given alpha (acceptable type I error):

$$|\overline{x} - \overline{y}| > t_{(1-\frac{\alpha}{2};n+m-2)} * S_p\sqrt{\frac{1}{n} + \frac{1}{m}}$$

where:

$|\overline{x} - \overline{y}|$: absolute value of the estimated difference between the mean values of the two samples

S_p: pooled standard deviation

t = Student's t-distribution for a level of confidence of 1-alpha and n+m-2 degrees of freedom

n = sample size for x

m = sample size for y

$S_p^2 = \frac{(n-1)s_x^2+(m-1)s_y^2}{m+n-2}$

where: S_p: pooled standard deviation

s_x= standard deviation of the results for x

s_y= standard deviation of the results for y

n = sample size for x

m = sample size for y

When we apply this formula to our case where the means of real time sample and simulation sample are μ_x=1504,13 sec and μ_y=1460,83 sec, respectively and the standard deviations of the samples are s_x=114,34 and s_y=147,9 with n=30 and m=30 in the %95 level of confidence it can be found that the null hypothesis that $\mu_(x)$ - $\mu_(y)$ = 0 can not be rejected. In other words, it can be said that the developed simulation model is well-enough to capture the real-system.

Appendix B

Survey Questionnaire

1. Please indicate your age interval:

   a. 18-25

   b. 26-34

   c. 35-44

   d. 45 +

2. Please indicate your gender:

   a. Male

   b. Female

3. Please indicate the highest level of education you have completed:

   a. High school or below

   b. University

   c. Master

   d. PhD or above

4. Please indicate your working style:

   a. Full-time

   b. Part-time

   c. Unemployed

5. Please indicate your average monthly income (TL):

   a. Up to 2000

   b. 2000 - 4000

   c. 4000 - 8000

   d. 8000+

6. Please write down your work/school place county:

7. Please write down your residence county:

8. Please indicate average commuting time from your home to workplace:

   a. 0 -15 min

   b. 15-30 min

   c. 30-60 min

   d. 60 min+

9. Please indicate estimated distance between your home and workplace:

a. 0-1 km

b. 1-5 km

c. 5-10 km

d. 10 km +

10. Please indicate estimated commuting time in case of no traffic congestion:

a. 0-25 min

b. 15-30 min

c. 30 - 60 min

d. 60 min +

11. Which of the following is your main transportation mode?

a. Only walking

b. Only car

c. Car + Public Transportation

d. Cycling + Public Transportation

e. Cycling

f. Walking + Public Transportation

g. Walking + Taxi/Shared Taxi

12. How often do you drive?

a. Everyday

b. 5-6 times a week

c. A couple of time in a week

d. A few time in a month

e. Non-car owner

13. If you own a car, please indicate annually estimated driven kilometer range :

a. Up to 15.000

b. 15.000 km - 20.000 km

c. 20.000 km-30.000 km

d. 30.000 km +

e. Non-car owner

14. How often do you get stressed while commuting between your home and workplace/school?

a. Every day, every moment i drive

b. Every day, in rush hours

c. Often

d. Sometimes

e. Almost never

15. Traffic daily causes extra ....(min) time to me.

16. Traffic monthly causes extra .... TL cost to me.

17. Do you agree driving a car is harmful to both health and environment?

a. Agree

b. Disagree

c. No idea

18. How satisfied are you for transportation services in Istanbul?

a. Very satisfied

b. Satisfied enough

c. Not satisfied

d. Not satisfied at all

19. Which of the following do you concern the most for Istanbul? Please order from most important to least. (Ex: a>b>d>c>f>g>e): ....

a. Traffic and transportation problem

b. High cost of living

c. Security problem

d. Job opportunities

e. Home rental/owning prices

f. Human diversity and overcrowd

20. Do you think which of the following is mostly responsible for solving traffic problem in Istanbul and how can it be solved? Please order from the most important to the least. (Ex: a>b>d>c>f>g>e): ....

a. Government

b. Metropolitan Municipality

c. Local county municipalities

d. Individuals (Residents must obey rules and care public more than themselves)

e. It will be solved by time

f. It is impossible to solve.

21. Do you think which of the following is the most effective in solving traffic problem in Istanbul? Please order from most important to least. (Ex: a>b>d>c>f>g>e): ....

a. By expanding metro and metrobus network

b. By more bus based public transportation

c. By expanding road infrastructure and building 4th bridge

d. By restriction on license plates and congestion charging

e. By improving and expanding pavements and cycle lanes

f. By making people choose more sustainable transportation modes (walking, cycling, PT) and adapting their travel time according to rush hours under the existing road and public transportation conditions

22. What do you think about restricting vehicle entrance into particular areas in the city in particular time (especially for sole drivers)

a. It absolutely works

b. It will have positive impacts

c. It is applicable

d. I don't think it will change anything

23. Do you currently hold IstanbulKart?

   a. Yes
   b. No

24. What do you think which of the following two are the most important reason behind not choosing public transportation?

   a. Overcrowded
   b. Uncomfortable (It is so cold/hot inside, lack of seating, bad smell)
   c. Safety
   d. Unreliability of waiting time
   e. So slow

25. "I would not like to drive in Istanbul if possible."

   a. I absolutely agree
   b. I agree
   c. I disagree
   d. I absolutely disagree

26. "If improved public transportation, decent pavements and cycle lanes were available, I would stop driving and prefer public transportation and walking mode most of the time."

   a. I absolutely agree
   b. I agree
   c. I disagree
   d. I absolutely disagree

27. How do you evaluate your knowledge regarding available public transportation mode (which bus/metro/ferry to take, which stop to get off, where to wait, when they arrive etc.)

   a. Very well
   b. Good
   c. Average
   d. Low
   e. Very low

28. Which of the following regulation will be the most effective for alleviating traffic congestion problems? Please order from most important to least. (Ex: a>c>b>): ....

   a. Regulations based on employees commuting time and modes (Different working times, dedicated buses, PT car etc.)
   b. Regulations based on students commuting time and modes (Different school time etc.)
   c. Regulations for other activities (shopping, leisure)

29. Do you think how important your workplace being close to your home?

   a. Very important
   b. Normal
   c. Little
   d. Not important at all

30. Does your workplace provide you free dedicated buses?

a. Yes

b. No

31. Does your workplace provide you free parking?

a. Yes

b. No

32. Do you think how much your workplace concerned your mode of transportation for commuting?

a. Very much concerned

b. Normal

c. Little

d. Not concerned at all

33. "If there would be safe and wide pavements/sidewalks available, I would like to walk to my workplace/school"

a. I definitely would walk

b. I would walk couple days in a week

c. I would walk sometimes

d. I would never walk

34. What is the estimated distance between your child's school and home?

a. 0-1 km

b. 1-5 km

c. 5-10 km

d. 10+

e. I'm not a parent

35. What transportation mode do you prefer for your children to commute to school?

a. Dedicated school shuttle

b. Walking

c. Cycling

d. I drive them by myself

36. What transportation mode do you children should use ideally?

a. Walking

b. Cycling

c. I would like to drive them by myself

d. Dedicated school shuttles

37. "Streets are dangerous for our children because of cars"

a. I agree

b. I disagree

c. No idea

38. "If streets would be safe for children, I would prefer my children to go school with accompany of their friends and teachers"

a. I agree

b. I disagree

c. No idea

39. "Traffic education is inadequate in schools."

a. I agree
b. I disagree
c. No idea

40. What would you think if workplace/school working hours will be changed in-compliance with alleviating traffic levels?

a. I would definitely be optimistic
b. I would be optimistic
c. I would be pessimistic
d. I would definitely be pessimistic

41. "I would work at my home without going to my workplace one or two days in a week, and this will not be a loss for my workplace but it will be very beneficial for me"

a. I definitely agree
b. I agree
c. I disagree
d. My job is not appropriate for this

42. Do you change your time for travel, mode of transportation according to traffic congestion?

a. Always
b. Usually
c. Sometimes
d. Never

43. Have you ever heard about car clubs or DriveYoyo?

a. Yes
b. No

44. How often do you shop online?

a. Once a week
b. Couple times a month
c. Couple times a year
d. I shopped online couple times in my lifetime
e. Never

45. What do you think about the main reason for shopping online?

a. Transportation problem
b. Better prices
c. Searching/fitting trials problems
d. Time saving

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