Master Thesis in Geographical Information Science nr 60

Bicycling Suitability in Downtown, Cairo, Egypt

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2016
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Master degree thesis, 30/ credits in Master in Geographical Information Sciences
Department of Physical Geography and Ecosystem Science, Lund University

Bicycling Suitability in Downtown, Cairo, Egypt

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Master thesis, 30 credits, in Geographical Information Sciences

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Dedication

At the beginning, I would like to thank God, for supporting me during the Master's Degree journey and for giving me the ability to complete this thesis.

Many thanks to my family especially my wife Dina and my kids Yahia and Yasin for their understanding and support during the Master's journey that took me away from them for a long time. A special thanks to my best friend, Ahmed Makram.
I would like to send a special dedication to the soul of my father Hossam Khairat who died before completing this Degree. He encouraged and supported me in all possible ways; I wish he were with me now.

Acknowledgment

A very special thanks and appreciation to my supervisor Dr. Vaughan Philips, Department of Physical Geography and Ecosystem Science, LUND University for his kindness and valuable support, and providing the expert guidance. Special thanks also to Dr. Amr Ali for his valuable suggestions and discussions throughout the LUMA program as a co-supervisor for this research. Also, I would like to thank Eng. Heba El Kady for her great support.

I wish to express my gratitude to Dr. Ulrik Mårtensson, Dr. Micael Runnstöm and Dr. Petter Pilesjö for their assistance throughout LUMA program.

Finally, I would like to thank LUND University-GIS Centrum team for their support during the whole Master’s journey.

Karim El Attar

Abstract

The Greater Cairo is one of the most crowded cities in the world and it is the biggest metropolitan area in Middle East. The high population density in the Greater Cairo causes traffic problems that harm many living aspects. This study discusses one of the solutions for limiting the traffic congestions using bicycle as an alternative transportation mean which is already applied in many other countries.

There are many models have been introduced to study the suitability of having bicyclists on a motor road. This study will apply some of the most commonly used models created to measure bicycling suitability.in Down Town Cairo area.

A GIS tool has been created to conduct applying the bicycling suitability models on the study area's streets. The tool was developed in ArcMap using Microsoft Visual Studio.

The results of this study encourage having alternative transportation network for bicycles in Down Town Cairo. The tool created is a user-friendly tool and it could be used for other researches in different areas or countries.

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List of Abbreviations

AADT: Average Anual daily Traffic.
ADT: Average daily traffic.
BCI: Bicycle Compatability Idex.
BLOS: Bicycle level of service.
BSA: Sicycle Suitability Assessment.
BSIR: Bicycle Suitability Score Index.
BSL: Bicycle Stress Level.
BSS: bicycle Suitability Score.
HCM: Highway capacity manual.
LTS: Level of Traffic Stress.
RCI: Road Condition Index.

1 Introduction

The city of Cairo, Egypt is ranked as the 42nd most crowded city in the world, with around 12 Million inhabitants and a density of about 1540/sq. km (Maps of World, 2015). 5.854 million Vehicles are registered in Egypt 31.6 percent of which exist in Cairo only with an ownership rate of over 20/100 people (Ahram Online, 2011). Over 1.2 million vehicles are registered in Greater Cairo only, with an annual incremental rate of 10% (Ali & Tamura, 2002) especially through Down Town, where most of the ministries, governmental institutions, banks, and local or private companies are located.

President Abd el Fattah El Sisi has recently started encouraging cycling by showing up at many events riding a bicycle. Even during his presidential campaign before the elections; the co-founder of Cairo Cycler's Club commented on Sisi's cycling activities, saying that the sunny weather and suitable topographic nature make Cairo an attractive place for cyclists (Kingsley, 2014). Cycling has become a trend in Egypt in the recent years, as there are now multiple groups and parties that could be found on social media managing cycling events during the year (Rabie, 2015).

On an international level, many directed strategies aim to use sustainable transport means that are safe, clean and affordable. In addition to being an economic, safe, and healthy mean of transport, the bicycle contributes to the reduction of polluting emissions (World Bank, 2008).

1.1 Problem definition

Cairo, the capital of Egypt is considered as one of the most crowded cities in the world. Down Town, Cairo suffers from traffic jams and many other problems. It is a historical area that is full of museums, banks, governmental offices, shopping spots and site scenes.

Riding bicycles is not a common behavior in the Egyptian culture. However, in the past few years, a trend has developed among the young generation to use bicycles instead of other transportation means. Unfortunately, the road network infrastructure is not ready for such kind of means.

Establishing a bicycle route network in the downtown area will contribute to decreasing the traffic jams and pollution problems, as the new network would encourage inhabitants and visitors to ride bicycles instead of other motorized means. Down Town streets' features and dimensions need to be studied to determine the best fit ways for the bicycle route network through applying known methodologies and models of the bicycle level of service and compatibility to help the decision maker select the suitable streets for the new users' segment.

1.2 Objectives

The aim of this research project is to use Arc GIS in testing the bicycle suitability models to establish a route network for cycling in Down Town Cairo for the purpose of traffic reduction and to support an alternative mean of transportation in Egypt.

1.2.1 Proposed method

The proposed method is to use GIS capabilities in planning the cycling route network in Downtown, Cairo with respect to factors chosen based on the current situation in the study area and similar projects applied in other countries – listed as following:

1-Road Bicycle Level of Service (BLOS) or Compatibility.

2-Traffic (speed, function class, number of points of interest) – sourcing from educational/governmental authorities.

3- Road Characteristics (width, number of lanes, type and condition of pavement, number of intersections) – Field data collection.

1.3 Research Questions

Research questions are the main lead for the hypotheses of this resreach so the questions listed below are being asked all the time while writting this thesis.

- Do Egypt need a cycling network? Why?
- What is the applicability of establishing a cycling routes network in Egypt?
- Is cycling a solution for reducing traffic?
- Is cycling a trend in Egypt?
- Who would use bicycle as a transportation mean?
- How GIS would help in establishing Cycling Routes network?

2 Study Area

2.1 Geographic Location

Egypt is located approximately between latitudes 22° – 31° north and longitudes of 25° – 37° East, at the North-eastern part of Africa (Maps of World, 2015). Libya lies on the eastern border of Egypt, while Sudan lies on the Southern border. The Red Sea on the Western border separates the land of Saudi Arabia but, the semi-island of Sinai is bounded by Palestinian lands and the Mediterranean Sea lies along the Northern border (Columbia Electronic Encyclopedia, 2015), as shown in (Figure 1 Egypt Map).

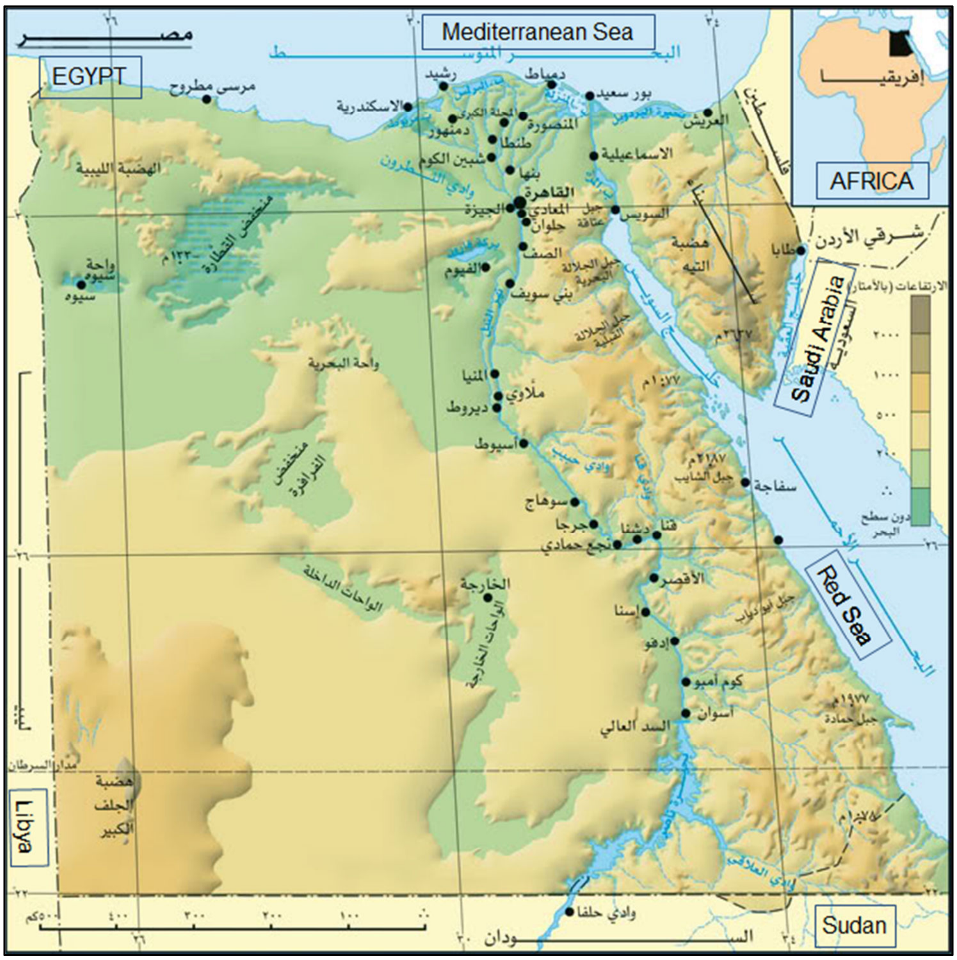


Figure 1 Egypt Map from the official web site of GIZA governorate (www.giza.gov.eg)

The Nile River, which is the longest river on Earth, traverses Egypt Longitudinally. Herodotus, a Greek historian, said *''Egypt is a gift of the Nile''* – in other words, the Nile River is the main source of water for agriculture and drinking in Egypt (Adams, 2007).

2.2 Historical Importance

Egypt is the land of the second oldest civilization after Sumerians: the Pharaohs. Not only did they build the oldest standing structure, the Great Pyramid, which was made for the Pharaoh "Khufu" they also preserved Pharaohs' bodies with a mysterious process known as mummification (Maps of World, 2015).

2.3 Economic Importance

Egypt roles Suez Canal that links between Mediterranean Sea to the Red Sea that represents the shortest water path from Atlantic Ocean to the Indian Ocean by saving about 7000 KM between Europe and India (Suez Canal Authority, 2008). The GDP of Egypt contributes 0.46% to the world economy, and its growth rate has been increasing over the last 10 years, to reach a peak of 7.3%. Thus, Egypt is considered as one of the significant developing countries in Middle East and Africa (Trading Economics, 2015).

2.4 Population

Egypt is the densest Arab country in the Middle East in terms of population, with about 1540 per kilometer squared, its population exceeds 90 million (Maps of World, 2015); Egypt is divided/categorized into two regions – Upper Egypt, which includes rural areas nearby the Sudanese borders in the south, and Lower Egypt in the south which covers the Nile delta and cities by the Mediterranean shore including the capital, Cairo (Samari & Pebley, 2015). 75% of Egypt's population lives in Lower Egypt (Handoussa, 2008).

The prevailing religions in the country are Islam and Christianity, and the official language is Arabic (Maps of World, 2015) . Furthermore, according to 2006 census data, around 25% of the population is under 29 years (Handoussa, 2010).

2.5 Cairo

Cairo, Egypt's capital is the largest metropolitan city in Africa and is ranked as the 13th largest mega city across the world (Huzayyin & Salem, 2013).Cairo's population exceeds 22% of the total Egyptian population; thus it suffers from serious traffic problems that affect the economy negatively (World Bank, 2013).

2.6 Downtown

Khedive Ismail built Downtown between years 1863 and 1879. Most of the buildings were constructed based on European designs such as French and Belgian (Hassan , Lee & Yoo, 2014).

Figure 2 European Style Buildings, downtown Cairo (Berthold Werner, 2010)

Downtown or "Wust-al-balad" is one of the most popular meeting spots for several segments of the Egyptian society: politicians, artists, musicians and journalists all have their favorite spots there. Most of the political parties' headquarters and professional syndicates are located in Downtown. In 2011, Tahrir square, which is also located in Downtown, was the heart where the revolution against the government sprang (Soliman, 2011).

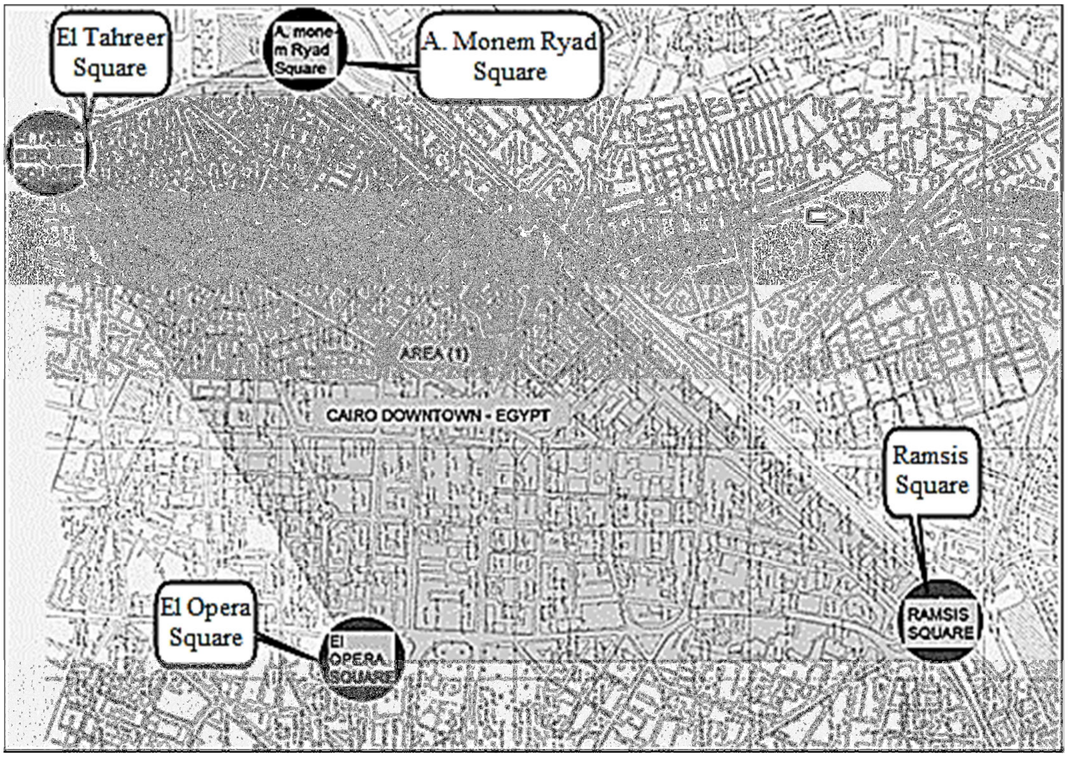


Figure 3 Borders of Cairo Downtown area (Hassan , Lee & Yoo, 2014)

The downtown area is not a separate entity ruled by a local municipality, as it is extended from Tahrir square to El Opera Square on the Eastern border, and from Abd El Moneim Ryad Square to Ramsis Square on the Western Border (Hassan , Lee & Yoo, 2014). It intersects with 3 local municipalities ruled by the same governorate as shown in Figure 3.

2.7 Cycling in Egypt

Cycling is not a common part of the Egyptian culture. There are no cycling lanes in Egypt, which causes cyclists to use pedestrian pavements resulting in pedestrians using traffic roads as mentioned by Ahmed El-Dorghamy, co-founder of Cairo Cycler's Club (Kingsley, 2014).

Furthermore, due to its immense traffic problem, the Egyptian government spends one fifth of its budget on energy subsidies yearly. Twelve Egyptian pounds are spent on fuel for each 20 kilometers (Staff Writer, 2014). Recently, the Egyptian president led a ride of a group of cyclists through Cairo several times, and appealed to the people to use bicycles as an indispensable transportation mean that will result in saving a noticeable part of energy spending (Kingsley, 2014).

3 Literature Review

3.1 Theoretical Approaches

3.1.1 Egypt's Infrastructure and Road Network

Egypt has languid road infrastructures caused by unplanned operations and lack of tactical management (Semeida, 2013). One of the major road network problems in Egypt is the lack of secondary roads that connect between main roads and the heart of the city; for example, the Down Town area (El Araby, 2002).

Around 31 thousand kilometers of paved roads in good condition exist in Egypt, connecting main cities with in the areas of the Nile Delta and Nile valley. However, a lack of road markings and international standards is obvious on Egyptian highways. Main roads are not sufficient for pedestrians in urban areas, as almost 50% of road accidents occur on the roads maintained by the local authorities. Road signs follow European standards on main roads only. Safety procedures such as emergency phones, traffic lights, and reflectors are fairly widespread on highways unlike on secondary roads. Speed bumps are scattered without planning and are barely marked. A non-safe driving environment prevails throughout the street network due to the diversified and unrelated traffic mix that consists of donkey carts, motorized tricycles, heavy trucks, busses, taxis, private vehicles and minibuses (Association For safe International Road Travel, 2009).

The road fatality rates in the U.S. and UK are 0.9 and 0.7 respectively per 100-kilometers, while in Egypt, rates reach 43.2, which is extremely high (Association For safe International Road Travel, 2009). About 9608 deaths occurred in 2013 on Egypt's roads, as reported by the World Health Organization (Exelby, 2014).

3.1.2 Traffic congestion in Cairo

Traffic problems are caused by the increasing rate of owned vehicles registered in Cairo, specifically 1.2 million, with an increasing ownership rate of 10% (Ali & Tamura, 2002). About 4.2 million vehicles move daily in streets that have an actual capacity of 500,000 vehicles only (Association For safe International Road Travel, 2009). This volume of traffic congestion in Cairo actually costs the government about 8 billion USD annually, which represents about 4% of the total Gross Domestic Product of Egypt (Exelby, 2014).

The Greater Cairo Metropolitan Region is considered as one of the worst cities with respect to traffic (El Araby, 2002).

Around 59% of traffic problems are due to bad driving behaviour, including horn use, wrong way driving, driving without focus, non-maintained vehicles, breaking speed rules, and lack of lane commitment. (Ali & Tamura, 2002)

The Egyptian government started to plan and execute mega projects such as ring road, new bridges and satellite cities surrounding greater Cairo, in order to try and handle the rapidly increasing rate of private car ownership (World Bank, 2013).

There are solutions not that might not be considered mega projects, but will positively affect the traffic situation, such as increasing the number of public buses, preventing side parking in heavily crowded areas or at least during rush hours, carpooling, and toll-roads (El Araby, 2002). Public transports serve over 60% of people’s daily trips in Greater Cairo (World Bank, 2013).

3.1.3 Why Downtown?

The downtown area is mainly full of commercial stores, banks, headquarters, and governmental offices; in addition to universities, institutes, schools, and tourist attraction spots. As a result, there are employees, workers, students, shoppers, and tourists who frequently visit Downtown (Hassan , Lee & Yoo, 2014)and (Laura, 2011). Figure 4 illustrates the land use coverage for the ground and first storeys in the Downtown Area:

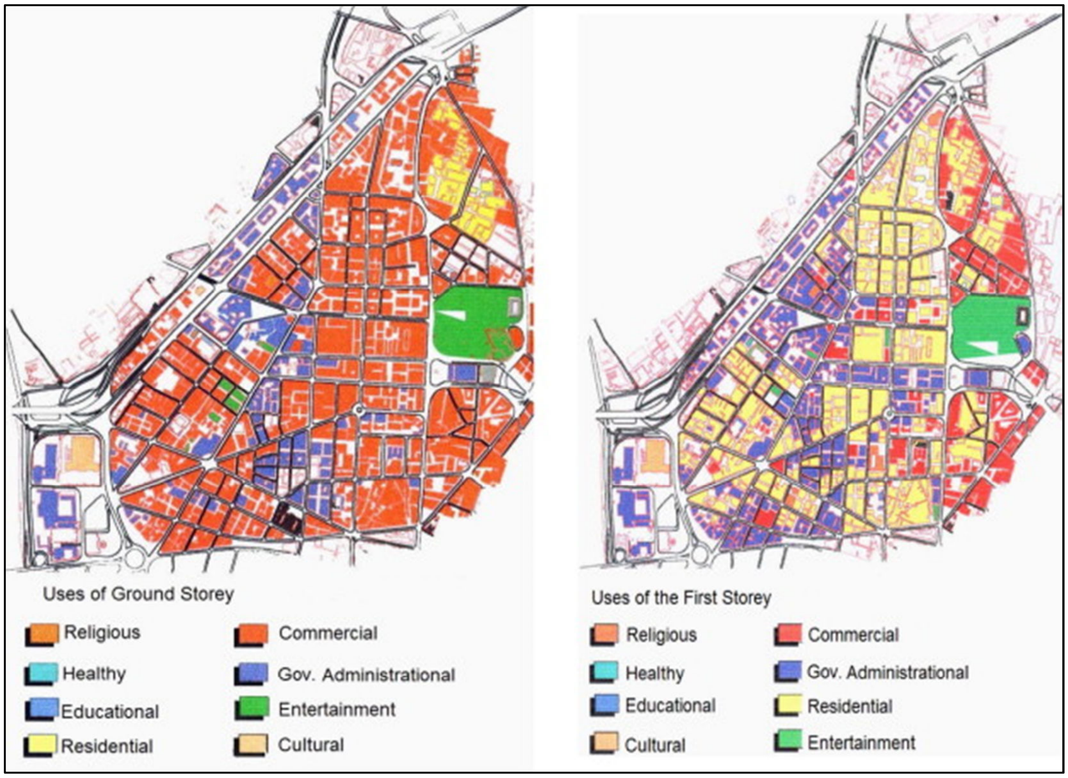


Figure 4 Ground and first storey use of the Cairo downtown area (Hassan , Lee & Yoo, 2014)

Downtown area was recently evacuated from all street vendors, as a part of the plan to transform the area to a pedestrian-only zone with the exception of allowing environmentally friendly transportation means to serve the area (Awatta, 2015).

Traffic congestion in Cairo is now the main challenge for the government, as it is not easy to determine rush hour times. This is mainly due to the fact that the jam begins from the early morning and lasts until late night during working days, especially in Downtown. The poor road network and connectivity result in one finding many places hard to reach using any of the available transportation means due to the narrow or crowded streets (El Araby, 2002) so other types of transportation means could contribute in solving this problem.

One thousand questionnaires have been spread to Greater Cairo residents regarding road traffic noise, and the result showed that the Downtown area is the second noisiest area within Greater Cairo during the whole day and night, while the industrial areas with heavy industries come first, (Ali & Tamura, 2002) so using non-motorized transportation means could contribute in decreasing the noise level.

The number of vehicles in Greater Cairo increases by 14 times every 30 years, and keeping up with the pace of this rate by expanding or increasing the capacity of the streets is difficult, and leads to more energy consumption. Consequently, the CO2 and other pollutant emissions increase severely - especially in central residential areas. (Huzayyin & Salem, 2013) Therefore, using a non-motorized transportation means will decrease the pollution.

Figure 5 Pedestrians are exposed to motor vehicle emissions in Downtown (El Araby, 2002)

In 2010, the investment bank Beltone Financial, was seeking to finance a project to pedestrianize a large area of Downtown Cairo with support from all concerned authorities. The project was supposed to be executed in one year. The responsible of that project claimed that the return of such an investment would achieve extremely positive rates. For example, all one star hotels in Downtown would automatically be up-graded to three stars; many businesspersons in the Middle East were willing to invest their own money in this project (Hadfield, 2009).

Recently in 2015, the government opened a new parking garage in Downtown with a large capacity, and then started preventing parking throughout the Downtown area streets for the sake of traffic ease (Awatta, 2015). The traffic police occupy the street parking spaces with metal barriers on both sides (Samih, 2015). The authorities provide shuttle buses to transport people from Tahrir garage to some spots in Downtown, but the service is not sufficient and needs a lot of enhancements (Awatta, 2015). Not everyone was happy with the new structure, as employees claimed that it would cost them more time to park in a central garage, and then take other transportation means to reach work (Samih, 2015).Moreover, the new parking monthly fee is almost triple the old one, which is not fair for the middle-income employees (Awatta, 2015). On the other hand, some of the shop owners admitted that the street parking ban would negatively affect sales as it would be unpleasant for some customers to buy goods and then take a bus to reach their vehicles. (Samih, 2015) Therefore, the new space in the streets could be an opportunity for another usage instead of the metal barriers.

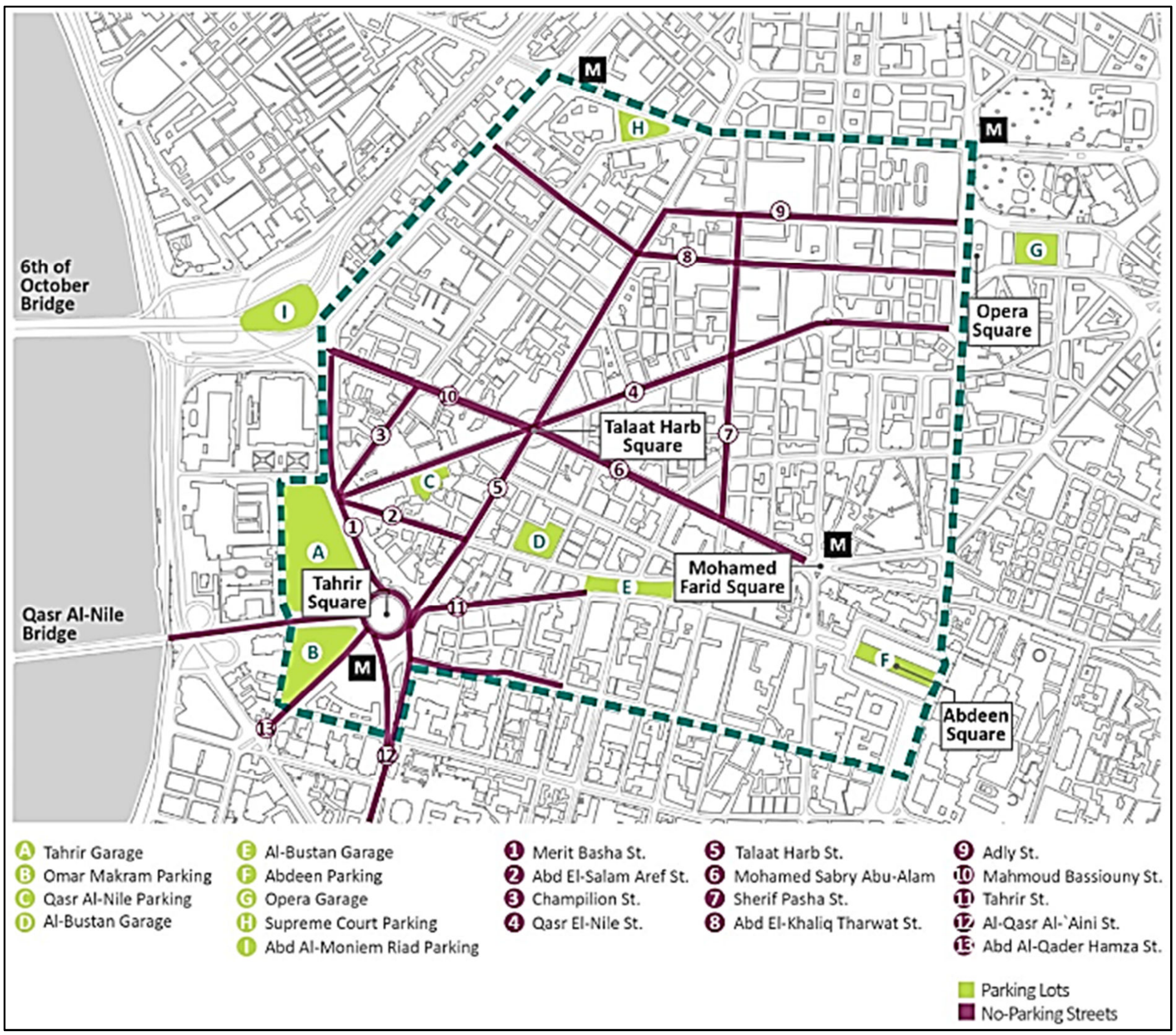


Figure 6 A Map illustrates the no-parking streets in downtown area (Awatta, 2015)

3.1.4 Bicycle as an indispensable transportation mean

In order to design a cycling route network, all transportation systems should be subjected to an assessment. Bicycles cannot be the only transportation mean for a certain city, but must be integrated to the current transportation system to serve people in the best way. This is not about which transportation mean is better than the other, but about the most suitable transportation system for a certain area or city, In urban dense areas, bicycles will not need much parking space and will save the time consumed waiting for public transportation (Godefrooij & Schepel, 2010).

In general, each transportation mean has some pros and some cons, as for the bicycle, there are many pros and limited cons. The bicycle as a transportation mean is an environmentally friendly mean, and its usage requires simple training. Furthermore, its cost per kilometer is low compared with other transportation means (Godefrooij & Schepel, 2010); in Egypt, a two way trip by bicycle will save around 60% of the trip's total cost. (Kingsley, 2014). On the other hand, the bicycle is not sufficient for long distance travelling as it limits the size of luggage that could be taken and it has a high vulnerability level due to the lack of respect by other road users (Godefrooij & Schepel, 2010).

3.1.5 Co-benefits of Cycling

The main aim for any transportation system is to allow access to any part of the area served within a proper period. In that regard, the bicycle provides additional accessibility options to its user especially in the metropolitan cities that might have narrow streets and bad pavement conditions. Another beneficial advantage of using a bicycle is the freedom of time, compared with public transportation means, as they have fixed times to move from one station to another, which might not suitable for some people. The bicycle as transportation mean is the best option for those who do not have alternatives rather than walking, as it will increase the distances that could be reached (Deffner , Hefter , Rudolph & Ziel, 2012).

Traffic congestion is one of the main problems in all urban areas, and the solution of establishing new roads or extending existing ones proved its inefficiency. The bicycle could possibly be the best solution for congestions as the road capacity will improve, and if cycling routes become connected with the public transportation system that will create the perfect mix to decrease traffic jams to the minimum (Godefrooij & Schepel, 2010).

Cycling will make cities more attractive for families in order to raise their kids in a healthy and clean environment, as it is a people oriented way of travelling rather than being a vehicle oriented place that limits the freedom of movements for pedestrians and increased pollution (Godefrooij & Schepel, 2010).

CO_2 is positively correlated to the distance travelled, and it is one of the most harmful emissions to the environment. It comes mainly from motorized vehicles, where a 57% CO_2 emission increment is expected between years 2005-2030 and 80% of that increment will come from developing countries. The bicycle produces no emissions; it is an environment friendly transportation mean and if it is promoted correctly, its usage will potentially contribute to saving the environment and limiting the amount of pollution (Godefrooij & Schepel, 2010).

A healthy person should have a few minutes of exercising daily; nevertheless, due to the busy environment that urban residents live, they might forget to spend even one minute exercising. Using the bicycle will provide a moderate time of exercise to keep in shape and take care of one's general body health (Ege & Krag, 2010).

As a summary, the bicycle does not need fuel, maintenance, registration, insurance, big parking space or high acquisition cost. Its user enjoys exercising in every trip (Allen-Munley & Daniel, 2006), It is the best alternative for all motorized means in order to save money, energy, hustle, space and avoid noise, traffic congestions, pollution in addition to living in a healthy way.

3.1.6 Factors Affecting Cycling

There are many factors that affect cycling in different levels. Cycling route choice by cyclists is very relevant to the cycling route design, as they rate their satisfaction and comfort level towards the route specifications and conditions. Some of the influential factors are road slope, number of traffic lights, street direction, number of intersections, street width, quality of pavement, security, traffic speed, traffic volume and number of buses or trucks that use the street (Segadilha & da Penha Sanches, 2014).

Width of the street or the number of lanes is one of the major factors that affect cycling routes design; cyclists may choose their route based on the number of lanes (Shankwiler, 2006). The more driving lanes in the road, the more exposed cyclists are to accidents (Segadilha & da Penha Sanches, 2014); in other words it is a safety issue for the cyclists.

The road condition is an influential factor on cycling; it is very relevant to the service level existing on the road, which is a safety or security issue from the cyclists' perception. Cyclists may avoid the use of unpaved roads (Stinson & Bhat, 2004).

Cyclists tend to use roads with low traffic volumes, and in some cases and that decision could be influenced by the cycling experience. On the other hand, traffic volume is not a standalone factor, as it is negatively correlated with the traffic speed on a certain road. The higher the traffic volume, the lower the traffic speed; this factor also affects the safety level on roads (Segadilha & da Penha Sanches, 2014). Speed and volume are an indicator for the road functional class, the road type such as arterial, collector, and local roads reflects the speed, volume and level of safety expected that influence the cycling flow (Snizek , Nielsen & Skov-Petersen, 2013). 75% of accidents occur when the posted speed limit for a certain road is higher than 35 miles per hour (Hunter , Pein & Stutts, 1996).

As a conclusion for all the main factors discussed, the safety perception is the main factor when designing a cycling route network, as cyclists evaluate all road characteristics and conditions including the risk of having accident or being injured (Lawson , Pakrashi , Ghosh & Szeto, 2013). Based on the World Health Organization report for 2013, most of road accidents victims or injuries are cyclists, pedestrians, or motorcyclists (Asadi-Shekari , Moeinaddini & Zaly Shah, 2015). Safety is a highly considered factor in planning bicycle facilities for most of the metropolitan areas (Allen-Munley & Daniel, 2006).

3.1.7 Previous studies about planning a Cycling network

Previous studies illustrate practical and applied examples in different cities that would help in developing new practices in other areas.

3.1.7.1 Selecting Bicycle Commuting Routes Using GIS

Huang, Yuanlin and Ye, Gorden (1995) introduced a study called "selecting Bicycle Commuting Routes Using GIS" that takes travel time, volume, road slope and surface conditions into consideration to determine the desirable cycling routes in the city of Berkeley, USA. In this study, GIS proves that it is a unique operating environment that allows analysis, manipulation, and visualization for many groups of data with different types that are essential for facilitating cycling routes selection. All data types used are illustrated in Figure 7, which explains the procedure followed to select the best cycling routes including 2 phases; the first is to develop the spatial database. That means data conversion, transformation or any other suitability process using any GIS package to be able to apply spatial analysis correctly.

The second phase is about the spatial analysis itself that includes routing, modelling and summarizing processes (Huang & Ye, 1995).

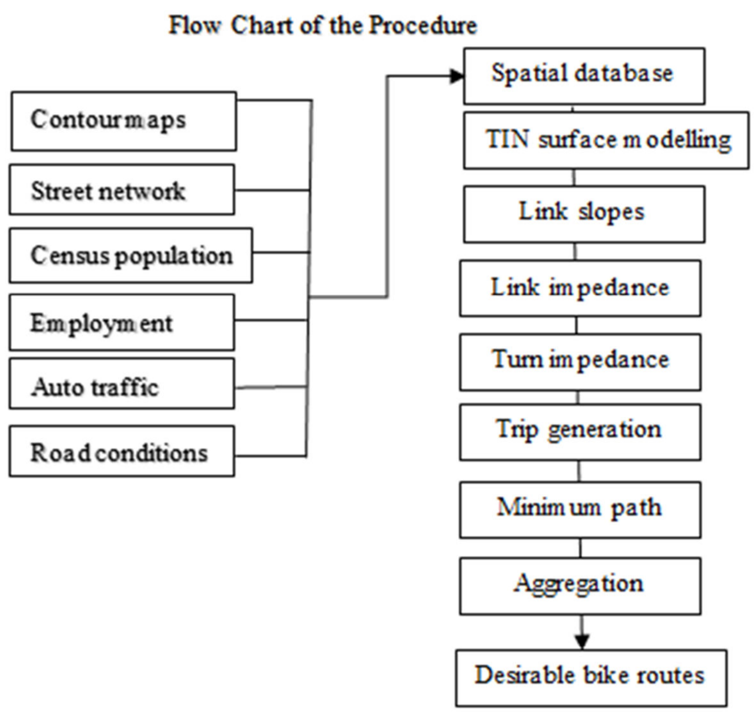


Figure 7 Flow chart of the Procedure (Huang & Ye, 1995)

Berkeley's study considered only the trips inside the city for commuting purposes only, so it is not a general study where other purposes such as shopping or recreation trips are included. Inference, this study is not beneficial for people who work inside the city but lives outside it or vice versa (Huang & Ye, 1995). Furthermore, some of the factors that have been analyzed in this study are strongly related to the study area's topographic nature such as the slope; and there are other factors that might be important for this type of analysis such as the direction of travel.

3.1.7.2 Bicycle facility planning using GIS and multi-criteria decision analysis

Many studies introduced models to plan a bicycle facility, and they are divided into two individual groups; one of them is related to the demand based model and the other is related to the supply based models. Greg Rybarczyk and Changshan Wu introduced a study combining the two groups by using the geographic Information system and the Multi-criteria analysis to formulate a better tool to plan a suitable bicycle facility in Milwaukee City, WI, U.S.A. (Rybarczyk & Wu, 2010).

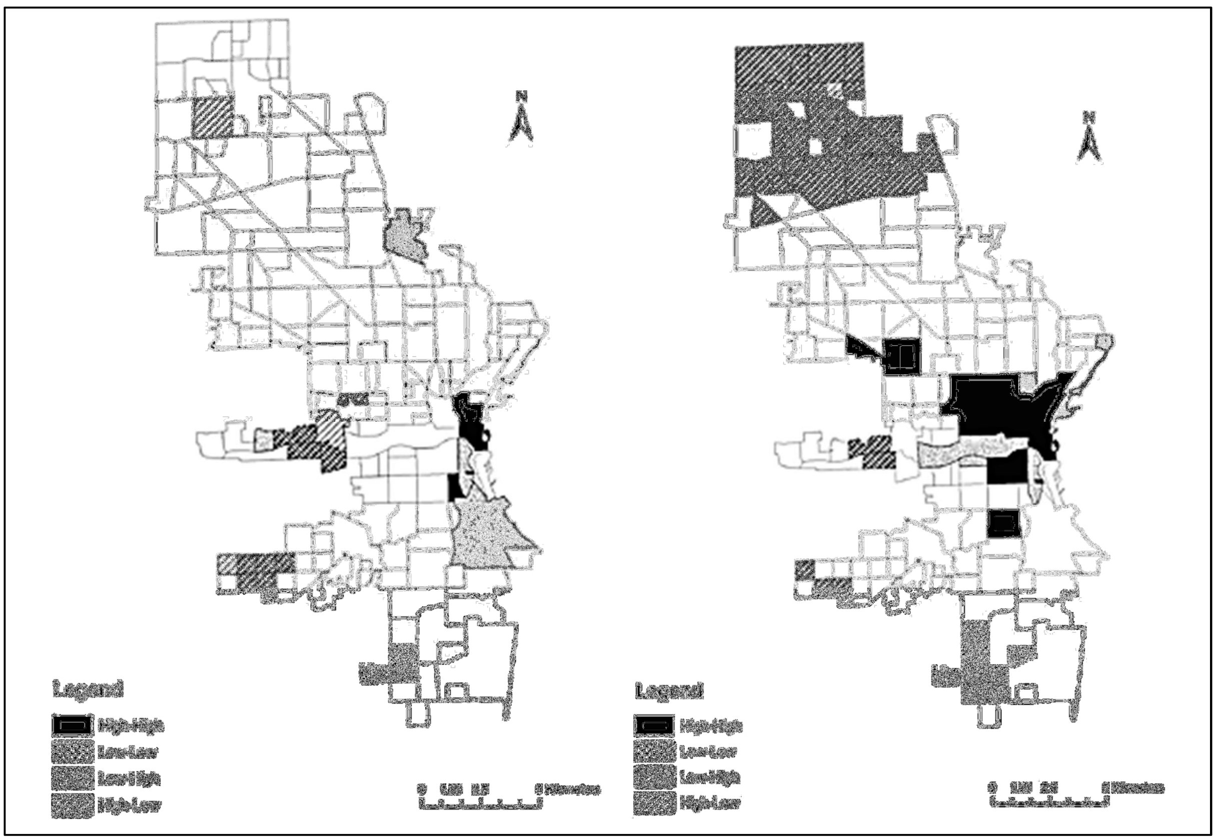


Figure 8 Bicycle Level Of service and DEMAND cluster maps (Rybarczyk & Wu, 2010)

Combining the supply and demand based models gives the planners a good alternative method to plan a bicycle facility as the results of this study indicate that the network analysis is able to detect the suitable road segments where the neighborhood level analysis is a main contributor in a citywide strategic plan. That analysis, applied in terms of Bicycle Level Of service (BLOS) grades, measures the cyclists safety based on the route design and traffic condition versus the DEMAND on a network level and neighborhood level (Rybarczyk & Wu, 2010).

3.1.7.3 Build it. But where? The use of geographic information systems in identifying locations for new cycling infrastructure

Cycling in North America must be considered in all infrastructure plans that create the need for a systematic method to locate new cycling facilities. The island of Montreal was the study area chosen by Jacob Larson, Zachary Patterson and Ahmed M. El-Geneidy (2013) to apply a case study in using GIS systems, in identifying locations for new cycling infrastructure.

The methodology followed was to calculate a prioritizing index for each segment based on combining several factors to be visualized through a cell value. The process was to locate the potential areas for the analysis, then to calculate the index for each segment using equation 1, as the higher the index, the more suitable is the segment for improving or creating a new bicycle facility. At the end, combining everything with the existing facilities to be visualized would support decision makers in proposing the new sites and routes as shown below (Larsen , Patterson & El-Geneidy, 2013).

Equation 1 The prioritization index equation (Larsen , Patterson & El-Geneidy, 2013)

$$\mathrm{Xi} = \frac{\mathrm{oi}}{\sum \mathrm{j\ oj}} + \frac{\mathrm{Pi}}{\sum \mathrm{j\ Pj}} + \frac{\mathrm{coli}}{\sum \mathrm{j\ colj}} + \frac{\mathrm{prij}}{\sum \mathrm{j\ prij}}$$

Figure 9 Display for the prioritization index applied on the Island of Montreal (Larsen , Patterson & El-Geneidy, 2013)

This study is not presenting the ultimate method for using GIS in such a purpose, but it illustrates the applicability to do so as the selected factors are not complete; they have been used discreetly without any deep analysis or weighting process. GIS has been used to analyze grid cells and various data sources such as observed bicycle trips, potential bicycle trips, high priority segments chosen by survey respondents, bicycle accidents data, and dead end bicycle facilities to help in planning new bicycle facilities (Larsen , Patterson & El-Geneidy, 2013).

3.1.7.4 Urban Bicycle Route Safety Rating Model Application in Jersey City, New Jersey

Cheryl Allen-Munley and Janice Daniels (2006) claim in their study that to increase non-motorized transportation means usage, safety standards should take the ultimate priority in designing routes. The main aim of this study was to develop a decision support tool for planners to help them in establishing safe bicycle route networks in Jersey City.

The model used in this study is a function of nine factors including slope, traffic volume, lane width, road classification, housing density, heavy trucks routes, direction of travel, road condition, and daylight period. The mentioned factors were used to study and analyze the expected severe injuries caused by bicycle-vehicle crashes or accidents (Allen-Munley & Daniel, 2006).

Table 1 1997–2000 Jersey City Bicycle Crash Severity Index Distribution (Allen-Munley & Daniel, 2006)

NJDOT injury class	Injury severity index	Quality	Description
0	1	32	**Not known**
1	3	0	**Amputation**
2	3	2	**Concussion**
3	3	0	**Internal**
4	3	36	**Bleeding**
5	3	59	**Contusion/bruise/abrasion**
6	3	0	**Burn**
7	3	12	**Fracture/dislocation**
8	2	146	**Complaint of pain**
9	1	27	**none visible**

3.1.8 Common Methods, Theories and Models

There are many terminologies for bicycle facility planning, such as bicycle suitability, bikeability, and bicycle friendliness. Bicycle friendliness is the community's acceptance to use the bicycle as transportation mean in their daily lives, while bikeability is about the ease of accessibility for the intended destinations that include bicycle parking spaces and cycling route networks' richness. Bicycle suitability is about the level of safety provided on the chosen or planned routes for cycling which is what this study is about (Lowry , Callister , Gresham & Moore, 2012). Table 2 illustrates the common proposed methods to measure bicycle suitability in terms of a score or index that assessed for a linear segment of a bikeway using different groups of attributes.

Table 2 Common Bicycle Suitability Methods (Lowry , Callister , Gresham & Moore, 2012)

Name of Method	Acronym	Reference	Reference Date
Bicycle Safety Index Rating	BSIR	Davis	1987
Bicycle Stress Level	BSL	Sorton and Walsh	1994
Road Condition Index	RCI	Epperson	1994
Interaction Hazard Score	IHS	Landis	1994
Bicycle Suitability Rating	BSR	Davis	1995
Bicycle Level of Service (Botma)	BLOS	Botma	1995
Bicycle Level of Service (Dixon)	BLOS	Dixon	1996
Bicycle Suitability Score	BSS	Turner et al	1997
Bicycle Compatibility Index	BCI	Harkey et al	1998
Bicycle Suitability Assessment	BSA	Emery and Crump	2003
Bicycle Level of Service (Jensen)	BLOS	Jensen	2007
Bicycle Level of Service (Petitsch et al)	BLOS	Petritsch et al	2007
Bicycle Level of Service (HCM)	BLOS	HCM	2011

In this section, some of the methods mentioned in Table 2 will be discussed briefly in order to pick the most applicable one for the study area of Downtown.

At the very beginning, engineers and planners used to be more interested in the road capacity, but have recently found another factor to measure called the level of service (LOS). LOS is an indication of the road condition and the quality of using it that describes the level of safety in terms of lane width, number of lanes, and how comfortable the road is in terms of maneuverings and traffic jams. LOS is being measured using six grades that start with grade A and end by grade F. Grade A indicates the perfect road for cyclists, all factors considered, in the methodology used for the measuring, while grade F indicates the lowest road suitability level for cycling (Epperson, 1994).

Table 3 Bicycle Suitability/Safety/LOS Methodologies Affecting Factors (Turner , Shafer & Stewart, 1997)

Input variables / Methodology	Traffic Volume Per Lane	Curb Lane Width	Vehicle Speed	Speed Limit	Pavement Type/Condition	Parking/Turn Lanes	Grades	Sight Distance/Visibility	Driveway Frequency	Adjacent Land Use	Signalization/Intersections	Heavy vehicles	vehicle LOS	Maintenance	TDM/Multimodal Support	Provision/Type of facility	Cyclist Input	Passing/Meeting Frequency	Service Volume	Bicycle Density	Curve Radius	Total delay	Average Bicycle Speed
Bicycle Stress Level-Based Criteria																							
Bicycle Stress Level	√	√	√																				
Roadway Condition Index/Suitability-Based Level of Service Criteria																							
Bicycle Safety Index Rating	√	√		√	√	√	√	√	√	√	√					√							
Bicycle Suitability, Davis	√	√		√	√	√	√	√	√	√						√							
Roadway Condition Index	√	√		√	√	√	√	√	√	√						√							
Modified Roadway Condition	√	√		√	√	√	√	√	√	√		√				√							
Intersection Hazard Score	√	√		√	√				√	√		√											
Bicycle Level of Service	√	√		√	√				√	√		√					√						

3.1.8.1 Bicycle Safety Index Rating (Davis)

Davis (1987) introduced the first systematic measurement to road suitability for cycling as a combination between two indices: roadway segment index (RSI) and the intersection evaluation index (IEI) (Epperson, 1994); the two indices are calculated using the following equations:

Equation 2 (RSI) and (IEI) Equations (Epperson, 1994)

$$\textbf{RSI} = [ADT/(L * 2500)] + (S/56) + [(4.25 - W) * 1.635] + \sum PF + \sum LF$$

Where:

ADT = average daily traffic,

L = number of traffic lanes,

S = speed limit (km/hr),

W = width of outside traffic lane (m),

∑PF = sum of pavement factors, and

∑LF = sum of location factors.

$$\textbf{IEI} = [(VC + VR)/10000] + [(VR * 2)/(VC + VR)] + \sum GF + \sum SF$$

Where:

VC = cross street volume (ADT),

VR = traffic volume on route being indexed,

∑GF = sum of geometric factors, and

∑SF = sum of signalization factors.

Both indices are graded as the lower the number, the better for cycling. It is clear that the constant values calculated for pavement and location factors represent from 30 -50% of the total score, which affects the impact of the main variable factors on the final index rate for the segment. On the other hand, the BSIR is the summation of the actual average for RSIs for all segments and the IEIs for all intersections that may produce a non-representable index for some cases with longer segments than others or a higher individual index (Epperson, 1994). One other comment about this early version was that this model is not validated with respect to the cyclists' perception itself; in the reviewed version of this model, Davis dropped the IEI from his calculations and related his analysis to cyclists' perception evaluation (Turner , Shafer & Stewart, 1997). In fact, Davis' equations are the pioneer attempt for measuring the true LOS rating for bicycles (Epperson, 1994).

3.1.8.2 Road Condition Index (Davis-Epperson)

After the first attempt by Davis, all researchers and planners who worked on the development of that model had the same conclusion, which was decreasing the effect of the pavement and location factors in parallel to increasing the effect of the lane width and speed limit (Epperson, 1994). Equation 3 demonstrates results after one of the modifications were applied to Davis' first model:

Equation 3 Epperson-Davis RCI (Turner , Shafer & Stewart, 1997)

$$\textbf{Modified RCI} = \left[\frac{\text{ADT}}{\text{L} * 3100}\right] + \left[\frac{\text{S}}{48}\right] + \left[\left(\frac{\text{S}}{48}\right) * (4.25 - \text{W}) * 1.635\right] + \sum[\text{PF}] + \sum[\text{LF}]$$

Where:

RCI = Roadway Condition Index,

ADT = average daily traffic (vehicles),

L = number of traffic lanes,

S = speed limit (kph),

W = width of outside traffic lane (m),

PF = pavement factors, and

LF = location factors.

The multiplying of the speed limit by the lane width increases the sensitivity of both factors, especially for the narrow roads with a high travel speed. However, this model proved its sensitivity to the main factors but when it is tested versus the accidents rate, the result was that this model describes only about 18 percent of the actual variation. The researchers claimed that the nature of cyclists and their expected flow on certain roads is the main influencer on the accident rate. Therefore, if the model does not consider such factors the result would not be accurate enough (Epperson, 1994).

Another modification applied on Davis' model was to add a weighted multiplier to the pavement factor and location factor to decrease their effect to the least possible amount; in addition to simplifying their values to be on a scale between zero to three only (Epperson, 1994). The equation results are shown in equation 4:

Equation 4 Modified RCI (Epperson, 1994)

$$\mathbf{RCI} = \left[\frac{\mathrm{ADT}}{\mathrm{L} * 3100}\right] * \left[\frac{\mathrm{S}}{48}\right] * \left(\frac{4.25}{\mathrm{W}}\right) * [(1+.\mathrm{HV})]1.8 * [1 + (0.03 * \mathrm{PF}) + (0.02 * \mathrm{LF})]$$

This model looks much different compared with the original form but it proved its efficiency for low volume roads and those in very good condition. However those road types had already been evaluated correctly with the previous modification (Epperson, 1994).

3.1.8.3 Interaction Hazard Score (Landis)

Interaction Hazard Score (IHS) model is to aid planners and decision makers to assess the hazards that bicyclists may face while using a designed bicycling route network. The groups, that were approached to evaluate the factors used in that model, were consensus that IHS considers the appropriate exposure variables to measure the road suitability and friendliness for bicyclists (Landis, 1994). The equation used for that purpose is as shown in equation 5:

Equation 5 Interaction Hazard Score (IHS) Equation (Landis, 1994)

$$\mathbf{IHS} = \left\{\frac{\mathrm{ADT}}{\mathrm{L}} * \left(\frac{14}{\mathrm{W}}\right)^2 * \left[\mathrm{a}_1 \frac{\mathrm{S}}{30} * (1 + \%\mathrm{HV})^2 + \mathrm{a}_2\mathrm{PF}\right] + \mathrm{a}_3\mathrm{LU} * \mathrm{CCF}\right\} * \frac{1}{10}$$

Where:

HIS = Interaction Hazard Score,

ADT = average daily traffic (vehicles),

L = total number of through lanes,

W = usable width of outside through lane (includes width of any bike lanes; measured from pavement edge, or gutter pan, to center of road, yellow stripe, or lane line, whichever is less),

S = speed limit,

%HV = presence of heavy vehicles (e.g., trucks) expressed as a decimal,

PF = pavement factor (the reciprocal of FHWA Highway Performance Monitoring System (HPMS) PAVECON factor),

LU = land use intensity adjoining the road segment (commercial value=15, non-commercial value=1),

CCF = curb cut (or on-street parking) frequency, a measure of uncontrolled access (i.e., turbulence per unit of distance), and

a_1, a_2, a_3 = calibration coefficients initially equal to unity.

This model use two major types of influential factors, one of them is called longitudinal interaction, which includes all vehicle characteristics such travel speed, traffic volume and vehicles sizes as well as road specifications such as number of lanes and width. The second major factor is transverse interaction, which describes the allowed direct interaction between motorized means and bicyclists such the on-street side parking and roadway access. The main strength of that model is the data format, as it is collected objectively and economically and all variables need to be updated annually as the sensitivity of most of them is considered high, so one change could produce devastating outputs (Landis, 1994).

Landis developed the calibration coefficients to adjust the model based on the cyclists' perceptions and evaluations to the factors included in a synchronized way. In his later work, he increased the calibration coefficients as he developed all variables to be more sophisticated and sensitive to changes. On the other hand, in that updated version of Landis' model, the pavement condition got more attention and became one of the dominant variables in the model, as the bicyclists' perceptions of roadway suitability highlighted its importance to cycling (Turner , Shafer & Stewart, 1997).

Equation 6 Landis' Bicycle Level of Service Model (The update) (Turner , Shafer & Stewart, 1997)

$$\mathbf{BLOS} = a_1 \ln\left(\frac{Vol_{15}}{L}\right) + a_2 \ln(SPD_p\,(1+\%HV)) + a_3 \ln(COM_{15} * NCA)$$

$$+ a_4(PC5)\text{-}2 + a_5\,(We)2 + C$$

Where:

BLOS = bicycle level of service, or perceived hazard of the shared roadway environment,

VOL_{15} = volume of directional traffic in 15-minute time period,

L = total number of through lanes,

SPD_p = posted speed limit (a surrogate for average running speed),

%HV = percentage of heavy vehicles (as defined in the 1994 Highway Capacity Manual, COM15 = trip generation intensity of the land use adjoining the road segment (stratified to a commercial trip generation of “15,” multiplied by the percentage of the segment with adjoining commercial land development,

NCA = effective frequency per mile of non-controlled vehicular access (e.g., driveways and/or on-street parking spaces),

PC_5 = FHWA’s five point pavement surface condition rating,

W_e = average effective width of outside through lane:

$= W_t + W_l - \sum W_r$

Where: W_t = total width of outside lane (and shoulder) pavement,

W_l = width of paving between the outside lane stripe and the edge of pavement,

W_r = width (and frequency) of encroachments in the outside lane,

$= W_p$ * % of segment with on-street parking + W_g

Where: W_p = width of pavement occupied by on-street parking activity,

W_g = combined width and frequency factor of other encroachments, and,

$a_1 = 0.589$ (calibration coefficient) $a_2 = 0.826$ (calibration coefficient) $a_3 = 0.019$ (calibration coefficient) $a_4 = 6.406$ (calibration coefficient) $a_5 = 0.005$ (calibration coefficient) C = 1.579 (calibration coefficient).

3.1.8.4 Bicycle Suitability Score (Turner)

This approach has been developed based on previous models and practices to evaluate bicycle facilities or roadways used for comfort by cyclists in Texas (Turner , Shafer & Stewart, 1997). After assessing the needs and gathering the available data, see equation 7:

Equation 7 Bicycle Suitability Score Equation (Turner , Shafer & Stewart, 1997)

$$\textbf{Bicycle Suitability Score, } S_{\textbf{Bicycle}} = S_{Width} + S_{Traffic} + S_{Speed} + S_{Pavement}$$

Where:

$S_{Bicycle}$ = bicycle suitability score,

S_{Width} = factor score for shoulder or travel width,

$S_{Traffic}$ = factor score for traffic volume,

S_{Speed} = factor score for speed limit,

$S_{Pavement}$ = factor score for shoulder or travel lane pavement conditions.

All variables in the stated model get equal weight. The score is calculated by summing all variables' scores that are categorized in terms of three to five scoring categories to define each factor. Each value range is assigned to an absolute score based on data collected from previous studies and cyclists' perceptions. The scores are interpreted as shown in Table 4 (Turner , Shafer & Stewart, 1997).

Table 4 Interpretation of Bicycle Suitability Scores (Turner , Shafer & Stewart, 1997)

Suitability	Interpretation
6 to 8	All four suitability factors have greater than minimum desirable values. The physica1 characteristics of the roadway are most likely desirable by intermediate to experienced bicyclists.
-Ito 5	At least three of the four suitability factors have minimum desirable or neater than minimum desirable values. One suitability factor y have less than desirable values The physical characteristics of the roadway could be desirable by intermediate to experienced bicyclists.
-2 to-5	At least two of the four suitability factors have minimum desirable or neater than minimum desirable values. One or two suitability factor y have less than desirable values The physical characteristics of the roadway May not be desirable by intermediate to experienced bicyclists
-6 to-5	All four suitability factors have less than minimum desirable values. The physica1 characteristics of the roadway ate most likely undesirable by intermediate to experienced bicyclists.

All factors encountered in this model are obtained based on cyclists' perceptions and general needs investigated in previous practices. Bicycle tour maps, assessing suitability changes, or bicycling improvements for a certain road network are all applications for Turner's model (Turner , Shafer & Stewart, 1997). Other factors are not considered, such as heavy truck volumes or directions of travel with respect to available data and study area's variables.

3.1.8.5 Bicycle Level of Service (Jensen)

The Danish road Directorate invested in a quantitative study to evaluate all factors affecting cyclists and pedestrians on the roads. The main aim was to generate a model able to measure the level of service for both pedestrians and bicyclists. The survey stated that traffic volume, traffic speed, urban land uses, rural landscapes, width of the facility, number of lanes and many other factors among 150 variables described and tested using recorded video analyzing for some selected roads. All reviews collected have been used to generate an index for each satisfaction level for all factors (Jensen, 2007)as shown in equation 8:

Equation 8 Jensen BLOS Model (Jensen, 2007)

$$\mathbf{logit}(\mathbf{p}) = \alpha \begin{bmatrix} \text{very satisfied} = -2.8526 \\ \text{moderately satisfied} = -1.2477 \\ \text{a little satisfied} = -0.0646 \\ \text{a little dissatisfied} = 0.8758 \\ \text{moderately dissatisfied} = 2.2543 \end{bmatrix} + \text{WA} \begin{bmatrix} \text{sidewalk concrete flags} = 3.5486 \\ \text{sidewalk asphalt} = 1.9149 \\ \text{bicycle path or track} = 1.0124 \\ \text{bike lane or paved shoulder} = -2.8293 \\ \text{driving lane} = -3.6464 \end{bmatrix}$$

$$+ \text{AREA} \begin{bmatrix} \text{residential} = 0.4871 \\ \text{shopping} = 0.5385 \\ \text{mixed} = -1.6349 \\ \text{rural fields} = 1.2380 \\ \text{rural forest} = 0.5122 \end{bmatrix}$$

-0.002476 * MOT + 0.0000003364 * MOT2 - 0.0303 * SPEED + 0.00002211 * SPEED * MOT - 0.005432 * PED + 0.000005062 * PED2 - 0.003772 * BIKE + 0.000003111 * BIKE2 + 0.4408 * BUF - 0.0365 * BUF2 - 0.05286 * PARK + 1.0180 * MED + 0.2938 * SB + 0.6277 * BL + 0.7380 * LANE + 0.3311 * TREE

Where:

logit(*p*) = utility function of the cumulative
logit model, α = intercept parameter of the
response level of satisfaction,

WA = type of walking area,

AREA = type of roadside development or landscape,

MOT = motor vehicles per hour in both directions,

SPEED = average motor vehicle speed (km/h),

PED = passed pedestrians per hour on nearest roadside at 5 km/h walking speed,

BIKE = bicycles and mopeds per hour in both directions,

BUF = width of buffer area between walking area and drive lane (m),

PARK = parked motor vehicle on road per 100 m,

MED = median dummy, no median = 0, median = 1,

SB = width of walking area, if this is a sidewalk or bicycle path/track (m),

BL = total width of walking area and nearest drive lane, if walking area is a bicycle lane, paved shoulder or drive lane (m),

LANE = drive lane dummy, four or more drive lanes = 1, one to three lanes = 0, TREE = tree dummy, one tree or more on road per 50 m = 1, otherwise 0.

This model shows the benefits for planners to design new roads, to redesign existing roads, to improve level of service, and to put plans for long-term planning decisions (Jensen, 2007). Many factors are taken into consideration in that model, as it was originally made based on the Danish community's perspective. This might lead to the need for many enhancements and edits in order to fit the model for each study area. The degree of importance for each factor is not the same everywhere.

3.1.8.6 Bicycle Level of Service (Petritsch)

The Florida department of Transportation sponsored a study to approach actual bicycle users in order to observe their perceptions on bicycle level of service model developing. The researchers invited a number of cyclists with different experiences and demographics in order to ride a course of 32 kilometers of roads with specified and restudied characteristics. After collecting feedback from all participants using a designed survey, the results were used to generate the following mathematical model to evaluate the level of service for cycling on arterial roads (, 2007); see equation 9:

Equation 9 Bicycle Segment LOS (, 2007)

$$\textbf{Bicycle Segment LOS} = a_1\ln(Vol_{15}/L) + a_2SP_t(1+10.38HV)^2 + a_3(1/PC_5)^2 + a_4(W_e)^2 + C$$

Where:

Vol_{15} = volume of directional traffic in 15-minute time period,

L = total number of through lanes,

SP_t = effective speed limit (see below),

$SP_t = 1.12\ln(SP_P - 20) + 0.81$,

SP_P = Posted speed limit (mi/h),
HV = percentage of heavy vehicles,
PC_5= FHWA's five point surface condition rating,
W_e = average effective width of outside through lane,
C = a constant.

Coefficients:

a_1: 0.507 a_2: 0.199 a_3: 7.066 a_4: - 0.005 C: 0.760

Equation 10 Bicycle Facility LOS (, 2007)

Bicycle Facility LOS = a_1(AvSegLOS) + a_2 (NumUnsigpm) + C

Where:
AvSegLOS = distance-weighted average segment bicycle LOS along the facility,
NumUnsigpm = the number of unsignalized intersections per mile along the facility,
C = a constant.

Even though, this study included a wide cross section of cyclists, it might be not suitable for any other kind of roads such as rural and streets with high access management (, 2007).

3.1.8.7 Bicycle Compatibility Index (Harkey)

The main aim of Harkey's study was to develop a new model to be used by planners and decision makers to accommodate the streets to serve non-motorized users. Lab videos were used to study road characteristics and list the factors affecting their compatibility. Using the contribution of 200 volunteers in 3 different study areas, the model was created as shown below (Harkey , Reinfurt , Knuiman , Stewart & Sorton, 1998):

Equation 11 Bicycle Compatibility Index Model (Harkey , Reinfurt , Knuiman , Stewart & Sorton, 1998)

BCI = 3.67 - 0.966BL - 0.410BLW - 0.498CLW + 0.002CLV + 0.0004OLV + 0.022SPD + 0.506PKG - 0.264AREA + AF

Where:

BL=Presence of a bicycle lane or paved shoulder >=0.9 m (no=0 , yes=1),

BLW=bicycle lane(or paved shoulder) width, m(to the nearest tenth),

CLW=curb lane width, m(to the nearest tenth),

CLV=curb lane volume, vph in one direction,

OLV=other lane(s) volume, same direction, vph,

SPD=85th percentile speed of traffic, km/h,

PKG=presence if parking lane with more than 30 percent occupancy (no=0, yes=1),

AREA=type of road side development (residential=1, other type=0),

$AF=f_t+f_p+f_{rt}$

Where:

f_t=adjustment factor for truck volumes,

f_p=adjustment factor for parking turnover,

f_{rt}=adjustment factor for right-turn volumes.

Adjustment factors:

Table 5 BCI Adjustment factors

Hourly Curb Lane Large Truck Volume	**f_t**	**Parking Time Limit(min)**	**f_p**	**Hourly Right Turn Volume**	**f_{rt}**
≥120	0.5	**≤15**	0.6	**≥270**	0.1
60-119	0.4	**16-30**	0.5	**<270**	0
30-59	0.3	**31-60**	0.4		
20-29	0.2	**61-120**	0.3		
10-19	0.1	**121-240**	0.2		
<10	0	**241-480**	0.1		
		>480	0		

Once the index is calculated, the bicycle level of service is defined using the rating scale below:

Table 6 BCI ranges associated with LOS Designations and Qualifiers (Harkey , Reinfurt , Knuiman , Stewart & Sorton, 1998)

LOS	BCI Range	Corruptibility Level
A	≤1.50	Extremely High
B	1.51-2.30	Very High
C	2.31-3.40	Moderately High
D	3.41-4.40	Moderately Low
E	4.41-5.30	Very Low
F	>5.30	Extremely Low

This model is still widely used; however, other models were also created as they showed high sensitivity to traffic volumes, and good level of service measuring for midblock roads.

3.1.8.8 Bicycle Level of Service by HCM

The Highway capacity manual introduced a sophisticated model in 2010 to evaluate the bicycle level of service using 10 different affecting factors that are outside lane width, number of lanes, speed limit, presence of curb, pavement condition, width of shoulder, vehicle traffic volume, on-street parking, width of bike lane, and percentage of heavy vehicles (Callister & Lowry, 2013); see Table 7.

Table 7 Roadway Attributes for Selected Bicycle Suitability Methods (Callister & Lowry, 2013)

Attribute	**Method acronym, date**					
	BSIR, 1987	**BSL, 1994**	**BSS, 1997**	**BCI, 1998**	**BSA, 2003**	**BLOS, 2010**
Width of outside lane	x	x	x	x	x	x
Width of bike lane	—	—	—	x	x	x
Width of shoulder	—	—	x	x	x	x
On-street parking	x	—	—	x	x	x
Presence of curb	—	—	—	—	x	x
Vehicle-traffic volume	x	x	x	x	x	x
Number of lanes	x	—	—	—	x	x
Vehicle speeds	x	x	x	x	x	x
Percent heavy vehicles	—	—	—	x	—	x

Pavement condition	x	—	x	—	x	x
Elevation grades	x	—	—	—	x	—
Adjacent land-use	x	—	—	x	x	—
Storm drain grate	x	—	—	—	x	—
Physical median	x	—	—	—	x	—
Turn lanes	x	—	—	x	x	—
Frequent curves	x	—	—	—	x	—
Restricted sight-distance	x	—	—	—	x	—
Numerous driveways	x	—	—	—	x	—
Presence of sidewalks	—	—	—	—	x	—
Railroad crossing	x	—	—	—	—	—

An index called the perception index is calculated according to inputs, and is graded between grades A and F. Default values are proposed for six factors out of the ten inputs, but not used as data value (Callister & Lowry, 2013). The formula proposed is as shown below:

Equation 12 BLOS Perception Index (Callister & Lowry, 2013)

$$\mathbf{B} = 0.760+0.507 \ln(v_{ma}/4N) +0.199[1.1199\ln(S_{Ra} —20) + 0.8103](1 + 10.38P_{Hva})^2 + 7.066(1/P_c^2) - 0.005w_e^2$$

Where:

B = perception index for bicycle level of service,

N = numberof through lanes in the subject direction of travel (lanes),

vma = adjusted midsegment directional demand flow rate (vehicles/h),

SRa = adjusted motorized vehicle running speed (mi/h),

PHVa = adjusted percent heavy vehicles,

Pc = pavement-condition rating (poor to excellent, 0–5), and

We = effective width of the outside through-lane (ft).

Sensitivity analyses from this model state that the important factors are very critical with respect to reliable data. A survey was distributed in Idaho City to evaluate the availability of reliable data for each affecting factor in the HCM model. The results showed considerable lack of information for most of the factors; either because of the needed funds for data collection or because there was no use for such data to be collected yet (Callister & Lowry, 2013).

3.1.8.9 Bicycle Levels of Traffic Stress (LTS)

This method is based on classifications using four types of classes based on factors that are easy to access for normal planners without complications or sophisticated equations or models. LTS is the route that a traveler should take to reach their destination without passing through stressful streets (Mekuria , Furth & Nixon, 2012). The criteria used to evaluate the stress level for each segment is shown in table 8:

Table 8 Levels of Traffic Stress (LTS) (Mekuria , Furth & Nixon, 2012)

LTS 1	Presenting little traffic stress and demanding little attention from cyclists, and attractive enough for a relaxing bike ride. Suitable for almost all cyclists, including children trained to safely cross intersections. On links, cyclists are either physically separated from traffic, or are in an exclusive bicycling zone next to a slow traffic stream with no more than one lane per direction, or are on a shared road where they interact with only occasional motor vehicles (as opposed to a stream of traffic) with a low speed differential. Where cyclists ride alongside a parking lane, they have ample operating space outside the zone into which car doors are opened. Intersections are easy to approach and cross.
LTS 2	Presenting little traffic stress and therefore suitable to most adult cyclists but demanding more attention than might be expected from children. On links, cyclists are either physically separated from traffic, or are in an exclusive bicycling zone next to a well-confined traffic stream with adequate clearance from a parking lane, or are on a shared road where they interact with only occasional motor vehicles (as opposed to a stream of traffic) with a low speed differential. Where a bike lane lies between a through lane and a right-turn lane, it is configured to give cyclists unambiguous priority where cars cross the bike lane and to keep car speed in the right-turn lane comparable to bicycling speeds. Crossings are not difficult for most adults.
LTS 3	More traffic stress than LTS 2, yet markedly less than the stress of integrating with multilane traffic, and therefore welcome to many people currently riding bikes in American cities. Offering cyclists either an exclusive riding zone (lane) next to moderate-speed traffic or shared lanes on streets that are not multilane and have moderately low speed. Crossings may be longer or across higher-speed roads than allowed by LTS 2, but are still considered acceptably safe to most adult pedestrians.
LTS 4	A level of stress beyond LTS3.

The output of this model mainly contains three elements that are a stress map, and another two measurements related to the intersection approach and crossing risk (Mekuria , Furth & Nixon, 2012). This method is closely focused on the factors that are easily controlled and based on researching, rather than those based on equations and mathematical formulas. However, enhancements may be needed for other study areas, as the model ignores many influencers that could strongly affect the LTS.

3.1.8.10 Which Model is the best?

Despite the fact that BLOS, which is introduced in the highway capacity manual, is commonly used in the USA, the Bicycle compatibility index showed high sensitivity to traffic volume and speed of travel factors (Munro, 2013). As the study area mainly suffers from traffic jams, BCI should produce good bicycle suitability analyses for the existing road networks. However, all models should be applied and the decision maker or the planner would select the best fit solution.

3.2 Technical Approaches

3.2.1 What is GIS?

GIS is a set of tools used to visualize, store, analyze, capture, retrieve, question, and interpret different types of data used to study relationships and trends in order to propose or provide different alternatives and options for the decision makers, planners, or analysts to select the best options for their projects (Schuurman, 2004).

3.2.2 GIS Applications

GIS has no identity, as it serves many fields and meets many interests. Some people have an interest in “where’’, as the geographical location represents the core information for them and GIS is a very powerful tool in dealing with such data. On the other hand, some have an interest in ‘’how’’ or ‘’attribute data’’ as descriptive data is more important than the location for them. GIS is very clever in sorting, analyzing, comparing, or even dealing mathematically with numerous types of data (Schuurman, 2004).

GIS has proved its importance for many fields but in general it is powerful in finding solutions and investigating the socio-economic and environmental problems. The core benefit that differentiates GIS from other systems is the ability of establishing relationships between spatial analysis and modelling or in other words linking location, condition, trend, routing, pattern and modelling together in one output with different views (Maguire, 1991).

4 Data Required

Several sources of the data had been acquired to be analysed in order to get the best of it. Sources were mainly govermental sectors and universities to get the most trusted data avaialble for the study area. The missing data, that could not be sourced, has been collected via field data collection project by the Author himself. A field sheet has been used to collect the needed data in field.

4.1 Geometry

A shape file for all geometries in Downtown Area is required, containing all streets with their names and a land-use coverage for the area surrounding. It could be acquired from a private or local authority or by digitizing the area using free satellite images that is available on the internet.

4.2 Attributes

Average Annual Daily Traffic (AADT): is the number of vehicles passing through a certain point on a street within one year divided by 365. Vehicle/day unit expresses it (Garber & Hoel, 2014).

Average Daily Traffic (ADT): is the number of vehicles passing through a certain point on a street within a number greater than one day but less than one year and divided by that number. Vehicle/day unit expresses it (Garber & Hoel, 2014).

Curb lane: is the first lane from the right hand side which is the first lane after the curb or the pavement. (Harkey , Reinfurt & Sorton, 1998)

Curb Width: is the distance between the edge of the driving lanes and the edge of the pavement or the sidewalk, according to the Department of Transportation of New York City.

Direction of Travel (DOT): is the direction of driving on a certain street that might be one way or both ways, according to wordreference.com.

Function Class (FC): is a class number represents the street's condition or its level of service, according to the Federal Highway Administration.

K-Factor: is representing a percentage of the average annual daily traffic (AADT) so it is used to estimate or calculate the AADT or the ADT (State of Florida Department of Transportation, 2012).

Lane Width: is the distance between the two edges' markings that define the lane (Karim, 2015).

Number of lanes: is the number of marked passages on one street having the same direction of travel, according to merriam-webster.com.

Pavement/Sidewalk width: is the distance between the physical edges for the space that pedestrians can use, according to San Francisco Better Streets.

Peak Hour Volume: it is the highest number of vehicles passing through a certain point on a street within one Hour. Vehicles/hour unit expresses it (Garber & Hoel, 2014).

Running Speed/Actual Speed/Average Speed: it is the average speed that vehicles follow on a certain street and it is calculated by dividing the street length by the time commuted starting from entering the street until reaching its end. Another method to calculate the running speed is to sum a sample number of vehicles' speeds on a certain street and divide it by the sample size (Fitzpatrick, 2003).

Shoulder Width: is the width of the emergency stop lane that is usually existed on the right hand side for the countries, which drive on the right and vice versa, according to the Traffic Technology Today.

Speed Limit: is the maximum speed that a vehicle could reach on a certain street according to its design and the law; called posted speed (Fitzpatrick, 2003).

4.3 Data Description

The average daily traffic is one of the main required variables to apply most of the bicycle suitability models discussed in the literature review. Average daily traffic or ADT is the average number of vehicles passing through a certain street within a period of more than one day and less than one year. It is essential for many planning purposes such as evaluation of the existing traffic flow or measuring the current demand, however gathering this type of information is relatively expensive (Garber & Hoel, 2014).

The average annual daily traffic is another important variable needed for evaluating the suitability of riding a bicycle on a certain street. Average Annual daily Traffic or

AADT is the average number of vehicles passing through a certain street during a period of one full year. AADT is mainly used for the purpose of planning new highways and designing a maintenance program (Garber & Hoel, 2014).

Counting the number of vehicles for many days or year is not the only way to get the ADT or the AADT as the peak hour volume plays an essential role in estimating both figures. The peak hour volume is the highest volume counted during one hour among 24 hours for the same day (World Bank, 2013). Usually the traffic counts is divided into 15 minutes periods so the highest 4 sequential quarters or intervals represent the peak hour volume for a certain street (Anderson, 1994).

After getting, the peak hour volume then the k-factor could be used for estimating the average daily traffic or the annual average daily traffic using the formula below:

Equation 13 Peak Hour Volume Equation (Harkey , Reinfurt , Knuiman , Stewart & Sorton, 1998)

$$\mathbf{PHV = AADT \times K \times D}$$

Where:

PHV = peak-hour directional volume,

AADT = average annual daily traffic (vehicles per day),

K = peak-hour factor (the proportion of vehicles traveling during the peak hour, expressed as a decimal), and

D = directional split factor (the proportion of vehicles traveling in the peak direction during the peak hour, expressed as a decimal).

Usually the k-factor ranges from 7% to 15% universally but as a default, it is 10% out of the AADT for urban roads (Harkey , Reinfurt & Sorton, 1998); in other references, it ranges from 12% to 18% out of the AADT for rural roads (Pline, 1992). What is applied for Egypt is 10% to 12% out of the AADT for rural roads (Semeida, 2013) and (ABBAS, 2003); for urban areas k-factor ranges from 8% to 10% out of the ADT (Abd-El-Latif , Sabry , Yousef & Badra, 2007) while, for rural roads, the Egyptian Code of Practices states that the peak hour ranges from 8% to 12% from the ADT.

Following the same regime for estimating the average daily traffic, universally, the peak hour volume represents 9-10% of the ADT (Note, n.d.). On the other hand, ADT represent 1.1% of the AADT in Egypt, approximately, according to Dr. Mostafa Sabry (Professor of transport and traffic Engineering, Ain Shams university). For the directional split factor, it ranges from 50% to 65% but the default value is 55% and for one-way roads, it is assigned as 100% as the whole flow is in one direction already (Harkey , Reinfurt & Sorton, 1998). So as a conclusion, if the peak hour volume acquired all other figures could be estimated using that volume.

For Egypt, the peak hours are divided into 3 periods as the morning peak hour is between 7 am and 9 am, afternoon peak hour is between 1 pm and 4 pm and the evening peak hour is between 8 pm and 9 pm; but even between 10 am and 12 pm there are a peak period in some areas (World Bank, 2010). Table 9 illustrates the percentage of occurrence in traffic count stations that observed in some areas in the Greater Cairo for each peak period:

Table 9 Traffic peak periods in the Greater Cairo Metropolitan Area (World Bank, 2013)

Peak	Period	Percentage of occurrence in traffic count stations
Morning	07:00-09:00	29.1 %
	10:00-12:00	21.8 %
Afternoon	13:00-16:00	27.3 %
	17:00-18:00	9.1 %
Evening	20:00-21:00	12.7 %
Total		100 %

Street lane is a painted/marked path that defines the space that vehicles should use within the street or the road. A single street may consist of more than one lane based on the designed capacity served, according to merriam-webster.com. Each lane has a certain width and that width should not be different among the same street for the same usage. That width defines the distance between the marked edges of a certain link and expressed by a measurement unit. For vehicles' lane, it is from 2.8 meters to 3.2 meters and for bicycle's lane, it is from 1.2 meter to 1.5 meter according to The American Association of State Highway and Transportation Officials (AASHTO).

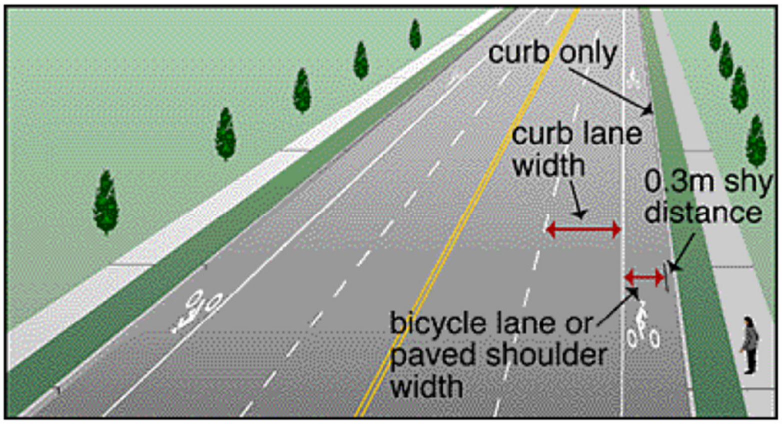


Figure 10 Street Lanes (Harkey , Reinfurt & Sorton, 1998)

Other lane types may exist according to the type of usage or the vehicles and transportation means that use a certain street such as the acceleration lane, deceleration lane, turn lane, passing lane, motorcycle lane, bus lane, tram lane, parking lane and bicycle lane, according to *AASHTO*.

The cross section of a street could be as shown in figure 10; starting from the pavement/walkway that ranges from 1.5 meter to 3 meters with reference to the land use type for the area, ending by the yellow solid line that divides the directions of travel, in case of two ways street, or the other edge of curb, in case of one way street. The shy distance is a small space between the walk way and the first riding/driving lane in case no curb or gutter exists. The curb is a different in the elevations between the driving street and the pavement while the gutter is the rainwater drainage path and it is few centimeters by the side of the curb. The first lane after the curb and gutter might be the bicycle lane that ranges from 1.2 to 1.5 meters or the parking lane that is usually 2.4 meters for the side parking allowed streets. After that, the first lane from right hand side is called the curb lane and its width is normal like the rest of the lanes that ranges from 2.8 to 3.2 according to the country's specifics but the traffic flow on it represents 60% of the total flow on the street compared to other lanes volumes (Harkey , Reinfurt & Sorton, 1998). A shoulder may exist or to be shared with the bicycle lane that is used for emergency stops, according to AASHTO. Egypt follows all other universal measurements with respect to the lane width, sidewalk, shoulder, curb or gutter existence according to the Egyptian code of practice.

The maximum speed that a vehicle could reach on a certain street called speed limit and unusually there is a posted sign indicates the speed allowed that called posted speed limit; and if it is not posted but known, then it is called unposted speed limit. However, the speed limit is assigned based on the street design and the capacity forecasted but for dense areas and jammed districts, the speed limit is hard to reach and usually a lower speed is being followed that called the running speed or the average speed (Fitzpatrick, 2003). For Egypt, the posted speed limit inside city and towns is 60 kph/37 mph for the collector roads, according to the Egyptian code in practice, but the estimated average running speed inside Great Cairo Metropolitan Area is between 20 to 45 kph (World Bank, 2013).

According to the Federal Highway Administration, The core meaning of road function class is to group roads that have same condition or level of service in one category. In general, there are three main road function classes defined as arterial roads that represent the highways and main roads, collector roads that represent the main corridors inside a certain city, and the local roads that connect districts and blocks to each other having a lower level of service compared with the other classes. In Egypt, the same categorization is used for defining its roads and streets with some sub-categories and more diversification according to the Egyptian code of practice.

Table 10 Urban Roads Specifications in Egypt (The Egyptian Code of Practice)

		Free Way	**Main Road**		**Secondary Road**		**Local Road**
		Road Type	**Road Type**		**Road Type**		**Road Type**
		Divided	**Divided**	**Not-Divided**	**Divided**	**Not-Divided**	**Not-Divided**
Rural	**Speed**	≥110	80-110	70-90	60-80	50-60	≤50
	AADT	>20000	8000-20000		2000-10000		<2000
Urban	**Speed**	≥90	70-90	60-80	50-70	40-60	<-50
	AADT	>2500	8000-25000		3000-12000		<3000
Number of Lanes		4-6	2-4		2-4		2
lane width (m)		3.75	3.5		3.25-3.5		3

4.4 Sources of the Data

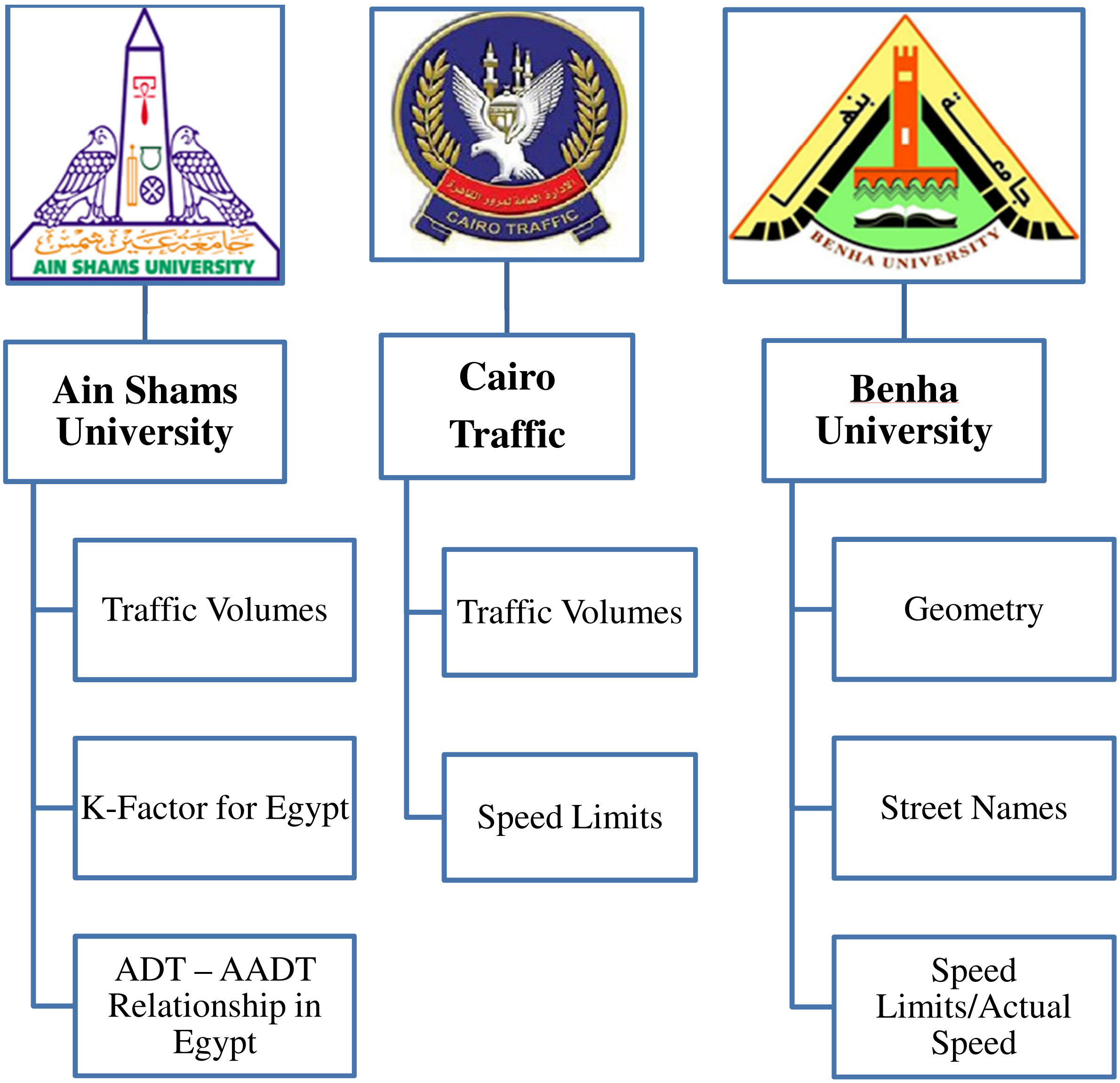


Figure 11 Data Sources

*The other Attributes have been collected from Field by the Author.

4.5 Received Data

4.5.1 Geometry

A shape file has been sourced from Benha University includes all street names, posted speed limits, function classes and direction of travels for the Downtown Area and some of the surrounding districts.

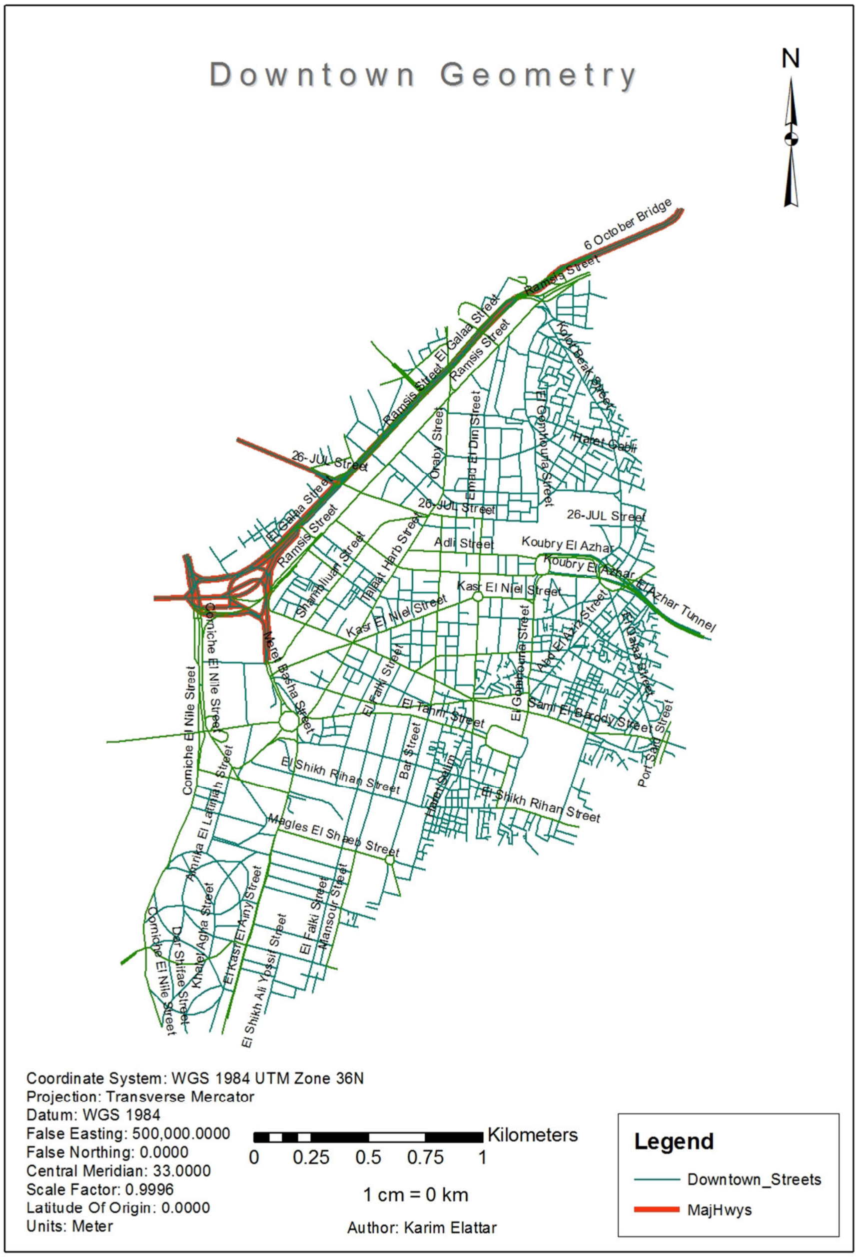


Figure 12 Downtown Geometry (Source: Benha University)

Table 11 Downtown Attributes (Source: Benha University)

Table

Downtown_Streets

Shape	LINK_ID	ST_NAME	TO_SPD_LIM	FR_SPD_LIM	DIR_TRAVEL	FUNC_CLASS
Polyline	808525837	Abd El Hamed Shaaban Street	0	40	F	5
Polyline	808561936	Abd El Hamed Shaaban Street	40	40	B	5
Polyline	808624807	Abd El Hamed Shaaban Street	0	40	F	5
Polyline	808794519	Abd El Hamed Shaaban Street	40	40	B	5
Polyline	808824481	Abd El Hamed Shaaban Street	0	40	F	5
Polyline	851072192	Abd El Hamed Shaaban Street	0	40	F	5
Polyline	808335362	Abd El Kadear El Maznay Street	40	40	B	5
Polyline	808811535	Abd El Kadear El Maznay Street	40	40	B	5
Polyline	808866039	Abd El Kadear El Maznay Street	40	40	B	5
Polyline	808882052	Abd El Kadear El Maznay Street	40	40	B	5
Polyline	808497980	Abd El Kadear Hamza Street	60	0	T	4
Polyline	808547373	Abd El Kadear Hamza Street	60	0	T	4
Polyline	808619888	Abd El Kadear Hamza Street	60	0	T	4
Polyline	808649686	Abd El Kadear Hamza Street	0	40	F	5
Polyline	808748567	Abd El Kadear Hamza Street	60	0	T	4
Polyline	808771073	Abd El Kadear Hamza Street	40	40	B	5
Polyline	808794736	Abd El Kadear Hamza Street	60	0	T	4
Polyline	808821135	Abd El Kadear Hamza Street	60	60	B	4
Polyline	960532139	Abd El Kadear Hamza Street	0	60	F	4
Polyline	960532140	Abd El Kadear Hamza Street	0	60	F	4
Polyline	960532141	Abd El Kadear Hamza Street	0	60	F	4
Polyline	960532142	Abd El Kadear Hamza Street	0	60	F	4
Polyline	808340051	Abd El Kalek Sarwat Street	60	0	T	4
Polyline	808409390	Abd El Kalek Sarwat Street	60	0	T	4
Polyline	808544219	Abd El Kalek Sarwat Street	0	60	F	4
Polyline	808653821	Abd El Kalek Sarwat Street	60	0	T	4
Polyline	808661188	Abd El Kalek Sarwat Street	0	60	F	4
Polyline	808662826	Abd El Kalek Sarwat Street	0	60	F	4
Polyline	808671578	Abd El Kalek Sarwat Street	60	0	T	4
Polyline	808747517	Abd El Kalek Sarwat Street	60	0	T	4

405 (0 out of 2582 Selected)

Downtown_Streets

The function classes that will be used for this research are 3 and 4 that represents the collectors classification. Street names have been checked compared with reality to avoid applying any misleading traffic flow numbers.

4.5.2 Traffic Volumes

Traffic volumes per 15 minutes for the fifth and eighth of January 2016 come from Ain Shams University and Cairo Traffic collected using automatic sensors that count vehicles per lane. The data received does not cover the whole 24 hours for the most of the Downtown streets as the sensor stops working between 12 pm and 8:45 pm because of a technical issue. The data covers the morning period for all streets and most of the evening time as shown in the example below:

Table 12 Gomhuria Street and Abd El Khalik Tharwat Street (Source: Ain Shams University)

Date/Time		1	2	3	4	5	6	7	8
52 intersection 2-2 (unknown)									
1/5/2016	8:15:00AM	18	13	12	0	131	134	130	125
1/5/2016	8:30:00AM	18	20	24	0	93	149	135	103
1/5/2016	8:45:00AM	23	31	33	0	67	134	148	96
1/5/2016	9:00:00AM	25	48	47	0	55	139	140	94
1/5/2016	9:15:00AM	28	63	46	0	88	155	151	83
1/5/2016	9:30:00AM	16	60	45	0	70	125	135	85
1/5/2016	9:45:00AM	27	63	42	0	60	126	117	108
1/5/2016	10:00:00AM	37	56	47	0	53	131	120	114
1/5/2016	10:15:00AM	19	50	34	0	50	131	138	115
1/5/2016	10:30:00AM	29	75	53	0	55	149	120	91
1/5/2016	10:45:00AM	32	70	58	0	59	136	138	82
1/5/2016	11:00:00AM	32	81	59	0	47	145	144	57
1/5/2016	11:15:00AM	30	72	58	0	53	117	131	76
1/5/2016	11:30:00AM	25	67	59	0	52	156	134	73
1/5/2016	11:45:00AM	14	30	25	0	24	46	46	14
1/5/2016	12:00:00PM	0	0	0	0	0	0	0	0
1/5/2016	12:15:00PM	0	0	0	0	0	0	0	0
1/5/2016	12:30:00PM	0	0	0	0	0	0	0	0
1/5/2016	12:45:00PM	0	0	0	0	0	0	0	0
1/5/2016	1:00:00PM	0	0	0	0	0	0	0	0
1/5/2016	1:15:00PM	0	0	0	0	0	0	0	0
1/5/2016	1:30:00PM	0	0	0	0	0	0	0	0
1/5/2016	1:45:00PM	0	0	0	0	0	0	0	0
1/5/2016	2:00:00PM	0	0	0	0	0	0	0	0
1/5/2016	2:15:00PM	0	0	0	0	0	0	0	0
1/5/2016	2:30:00PM	0	0	0	0	0	0	0	0
1/5/2016	2:45:00PM	0	0	0	0	0	0	0	0
1/5/2016	3:00:00PM	0	0	0	0	0	0	0	0
1/5/2016	3:15:00PM	0	0	0	0	0	0	0	0
1/5/2016	3:30:00PM	0	0	0	0	0	0	0	0
1/5/2016	3:45:00PM	0	0	0	0	0	0	0	0
1/5/2016	4:00:00PM	0	0	0	0	0	0	0	0

4.5.3 Speed Limits

There is no posted speed limit for the most of the Downtown streets but the default speed limit for this admin area is 60 kph, according to the Cairo Traffic Authority. On the other hand, the actual average speed limit for all streets in Downtown area is 40 kph, according to Benha and Ain Shams Universities.

4.5.4 Street Lanes Attributes

The maximum number of lanes collected is four lanes and the minimum is three lanes, according to the filed data collection. For the lane width, however the function class is vary for the study area streets but the width of three meters per lane is measured, according to the field data collection.

5 Methodology and Analysis

5.1 Introduction

In this chapter, we are going to apply different models using the collected attributes for the study area to let the decision maker review all possible solutions for planning a bicycling route network in the respective streets.

Applying the models will be executed using a GIS tool that is created by the author for this purpose, specifically. All Models explained in the literature review are implemented in that tool, where the used data are all collected via field operation or sourced from the respective authorities.

5.2 Bicycle Suitability Methodologies

The Researcher chose the following models to be applied on the study area geometry. The four models include Bruce Epperson modified roadway condition index, Petritsch's BLOS and the most commonly used ones such as the Bicycle Compatibility Index and Bicycle Level of Service by HCM (Callister & Lowry, 2013) and (Harkey , Reinfurt & Sorton, 1998). Table 13 shows the 4 models that will be applied on Downtown streets and it shows the factors that are covered within these models.

Table 13 The applied Methods and Factors

	Bruce Epperson Modified Roadway Condition Index	Petritsch's BLOS	Bicycle Compatibility Index (Harkey)	Bicycle Level of Service (HCM)
ADT (VC, VR)	■			
Hourly Volume (CLV,OLV,vma)			■	■
Number of Lanes (L, N)	■	■		■
Speed limit (S, SPD, SP, SRa)	■	■	■	■
lane width (W, We, CLW)	■	■	■	■

pavement factor (PF)				
location factor (LF)				
% of Heavy vehicles (.HV, %HV, HV, PHVa)				
Land Use (LU, COM15, AREA)			1 or 0	
Total Curb Cuts (CCF)				
VOL15				
Surface Condition (PC)				
Constants				
Effective Frequency per mile - parking existence (NCA)			1 or 0	
Proportion of parallel on street Parking(Ppk)				
Curb Existence				1 or 0
Bicycle lane Existence (BL)			1 or 0	
Bicycle Lane Width(BLW)				
Adjustment Factors				

5.3 Data Preparation

Average daily traffic has been calculated for all streets using the morning peak hour volume as explained previously. Minimum representing percentage of 8% and maximum representing percentage 12% have been used to calculate the ADT to illustrate the best and worst case scenarios for Downtown streets.

For the rest of the attributes, they have been collected and measured via field data collection fir each street individually. Table 14 has been used as a field sheet to facilitate the measurements to the collector.

Table 14 Field Sheet to facilitate the field measurements

Street Name	
Lane Width	2.8 m/ 3 m/ 3.25 m
Number of lanes	2 / 3 / 4
Pavement Width	1.5 m / 2 m / 2.5 m / 3 m
Shoulder Width	2.8 m / 3 m / 3.25 m
Parking	No / Yes
Notes	

Microsoft Excel has been used to spread all calculations for all needed attributes and to spread the collected ones as well. Then all attributes have been copied to the attribute table in the ArcMap.

5.4 The Bicycle Suitability Modelling Tool

A GIS tool has been developed to aid in applying all bicycling suitability models on any geometry needed. The tool contains the majority of the suitability models excluding any points based models such as the Bicycle Stress level and the Bicycle Levels of Traffic Stress. All other models are included in this tool such as Davis Bicycle Safety Index Rating, Epperson- Davis Roadway Condition Index, Bruce Epperson Modified Roadway Condition Index, Intersection Hazard Score - BRUCE W. LANDIS, Landis' BLOS, Petritsch's BLOS, Bicycle Compatibility Index (Harkey) and Bicycle Level of Service (HCM).

Microsoft Visual studio has been used to develop the Bicycle Suitability Modelling tool. Microsoft Visual Studio consists of multiple development platforms in order to form one integrated development environment. It is developed by Microsoft to be used for creating computer programs, web sites, web applications and web services supporting multiple programming languages such as C, C++, VB.NET and many others (Johnson, 2012). The programming language used in VB.NET to create the Bicycle Suitability Modelling Tool using the ESRI libraries that are impeded in ArcObject 10 and the compiler is .NET Frame Work 3.5. This tool is applicable with ArcMap versions of 10 and 10.2.

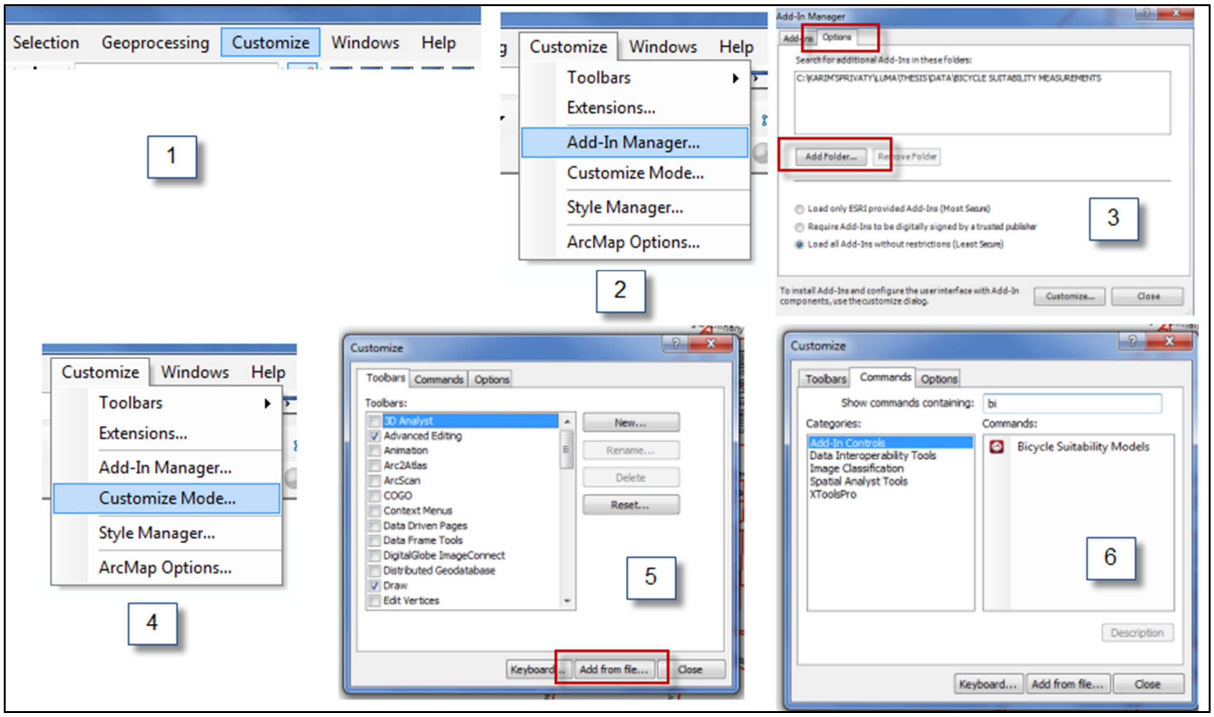


Figure 13 Adding the Add-In to the ArcMap

Figure 13 shows the steps that should be followed in order to install the Add-in.

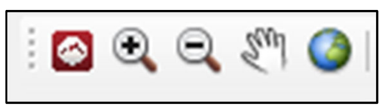


Figure 14 Displayed icons for the Bicycling Suitability Modelling Tool

Figure 14 illustrates how the Add-in's icon displayed in the toolbar and figure 15 shows how the interface looks.

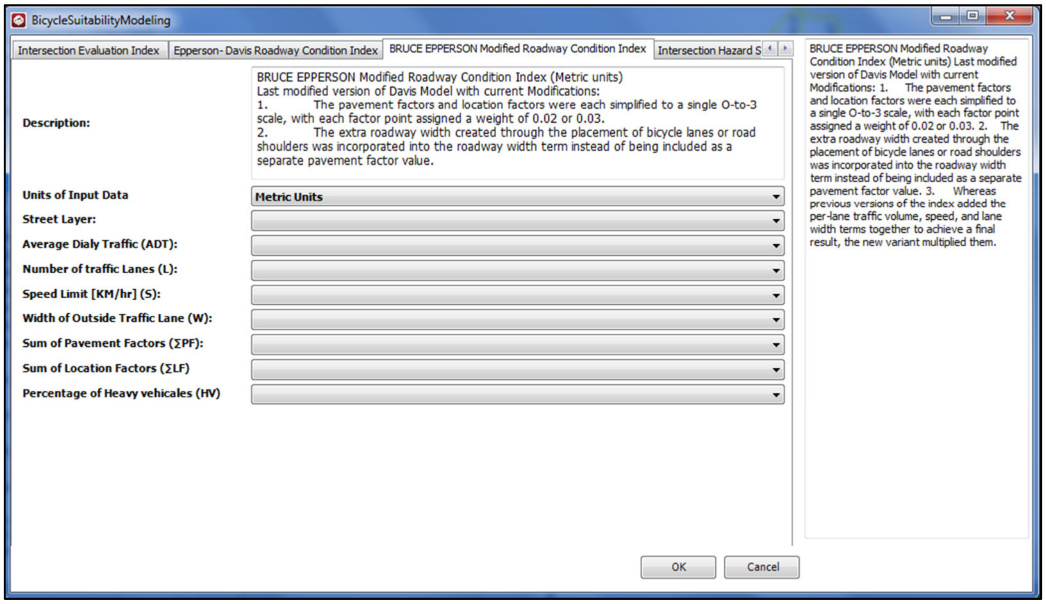


Figure 15 Bicycling Suitability Modelling Interface

The tool has a unit conversion function as some of the models use English units system and other use Metric units system. The function works on converting Metric measurements to English ones if the model uses English units and the inputs are in Metric system and vice versa, see figure 16.

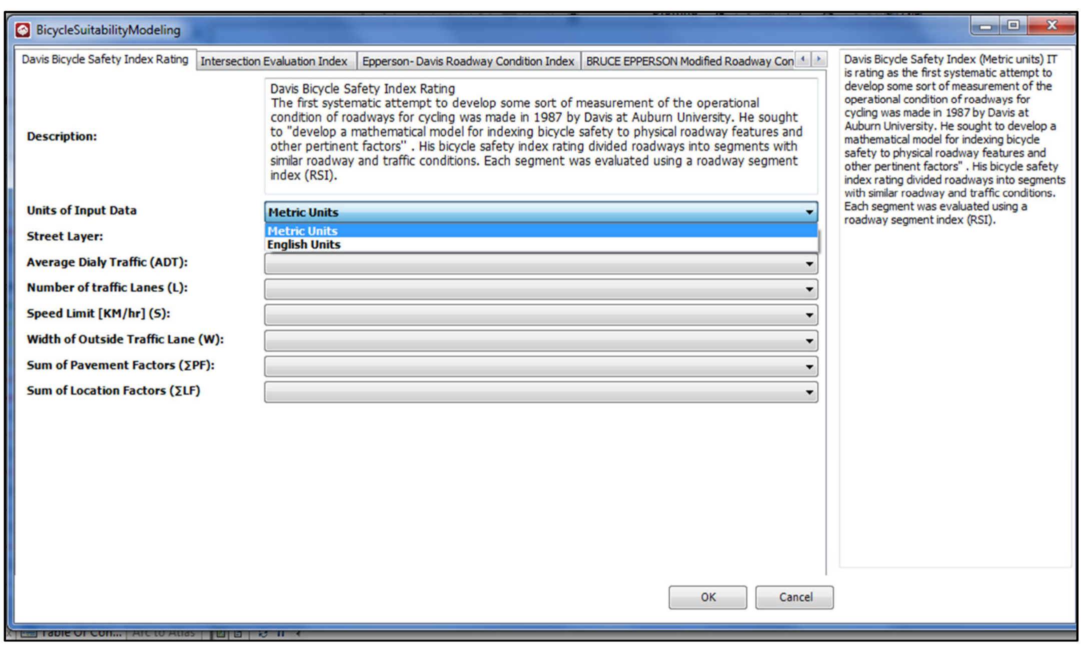
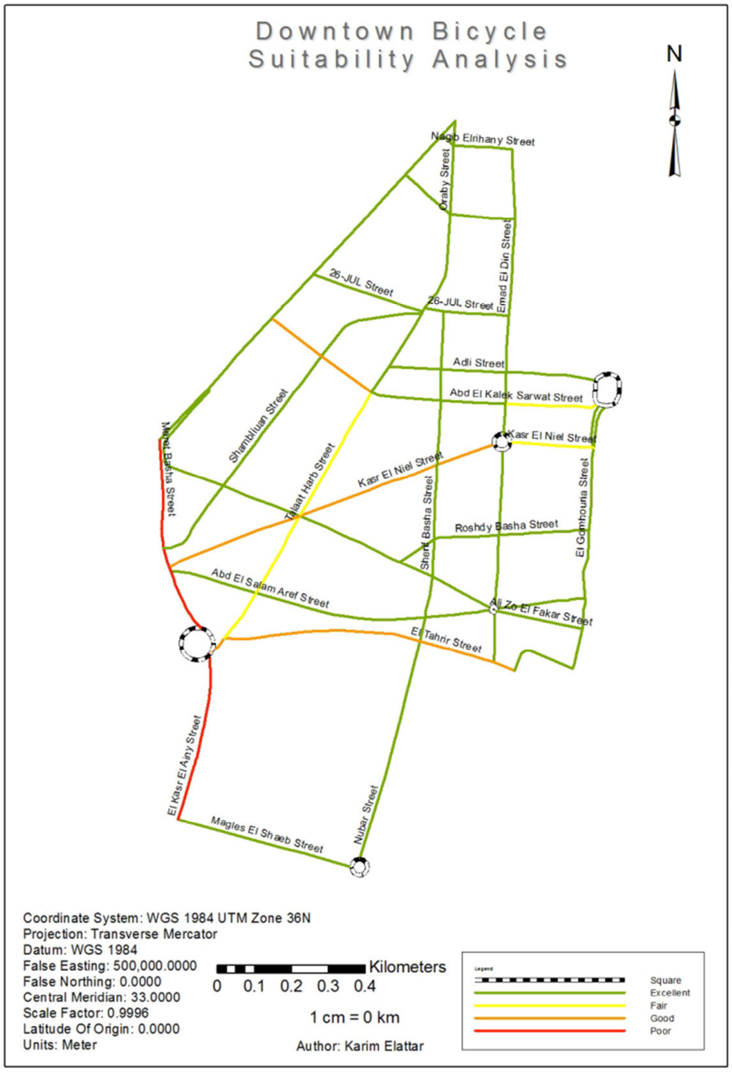
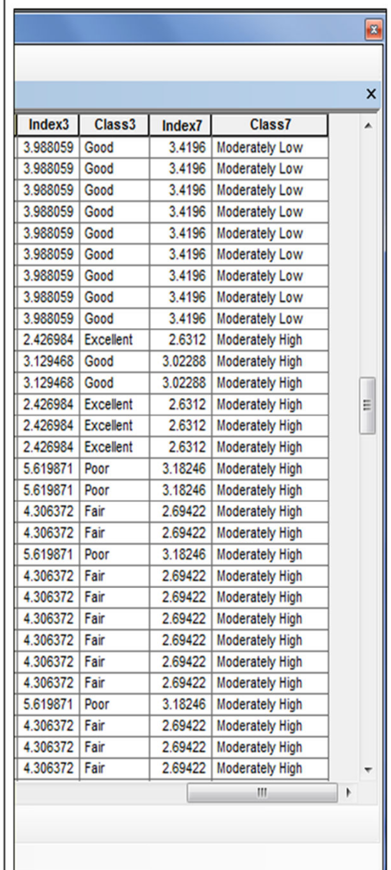


Figure 16 Bicycling Suitability Modelling Interface - Unit Conversion function

Figure 17 shows the outputs of the tool which are two columns, one column for the index values and the other for the index classes with reference to the scale used for each individual model. All models could be applied on the same shape file as each model generates new columns.





Index3	Class3	Index7	Class7
3.988059	Good	3.4196	Moderately Low
3.988059	Good	3.4196	Moderately Low
3.988059	Good	3.4196	Moderately Low
3.988059	Good	3.4196	Moderately Low
3.988059	Good	3.4196	Moderately Low
3.988059	Good	3.4196	Moderately Low
3.988059	Good	3.4196	Moderately Low
3.988059	Good	3.4196	Moderately Low
3.988059	Good	3.4196	Moderately Low
2.426984	Excellent	2.6312	Moderately High
3.129468	Good	3.02288	Moderately High
3.129468	Good	3.02288	Moderately High
2.426984	Excellent	2.6312	Moderately High
2.426984	Excellent	2.6312	Moderately High
2.426984	Excellent	2.6312	Moderately High
5.619871	Poor	3.18246	Moderately High
5.619871	Poor	3.18246	Moderately High
4.306372	Fair	2.69422	Moderately High
4.306372	Fair	2.69422	Moderately High
5.619871	Poor	3.18246	Moderately High
4.306372	Fair	2.69422	Moderately High
4.306372	Fair	2.69422	Moderately High
4.306372	Fair	2.69422	Moderately High
4.306372	Fair	2.69422	Moderately High
4.306372	Fair	2.69422	Moderately High
4.306372	Fair	2.69422	Moderately High
5.619871	Poor	3.18246	Moderately High
4.306372	Fair	2.69422	Moderately High
4.306372	Fair	2.69422	Moderately High
4.306372	Fair	2.69422	Moderately High

Figure 17 Columns generated via the Bicycling Suitability Modelling tool and the sympology map that could be created using them

If the same model applied on the same shape file then the new outputs will replace the existing ones without adding new columns.

6 Results and Analysis

This chapter is about the results and analysis generated by applying four selected models on the study area, using the tool created on Ars GIS.

6.1 Bruce Epperson Modified Roadway Condition Index

This model represents the last modification applied on the initial one created by Davis (Epperson, 1994) for assessing the bicycle suitability on a certain road.

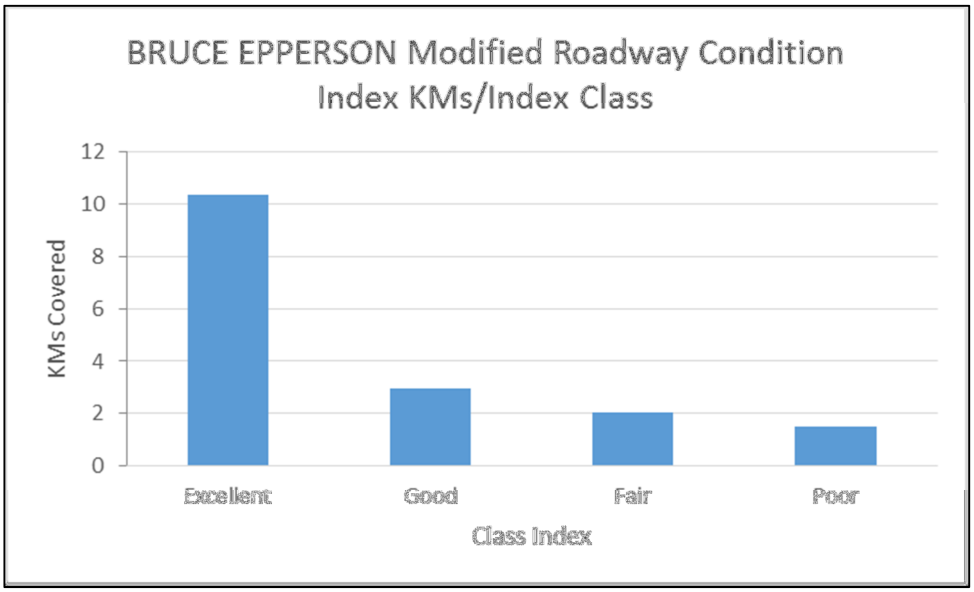


Figure 18 Chart illustrates Bruce Epperson Modified Roadway Condition Index KMs/Index Class

The above chart shows that the excellent class is the dominant for this applied model in the study area.

Table 15 Bruce Epperson Modified Roadway Condition Index KM covered per Index Class

Index Class	KMs/Class
Excellent	10.382
Good	2.984

Fair	2.057
Poor	1.473

Excellent and good classes represent 61% and 18% of the total result. Fair and Poor classes are only 12% and 9%. In total, more than three fourth of the streets in Down Town Cairo is suitable for bicycling.

Table 16 Bruce Epperson Modified Roadway Condition Index Class' KMs covered per Street Name

Street Name	Excellent	Good	Fair	Poor	Grand Total(KMs)
26-JULY Street	0.544				0.544
Abd El Kalek Sarwat Street		0.367	0.337	0.253	0.957
Abd El Salam Aref Street	0.707				0.707
Adli Street	0.423	0.141			0.564
Ali Zo El Fakar Street	0.239				0.239
El Gomhouria Street	1.048				1.048
El Kasr El Ainy Street				0.458	0.458
El Raeeis Abd El Salam Aref Street	0.423				0.423
El Tahrir Street		0.855			0.855
Emad El Din Street	0.264	0.189			0.453
Kasr El Niel Street			0.944	0.227	1.171
Magles El Shaeb Street	0.489				0.489
Mahmoud Basyony Street	0.605				0.605
Meret Basha Street				0.535	0.535
Mohamed Farid Street	0.882				0.882
Mohamed Sabry Abo Alam Street	0.577				0.577
Nagib Elrihany Street		0.210			0.210
Nubar Street	0.681				0.681
Oraby Street	0.406				0.406
Ramsis Street	1.221				1.221
Roshdy Basha Street	0.534				0.534
Shambliuan Street	1.001				1.001
Sherif Basha Street		0.831			0.831

Solayman Elhalaby Street	0.339				0.339
Talaat Harb Street		0.392	0.776		1.168
Grand Total	10.382	2.984	2.057	1.473	16.90

The output is accepted in most of the street segments as only Abd El Khalik Tharwat street represents a mixed result between Good and Poor classes on the other hand Talaat Harb Street has 392 meters that are suitable distance for bicyclists and more than 700 meters are fairly indexed for not suitable distance for riding a bicycle.

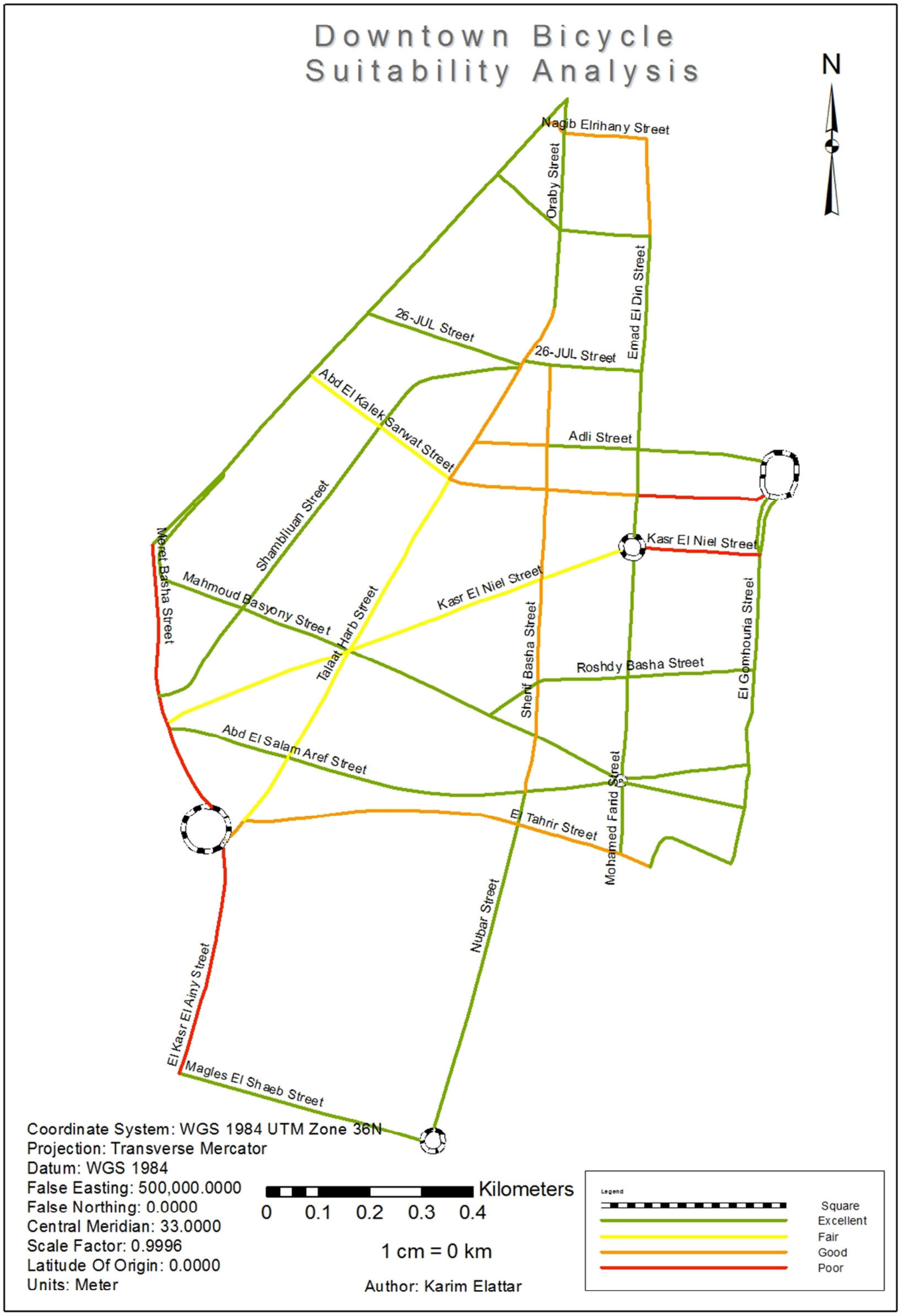


Figure 19 Bruce Epperson Modified Roadway Condition Index applied on Downtown area

If we consider the classes of excellent and Good only then we could get a nice route network for bicycling that covers the majority of the downtown streets and should achieve good bikeability if it is got measured in further research.

6.2 Petritsch's BLOS

This model represents the last updated version of the Intersection Hazard Score model that is created by Bruce W. Landis (, 2007).

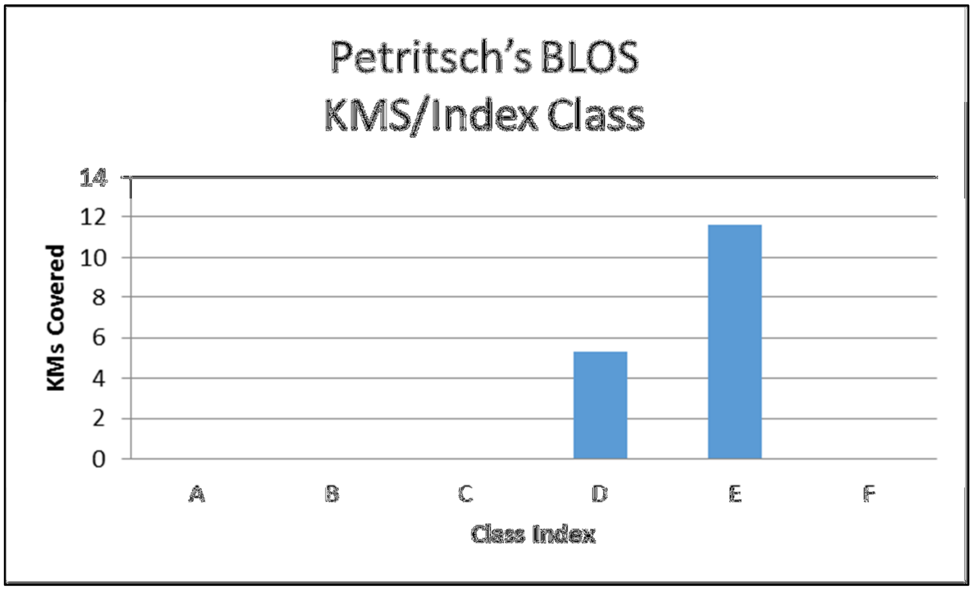


Figure 20 Chart illustrates Petritsch's BLOS KMs/Index Class

The above chart shows that the result is limited to 2 classes only that are D and E that indicate to moderate low suitability and very low suitability, respectively as class A indicates to extremely high suitability and class F indicates to extremely low suitability.

Table 17 Petritsch's BLOS KM covered per Index Class

Class Index	Kms/Class
A	0
B	0
C	0
D	5.29
E	11.61
F	0

Class D represents 30% of the total study area streets and class E represents 70% that indicates low classifications for all streets within the study area.

Table 18 Petritsch's BLOS Index Class' KMs covered per Street Name

Street Name	A	B	C	D	E	F	Grand Total(KMs)
26-JUL Street				0.54			0.54
Abd El Kalek Sarwat Street					0.96		0.96
Abd El Salam Aref Street				0.71			0.71
Adli Street					0.56		0.56
Ali Zo El Fakar Street				0.24			0.24
El Gomhouria Street				0.55	0.49		1.05
El Kasr El Ainy Street					0.46		0.46
El Raeeis Abd El Salam Aref Street				0.42			0.42
El Tahrir Street					0.86		0.86
Emad El Din Street					0.45		0.45
Kasr El Niel Street					1.17		1.17
Magles El Shaeb Street				0.49			0.49
Mahmoud Basyony Street					0.60		0.60
Meret Basha Street					0.53		0.53
Mohamed Farid Street					0.88		0.88
Mohamed Sabry Abo Alam Street				0.58			0.58
Nagib Elrihany Street					0.21		0.21
Nubar Street					0.68		0.68
Oraby Street					0.41		0.41
Ramsis Street				1.22			1.22
Roshdy Basha Street				0.53			0.53
Shambliuan Street					1.00		1.00
Sherif Basha Street					0.83		0.83
Solayman Elhalaby Street					0.34		0.34
Talaat Harb Street					1.17		1.17
Grand Total	0	0	0	5.29	11.61	0	16.90

All streets get either class D or class E else if there is only one street gets mixed classes between D and E which is El Gomhouria Street.

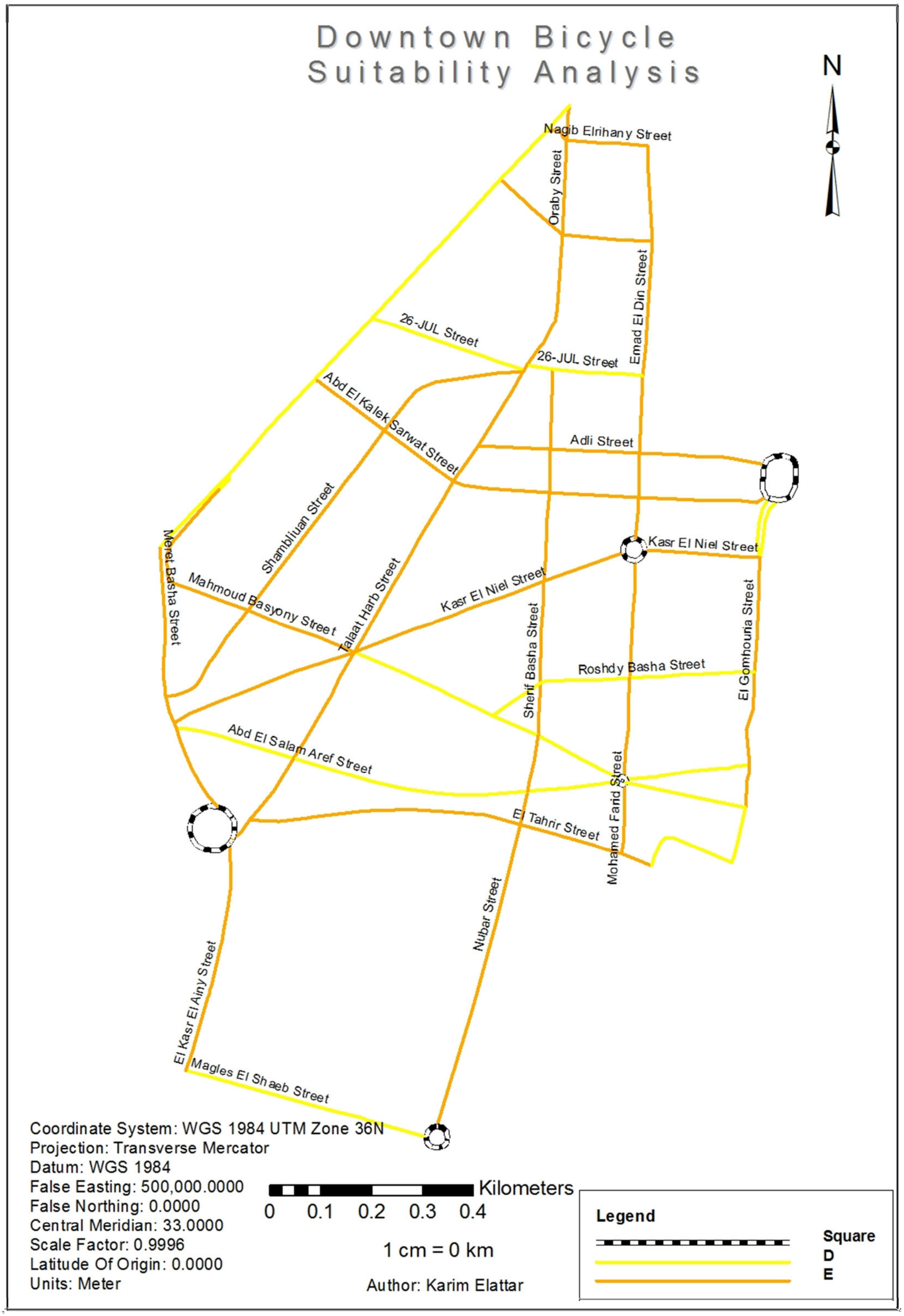


Figure 21 Petritsch's BLOS Model applied on Downtown area

The map above illustrates that the suitability is very low when applying this model.

6.3 Bicycle Compatibility Index (Harkey)

This model is considered as one of the most commonly used models for studying the bicycling suitability for any street (Harkey , Reinfurt , Knuiman , Stewart & Sorton, 1998).

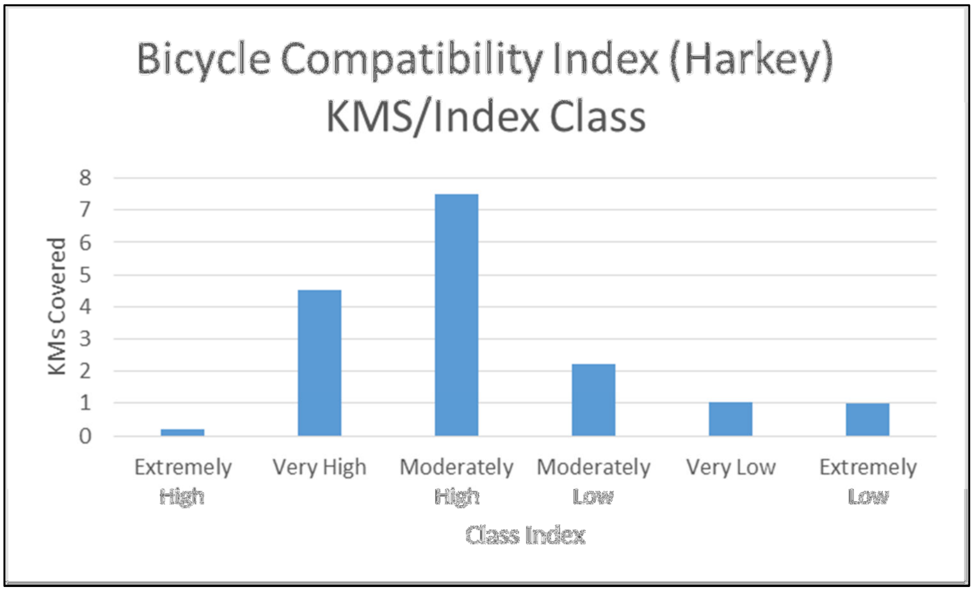


Figure 22 Chart illustrates BCI KMs/Index Class

The dominant classes in the above chart are Very High and Moderately High however there a considerable number of streets gets the class of Moderately Low.

Table 19 BCI KM covered per Index Class

Class Index	KMs/Class
Extremely High	0.194
Very High	4.522
Moderately High	7.506

Moderately Low	2.221
Very Low	1.053
Extremely Low	0.993

Almost 73% of the total KMs covered in the study area gets very high and moderately high compatible indices. On the other hand, there is only 12% receive very low and extremely low indices.

Table 20 BCI Index Class' KMs covered per Street Name

Street Name	Extremely High	Very High	Moderately High	Moderately Low	Very Low	Extremely Low	Grand Total(KMs)
26-JUL Street		0.314	0.229				0.544
Abd El Kalek Sarwat Street			0.367	0.590			0.957
Abd El Salam Aref Street		0.707					0.707
Adli Street					0.564		0.564
Ali Zo El Fakar Street			0.239				0.239
El Gomhouria Street		0.121	0.927				1.048
El Kasr El Ainy Street						0.458	0.458
El Raeeis Abd El Salam Aref Street		0.423					0.423
El Tahrir Street				0.855			0.855
Emad El Din Street			0.453				0.453
Kasr El Niel Street			1.171				1.171
Magles El Shaeb Street					0.489		0.489
Mahmoud Basyony Street		0.605					0.605
Meret Basha Street						0.535	0.535

Mohamed Farid Street	0.194	0.136	0.551				0.882
Mohamed Sabry Abo Alam Street			0.577				0.577
Nagib Elrihany Street			0.210				0.210
Nubar Street		0.681					0.681
Oraby Street			0.406				0.406
Ramsis Street			1.221				1.221
Roshdy Basha Street		0.534					0.534
Shambliuan Street		1.001					1.001
Sherif Basha Street			0.831				0.831
Solayman Elhalaby Street			0.339				0.339
Talaat Harb Street			0.392	0.776			1.168
Grand Total	0.194	4.522	7.506	2.221	1.053	0.993	16.90

Based on the matrix above, there are only four complete streets are not compatible with bicycling which are El Kasr El Ainy Street, Adli Street, Magles El Shaeb Street and Meret Basha Street; in addition to some parts from other streets such as Talaat Harb Street, El Tahrir Street and Abd El Kalek Sarwat Street.

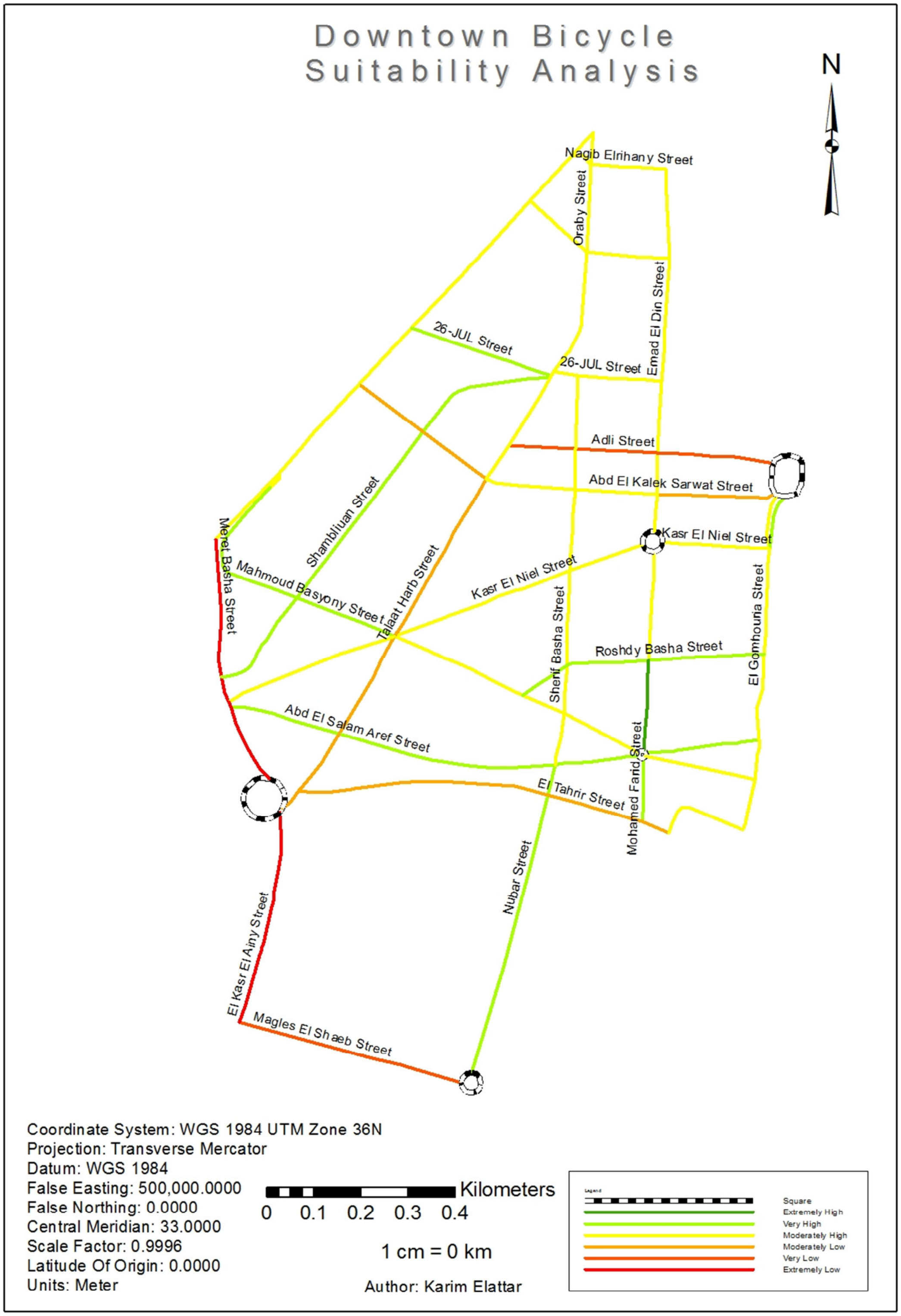


Figure 23 BCI Model applied on Downtown area

The map shows that we could get a compatible network of streets for bicycling that covers the majority of the study area without any concern regarding the network connectivity.

6.4 Bicycle Level of Service (HCM)

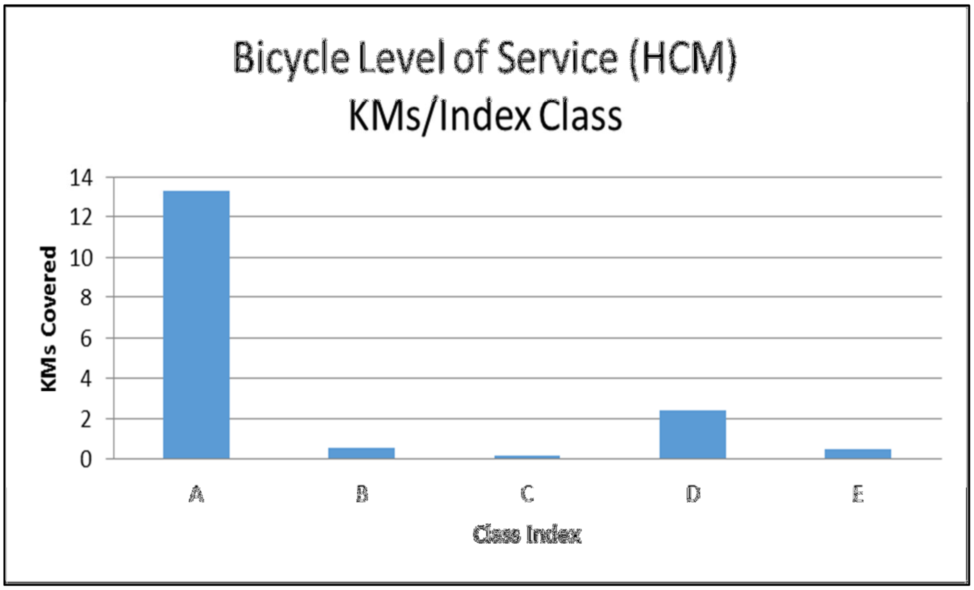


Figure 24 Chart illustrates HCM BLOS KMs/Index Class

The graph above shows a high number of KMs covered with the class index of A which indicates to the best suitability and limited number of KMs covered by class indices of B, C and E that indicate to less suitability, in a descending order from A to E.

Table 21 HCM BLOS KM covered per Index Class

Class Index	KMs/Class
A	13.30
B	0.53
C	0.18
D	2.40
E	0.49

A percentage of 82 from the total KMs in the study area receive class indices of A or B. for the low class indices of D and E; they cover only 17% of the study area streets.

Table 22 HCM BLOS Index Class' KMs covered per Street Name

Street Name	A	B	C	D	E	Grand Total(KMs)
26-JUL Street	0.54					0.54
Abd El Kalek Sarwat Street	0.96					0.96
Abd El Salam Aref Street	0.71					0.71
Adli Street			0.18	0.39		0.56
Ali Zo El Fakar Street				0.24		0.24
El Gomhouria Street	1.05					1.05
El Kasr El Ainy Street	0.46					0.46
El Raeeis Abd El Salam Aref Street	0.42					0.42
El Tahrir Street	0.86					0.86
Emad El Din Street	0.45					0.45
Kasr El Niel Street	1.17					1.17
Magles El Shaeb Street					0.49	0.49
Mahmoud Basyony Street	0.60					0.60
Meret Basha Street	0.53					0.53
Mohamed Farid Street	0.88					0.88
Mohamed Sabry Abo Alam Street	0.58					0.58
Nagib Elrihany Street				0.21		0.21
Nubar Street	0.68					0.68
Oraby Street	0.41					0.41
Ramsis Street				1.22		1.22
Roshdy Basha Street		0.53				0.53
Shambliuan Street	1.00					1.00
Sherif Basha Street	0.83					0.83
Solayman Elhalaby Street				0.34		0.34
Talaat Harb Street	1.17					1.17
Grand Total	13.30	0.53	0.18	2.40	0.49	16.90

Magles El Shaeb Street is the only street that gets E index while there are 3 complete streets receive D index in addition to a part of Adli Street, see Table 22.

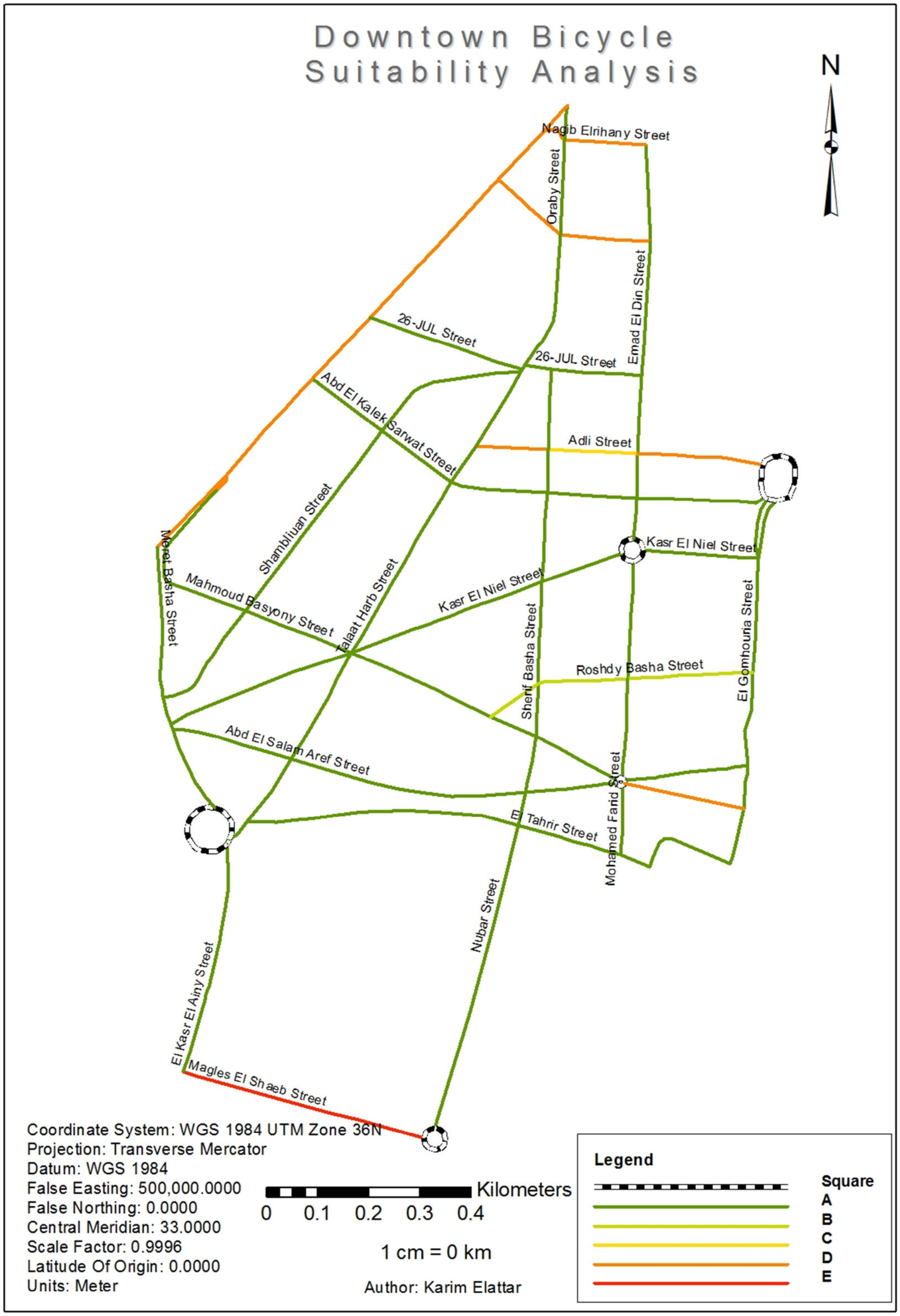


Figure 25 HCM BLOS Model applied on Downtown area

Figure 25 illustrates that the applicability of stablishing a bicycle route network in Downtown area is much relevant to bicycle level of service results that introduced by the high capacity manual.

6.5 Discussion

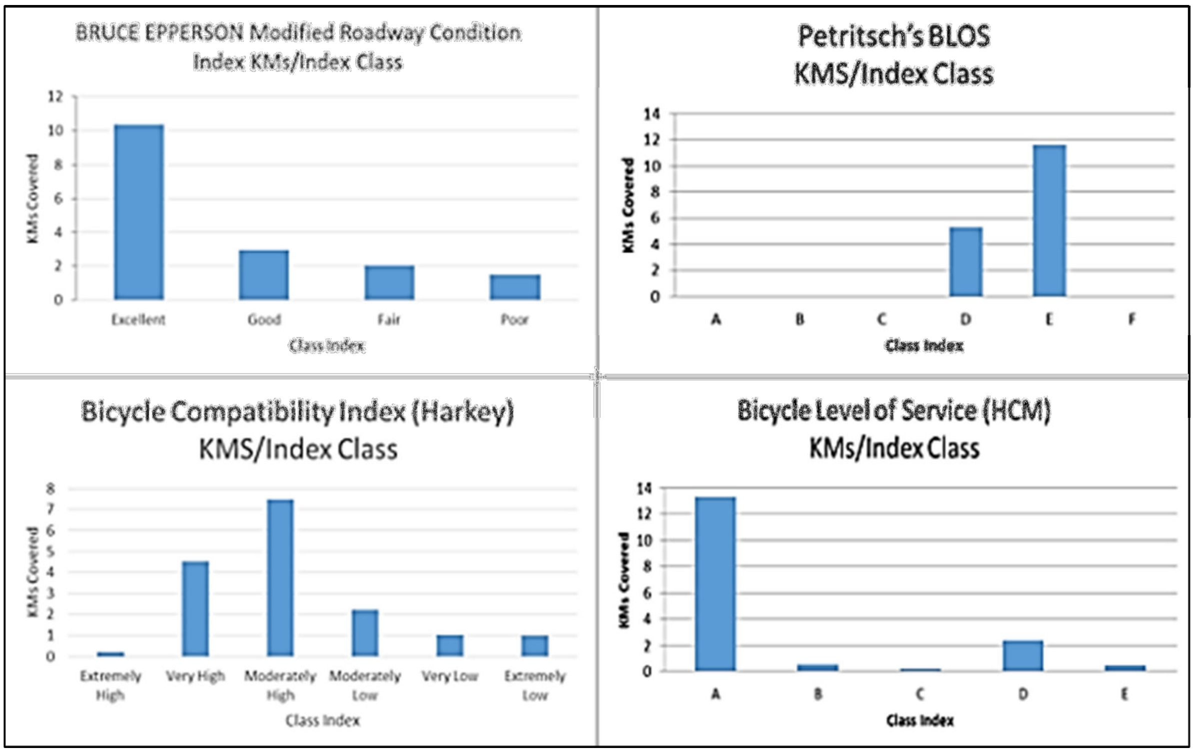


Figure 26 All Models Applied Results Comparison

The above group of charts explains the comparable results calculated by applying the four selected models on the study area streets using the GIS tool. The majority of the models show positive indicators for the applicability of designing bicycling routes in the study area. The most promising results are those calculated using the models of Bruce Epperson Modified Roadway Condition and the BLOS introduced by the highway capacity manual. More than 50% of the streets are suitable for bicycling with the highest class indices being under RCI, BLOS, and HCM. The results of applying the Bicycle Compatibility Index introduced by Harkey came in the second suitability rank; as more than 60% of the streets received the highest 3 class indices under this model, see Table 23.

Table 23 Average results per Street Name per Model and General suitablity score

Street Name	Modified RCI	Petritsch's BLOS	BCI	HCM	Generally
26-JULY Street	Excellent	D	Very High	A	Extremely Suitable
Abd El Kalek Sarwat Street	Fair	E	Moderately Low	A	Fairly Suitable
Abd El Salam Aref Street	Excellent	D	Very High	A	Extremely Suitable
Adli Street	Excellent	E	Very Low	D	Not Suitable
Ali Zo El Fakar Street	Excellent	D	Moderately High	D	Fairly Suitable
El Gomhouria Street	Excellent	D	Moderately High	A	Extremely Suitable
El Kasr El Ainy Street	Poor	E	Extremely Low	A	Not Suitable
El Raeeis Abd El Salam Aref Street	Excellent	D	Very High	A	Extremely Suitable
El Tahrir Street	Good	E	Moderately Low	A	Fairly Suitable
Emad El Din Street	Excellent	E	Moderately High	A	Extremely Suitable
Kasr El Niel Street	Fair	E	Moderately High	A	Fairly Suitable
Magles El Shaeb Street	Excellent	D	Very Low	E	Not Suitable
Mahmoud Basyony Street	Excellent	E	Very High	A	Extremely Suitable
Meret Basha Street	Poor	E	Extremely Low	A	Not Suitable
Mohamed Farid Street	Excellent	E	Moderately High	A	Extremely Suitable
Mohamed Sabry Abo Alam Street	Excellent	D	Moderately High	A	Extremely Suitable
Nagib Elrihany Street	Good	E	Moderately High	D	Fairly Suitable
Nubar Street	Excellent	E	Very High	A	Extremely Suitable
Oraby Street	Excellent	E	Moderately High	A	Extremely Suitable
Ramsis Street	Excellent	D	Moderately High	D	Fairly Suitable
Roshdy Basha Street	Excellent	D	Very High	B	Fairly Suitable
Shambliuan Street	Excellent	E	Very High	A	Extremely Suitable
Sherif Basha Street	Good	E	Moderately High	A	Fairly Suitable
Solayman Elhalaby Street	Excellent	E	Moderately High	D	Fairly Suitable
Talaat Harb Street	Fair	E	Moderately Low	A	Fairly Suitable

7 Conclusions

Egypt suffers from traffic jams, inadequate planning, and air and noise pollution especially in the capital, Cairo. One of the solutions that could contribute to limiting the respective problems is green transportation, which means using non-motorized transportation means to travel within a certain city or town such as the bicycle. On the other hand, Egypt needs a ready infrastructure to serve the bicycle users.

Riding a bicycle not only benefits the environment, the economy, the health and physical fitness of the country's citizens, but is also considered a green mean of transportation. Egypt does not have any designed bicycling route networks except some small trials in two or three areas far from Cairo, even though it is the main sufferer.

Bicycling in Egypt is becoming a trend among the new generation, as many parties and communities were created that nurtured and encouraged passion towards bicycling as a sport, or supported the idea of using non-motorized transportation means.

Many models have been created in the previous 30 years to measure the suitability of having bicycle riders on a certain street or road. Some of these models were created to serve a certain case in a specific city, and others were created based on cyclers' evaluation to the most related street attributes view.

GIS has the required functionalities to support re-planning the existing infrastructure to serve the bicycle users. A GIS tool has been especially created for research that includes all possible introduced models until now. The tool created is user-friendly, and could be used for other researches in different areas or countries to visualize the suitability analysis for every single street.

Four models were selected to be applied on the study area of Downtown Cairo, to provide the decision maker with a clear vision for the results produced by different methodologies. The results proved that around 90% of the streets in the study are suitable for bicycling.

In conclusion, the study area is suitable for bicycling on the majority of the streets, even the main ones with high densities of traffic showed acceptable results when tested with certain models. Generally, 35% of the total KMs of Downtown Cairo are Extremely Suitable for bicycling while 50% of the KMs are Fairly Suitable and only 15% are considered not suitable for bicycling.

7.1 Future Work

Every Few Years, a new model appears, and thus, there are many research points that may help for further work such as:

a- Applying all available models on different study areas in Egypt and comparing the results to find the most suitable one that could be generalized for all Egypt.

b- Creating a new model that suits the local specifications in Egypt.

c- Testing the bikeability and the bicycle friendliness of each area after establishing the physical cycling route network.

d- Include all other future models to the GIS tool introduced in this research.

e- Applying field survey to verify all results from all models applied.

7.2 Recommendations

The general recommendation is to use one of the commonly used models (e.g. BCI or HCM) and apply its results on the study area to generate the bicycling route network.

The researcher's recommendation is to generate a unified scale for the average score result for each road segment from the four models, and apply it on the study area to take/obtain the safest decision.

8 References

ABBAS, K., 2003. *User charging for roads in Egypt: a case study of Cairo-Alexandria toll road.* s.l., s.n.

Abd-El-Latif, H., Sabry, M., Yousef, S. & Badra, N., 2007. Determination of AADT from Short Period Traffic Volume Survey. *Journal of Applied Sciences Research,* 3(7), pp. 607-612.

Adams, C., 2007. *The Geography, Topography and Land Transport Networks of Egypt.* s.l.:Oxford University Press.

Ahram Online, 2011. *Egypt vehicles up 13.5 per cent in 2010, new figures show,* Cairo: Ahram.

Ali, S. & Tamura, A., 2002. Road traffic noise mitigation strategies in Greater Cairo, Egypt. *Applied Acoustics,* 63(11), p. 1257–1265.

Allen-Munley, C. & Daniel, J., 2006. Urban Bicycle Route Safety Rating Model Application in Jersey City, New Jersey. *Journal of Transportation Engineering,* 132(6), pp. 499-507.

Anderson, M., 1994. *Manual of transportation engineering studies.* s.l.:Englewood Cliffs: Prentice Hall.

Asadi-Shekari, Z., Moeinaddini, M. & Zaly Shah, M., 2015. A bicycle safety index for evaluating urban street facilities. *Traffic injury prevention,* 16(3), pp. 283-288.

Association For safe International Road Travel, 2009. *ROAD TRAVEL REPORT: ARAB REPUBLIC OF EGYPT ,* Egypt: Association For safe International Road Travel.

Awatta, H., 2015. *Whose Downtown is it Anyway? The Urban Transformation of Downtown Cairo between State and Non-State Stakeholders,* Cairo: The American University in Cairo.

Berthold Werner, 2010. Talaat Harb square. *Wikimedia Commons*, 5 November.

Callister, D. & Lowry, M., 2013. Tools and Strategies for Wide-Scale Bicycle Level-of-Service Analysis. *Journal of Urban Planning and Development,* 139(4), pp. 250-257.

Columbia Electronic Encyclopedia, 2015. *Egypt.* 6Th Edition ed. s.l.:Columbia University Press.

Deffner, J., Hefter, T., Rudolph, C. & Ziel, T. E., 2012. *Handbook on cycling inclusive planning and promotion.* Frankfurt/Hamburg: Capacity development material for the multiplier training within the mobile2020 project.

Ege, C. & Krag, T., 2010. Cycling will improve environment and health. *Hypertension,* 30(32), p. 30.

El Araby, M., 2002. Urban growth and environmental degradation. *Elsevier Ltd,* 19(6), p. 389–400.

Epperson, B., 1994. *Evaluating suitability of roadways for bicycle use: Toward a cycling level-of-service standard,* s.l.: Transportation Reserach Record.

Exelby, J., 2014. LINKING EGYPT'S URBAN CENTRES. *MEED: Middle East Economic Digest,* pp. 14-15.

Fitzpatrick, K., 2003. *Design speed, operating speed, and posted speed practices.* 504 ed. s.l.:Transportation Research Board.

Garber, N. & Hoel, L., 2014. *Traffic and highway engineering.* 4th ed. s.l.:Cengage Learning.

Godefrooij, T. & Schepel, S., 2010. *Co-benefits of cycling-inclusive : planning and promotion,* s.l.: World Bank.

Hadfield, W., 2009. Downtown Cairo to be pedestrianised. *MEED: Middle East Economic Digest,* 53(28), pp. 12-12.

Handoussa, H., 2008. *Egypt Human Development Report 2008 - Egypt's Social Contract: The Role of Civil Society,* Egypt: United Nations Development Program.

Handoussa, H., 2010. *Egypt Human Development Report 2010 - Youth in Egypt: Building our Future,* Egypt: United Nations Development Program.

Harkey, D. L. et al., 1998. *Development of the bicycle compatibility index: A level of service concept, final report,* s.l.: s.n.

Harkey, D. L., Reinfurt, D. W. & Sorton, A., 1998. *The Bicycle Compatibility Index: A level of service concept, implementation manual,* s.l.: s.n.

Hassan, A. M., Lee, H. & Yoo, U., 2014. Evaluation of the contemporary urban design through the classic urban theories: Cairo and Gwangju downtown as a case study. *HBRC Journal,* 10(3), pp. 327-338.

Huang, Y. & Ye, G., 1995. Selecting bicycle commuting routes using GIS. *Berkeley Planning Journal,* 10(1).

Hunter, W. W., Pein, W. E. & Stutts, J. C., 1996. *Bicycle-motor vehicle crash types of the early 1990s,* s.l.: Transportation Research Record.

Huzayyin, A. S. & Salem, H., 2013. Research in Transportation Economics. *Elsevier Science,* 40(1), pp. 104-115.

Jensen, S., 2007. Pedestrian and bicyclist level of service on roadway segments. *Transportation Research Record: Journal of the Transportation Research Board,* Issue 2031, pp. 43-51.

Johnson, B., 2012. *Professional visual studio 2012.* s.l.:John Wiley & Sons.

Karim, D. M., 2015. *Narrower Lanes, Safer Streets,* City of Toronto: academia.edu.

Kingsley, P., 2014. Sisi gets on his bike to tackle Egypt's bulging fuel subsidies – and waistlines. *The Guardian*, 13 June.

Landis, B. W., 1994. *Bicycle interaction hazard score: a theoretical model,* s.l.: s.n.

Larsen, J., Patterson, Z. & El-Geneidy, A., 2013. Build it. But where? The use of geographic information systems in identifying locations for new cycling infrastructure. *International Journal of Sustainable Transportation,* 7(4), pp. 299-317.

Laura, B., 2011. *Tahrir Square's tourism counterrevolution,* s.l.: USA Today.

Lawson, A. R., Pakrashi, V., Ghosh, B. & Szeto, W., 2013. Perception of safety of cyclists in Dublin City. *Accident Analysis & Prevention,* Volume 50, pp. 499-511.

Lowry, M., Callister, D., Gresham, M. & Moore, B., 2012. *Using bicycle level of service to assess community-wide bikeability.* Washington, DC, Transportation Research Board.

Maguire, D. J., 1991. An overview and definition of GIS. *Geographical information systems: Principles and applications,* Volume 1, pp. 9-20.

Maps of World, 2015. *Egypt Latitude and Longitude Map.* [Online]
Available at: http://www.mapsofworld.com/lat_long/egypt-lat-long.html
[Accessed 21 September 2015].

Mekuria, M. C., Furth, P. G. & Nixon, H., 2012. Low-stress bicycling and network connectivity. *Mineta Transportation Institute Publications.*

Munro, C., 2013. Level of service model for bicycle riders.

Note, G., n.d. Submitted to: Nebraska Department of Roads. *Lincoln, NE.*

Petritsch, T. et al., 2007. Bicycle level of service for arterials. *Transportation Research Record: Journal of the Transportation Research Board,* Issue 2031, pp. 34-42.

Pline, J. L., 1992. *Traffic engineering handbook.* s.l., Prentice Hall.

Rybarczyk, G. & Wu, C., 2010. Bicycle facility planning using GIS and multi-criteria decision analysis. *Applied Geography,* 30(2), pp. 282-293.

Samari, G. & Pebley, A. R., 2015. Individual and Household Determinants of Women's Autonomy: Recent Evidence from Egypt. *California Center for Population Research,* pp. 9-13.

Samih, M., 2015. Downtown traffic improves. *Al Ahram Weekly*, 4 March.

Schuurman, N., 2004. *GIS : a short introduction.* s.l.:Oxford : Blackwell, 2004.

Segadilha, A. B. P. & da Penha Sanches, S., 2014. Identification of Factors that Influence Cyclistś Route Choice. *Procedia-Social and Behavioral Sciences,* Volume 160, pp. 372-380.

Semeida, A. M., 2013. New models to evaluate the level of service and capacity for rural multi-lane highways in Egypt. *Alexandria Engineering Journal,* 52(3), p. 455–466.

Shankwiler, K. D., 2006. Developing a Framework for Behavior Assessment of Bicycle Commuters: A Cyclist-Centric Appriach. p. 87.

Snizek, B., Nielsen, T. A. S. & Skov-Petersen, H., 2013. Mapping bicyclists' experiences in Copenhagen. *Journal of Transport Geography,* Volume 30, pp. 227-233.

Soliman, M., 2011. Artistic interpretations of Downtown Cairo. *Journal of Postcolonial Writing,* 47(4), pp. 391-403.

Staff Writer, 2014. Egypt's Sisi goes cycling for fuel economy. *Al Arabiya News*, 13 June.

State of Florida Department of Transportation, 2012. *Project Traffic Forecasting Hand Book,* Florida: s.n.

Stinson, M. & Bhat, C., 2004. Frequency of bicycle commuting: internet-based survey analysis. *Transportation Research Record: Journal of the Transportation Research Board,* Issue 1878, pp. 122-130.

Suez Canal Authority, 2008. *About Suez Canal.* [Online]
Available at: http://www.suezcanal.gov.eg/sc.aspx?show=17
[Accessed 21 September 2015].

Trading Economics, 2015. *Egypt GDP.* [Online]
Available at: http://www.tradingeconomics.com/egypt/gdp
[Accessed 24 September 2015].

Turner, S., Shafer, C. S. & Stewart, W. P., 1997. *Bicycle suitability criteria for state roadways in Texas,* Texas: Texas Transportation Institute, Texas A & M University System.

World Bank, 2008. *Launch of the World Bank Group's Transport Business Strategy for 2008-2012.* Washington, World Bank.

World Bank, 2010. *Cairo Traffic Congestion Study Phase 1,* s.l.: World Bank.

World Bank, 2013. *Cairo Traffic Congestion Study,* s.l.: World Bank.

World Bank, 2013. *The Arab Republic of Egypt : For Better or For Worse, Air Pollution in Greater Cairo,* Washington, DC: World Bank.

9 Appendices

9.1 Appendix A

Data Sourced (Number of Vehicales passed on a certin day (28th Dec.16, 5th and 8th of Jan.16)for each road segment).

26 July with Ramses	ADT
Ramses (from Maspero)	1082
26 July	233
Ramses(to Maspero)	468

Abd El Khalik Tharwat with Gomhuria	ADT
Gomhuria	510
Abd El Khalik Tharwat	2087

Abd El Khalik Tharwat with Champilion	ADT
Champilion	439
Abd El Khalik Tharwat	1693

Tahrir with Nubar	ADT
Nubar	793
Tahrir	1635

Adly with Sherif	ADT
Adly	780
Sherif	881

Roshdy with Farid	ADT
Roshdy	186
Farid	158

Ali zo El Fakar with Gomhuria	ADT
Gomhuria	851
Zo El Fakar	466

Talsst Hareb with Adly	ADT
Adly	1398
Talaat	1360

Emad El Din with 26 July	ADT
Emad	887
26 July	991

Talaat hareb with Abd el Khalik Tharwat	ADT
Abd	1238
Talaat	2048

Emad EL Din with Soliman EL Halabe	ADT
soliman	738
Emad	955

Mohamed Farid Square	ADT
Mohamed Sabry Abu Alam	877
Abd El salam Aref	765
Farid	702

Emad El Din with Naguib El Rehany	ADT
Naguib	941
Emad	1283

Ramses with Orabi	ADT
Orabi	819
Ramses (from Maspero)	1059

Qasr El Nile with Gomhuria	ADT
Gomhuria	851
Qasr	1536

Mostafa Kamel square	ADT
Farid	982
Qasr	1177

Ramses(to Maspero)	489

Adly with Mohamed Farid	ADT
Farid	1141
Adly	1224

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