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Study of applying the congestion pricing system in central Cairo

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Abstract

In order for the Egyptian ministry of traffic to reduce traffic congestion, it has to apply the congestion pricing system. In difference from other areas around the world, the capital of Egypt stands out with sparse roads infrastructure, more than one business district area and long distances for traveller’s pairs of origins and destinations. The economic costs of Cairo’s congestion amounts to around 4% of the annual GDP, when the travellers start their trips from the origins to the destinations. This study presents an application of the congestion pricing system on of Al Qasr Al Ayni Street, which is one of Cairo’s city centre streets.

This thesis presents a mathematical model that is developed in order to reduce traffic congestion of traveller’s trips from the beginning of Al Qasr Al Ayni Street to the end of Al Qasr Al Ayni Street. The model seeks to find the optimal route for the travellers in order to reduce congestion on of Al Qasr Al Ayni Street. The model used to minimize the total monetary costs of fuel and tolls. An essential part of this research has been to establish different types of performance measurements such as Travel Time, Travel Distance, Travel Speed, Travel Demand, Roads Maximum Capacity and Roads Minimum Capacity that are reflected trough the mathematical model. The research shows that only focusing on monetary costs such as the consumed fuel and the congestion tolls, it also has an effect on the value of travel time saving (VTTS). In order to obtain a solution to the problem in some instances where the immediate solutions do not help, the congestion pricing system is proposed.

The cost-benefit analysis theory has been used to compare the social surplus between the traffic condition on Al Qasr Al Ayni Street before and after the congestion pricing system. Where the social surplus consists of consumer surplus, externalities, government costs and revenues, and tax effects.

The social surplus in this study is more than 33860 EGP per day as the author considered the shorter travel time and the cost of fuel. The social surplus has been calculated for the flow per hour, for daily working hours from 7 am to 8 pm. The social surplus in this study is not yet complete as some costs are missed, such as emissions and taxes. Al Qasr Al Ayni congestion percent has been decreased from 27% to around 2%.

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1.0 Chapter One

Introduction, Research questions and Literature review

1.1 Introduction

Areas like Cairo should be highly developed in terms of transportation facility and traffic flow. Since many citizens suffering in Cairo from the traffic congestion, this study is working to improve the traffic system in Cairo. The study of the congestion pricing system introduced in one of Cairo city centre streets (Al Qasr Al Ayni Street), to show how the congestion pricing system working effectively in Al Qasr Al Ayni Street.

The methodology of applying the congestion pricing system on Al Qasr Al Ayni Street is a combination of the collected data, the cost-benefit analysis theory, and Al Qasr Al Ayni mathematical model. The first part of the methodology is practical part, the data of that research collected from google traffic. The second part is the theoretical part, which is cost benefit analysis theory (chapter four). In that part, cost-benefit analysis theory determines if the congestion pricing system should be considered in the urban transportation improvements or not. The third part is Al Qasr Al Ayni mathematical model, which created by the author as a development of the network transhipment models. The methodology of applying the congestion pricing system on Al Qasr Al Ayni Street is applying the collected data to the Al Qasr Al Ayni mathematical model by using AMPL, and then analyses the computational answers by the cost benefit analysis theory.

This paper is structured in the following way: Chapter One illustrate introduction, in addition to describing the introduction, the research questions and the literature reviews are also presented. Chapter Two gives a description of the problem. It presents the city logistics definition, how the urban transport management deals with congestion, and the congestion reasons and solutions. Chapter Three presents the methodology and the build-up of parameters such as Street capacity and travel time, which are important for the understanding of the problem. Chapter Four presents relevant theory for the research. It presents brief description of the cost benefit analysis in general followed by description of the cost benefit analysis from the transport economics point of view. Chapter Five describes the Urban Transportations Network Design Problems and The Network linear programs. In addition to the Al Qasr Al Ayni mathematical model, which is used to find out the computational answers. Chapter Six is the computational results and analysis. It presents the founded computational results by Al Qasr Al Ayni mathematical model and the analysis of those results by the cost benefit analysis from the transport economics point of view. Followed by the conclusion, which involve answers of the research questions, in addition to conclusion, some recommendations for future research are presented in Chapter Seven.

1.2 Research questions

What is congestion?

- What are the reasons for congestion?
- What is the solution to congestion?

How the congestion pricing system will affect Al Qasr Al Ayni Street?

- Which are the areas affected by the congestion pricing system?
- What is the effect of the congestion pricing system on travel time?
- What is the effect of the congestion pricing system on Cairo's environment?
- Does the congestion pricing system affect the GDP?
- Does the congestion pricing system eliminate congestion?
- What are the disadvantages of the congestion pricing system?

Which transport model will fit Al Qasr Al Ayni Street?

Should the congestion pricing system be applied in Cairo or not?

1.3 Literature review

There are many researchers who have discussed congestion charges. Durantuan and Turner (2009) discussed the relationship between the vehicles kilometre travelled (VKT) and the highways inside the state, and found increasing demand for such highways. They noticed three roots of this extra VKT, which were the effect of public transportation not working with VKT, the increase of drivers in cities, and the arrival of new citizens. They worked with the data of US cities, and proved that the extension of roads faced increasing VKT and that applying the congestion charges policy was the best solution to reduce traffic.

Eliasson (2008) discussed that the Stockholm trial had two parts—the first was the improvement of the public transportation system and the second was the introduction of the congestion charge system. He studied the start-up cost, the operation cost, and the benefits of the investment, and found that the cost of the investment would be covered in 3.3 years. He also showed the improvement of the short-term effect, and built the long-term effect on assumption. He concluded that the perfect charging system produced a social surplus.

In his study on Oslo, Hårsman (2001) found that 50,000 cars had disappeared from the city after the application of the toll system, and the accident percentage had decreased by 20%. He based his discussion on some economic theories such as the Kaldor-Hicks criteria, and showed that the survey had used some methods such as PRIMA (2000). He developed nine keys for public acceptance, and concluded that the laws of road pricing system will take a part when the time period for the cordon financing toll expires in 2007.

Eliasson (2014) conducted a comparative research between the traffic before and after the application of congestion charges. He discussed the charging system and its effects, which were namely traffic effects, travel time, environmental effects, retail, and public transportation. He also showed that acceptability changed as the public attitude was against the idea at the beginning, but the public attitude later supported it. He based his conclusion on the cost benefit analysis, and showed that the social surplus would be more than the cost and operation.

2.0 Chapter Two

Problem description

2.1 Problem definition

2.1.1 City logistics definition

Congestion is one of the problems of city logistics, which is defined as ‘the process for totally optimizing the logistics and transport activities by private companies with the support of advanced information systems in urban areas considering the traffic environment, its congestion, safety and energy savings within the frame work of a market economy.’ (Taniguchi and Thompson, 2002). The objectives of city logistics are to reduce traffic congestion and pollution, and to increase the safety and security of urban transport. City logistics care about the economic aspect, which makes city logistics take a part in balancing between the economic and the social environmental issues responsibly. (Taniguchi and Thompson, 2002)

2.1.2 Congestion definition and solution

Road congestion is one of the most common problems around the world that occurs when the numbers of vehicles on the road exceed the road capacity. Researchers have tried to find solutions for road congestion, and they noticed that road expansion was a temporary solution, and more roads meant more drivers. According to economist Turner (2009), ‘in particular, if you had 1 per cent more roads, you had 1 per cent more driving in those cities.’ Finally, they found that the road pricing system was a suitable solution, and applied it in different ways.

2.1.3 Urban fright transport management

The aim of city logistics to reduce congestion is an urban fright transport management responsibility, and any system that is applied to reduce congestion should follow the urban fright transport management procedures. The procedures of urban fright transport management involve four important stages to reduce congestion. Stage one is the design stage, which includes public involvement, problem identification, the reasons for the problems, the goal framework, the vehicles movement demand, and a combination of measures and approaches. The second stage is the assessment stage or the planning stage, which includes the program experiment, and characterizes the side impacts (economic transfer). Stage three is the implementation stage, which is to proceed with the plan and the design to make it a reality. Stage four is evaluation, for instance of the social surplus. (Taniguchi and Eiichi, 2014)

2.2 Problem background

2.2.1 Cairo background

Egypt is one of the countries suffering from congestion. In this thesis, the author introduces a study to apply the congestion pricing system on Al Qasr Al Ayni Street, which is one of the streets in Cairo's city centre. The study of Al Qasr Al Ayni Street will be a good indicator for the application of the congestion pricing system in Cairo. It is kind a challenge to apply the congestion pricing system in Cairo as the city has the highest population in Egypt numbering around 9.5 million residents. But while the researcher will apply the congestion pricing system in Cairo, it should be applied to the Great Cairo (GC) area, which includes Cairo, Giza, and Qaliubiya. GC has a population of 22.5 million citizens with a huge number of vehicles that is estimated to be more than 3.3 million.[1]

2.2.2 Congestion reasons

Before introducing the congestion pricing system, the reasons for road congestion should be introduced, as it is one of the procedures of the first stage of urban fright transport management. There are six main reasons for Cairo's congestion, which are governmental fuel subsidies, few parking facilities, public transportation, bad planning, social behaviour, and large investment in highways. Governmental fuel subsidies reduce the price of gasoline and diesel, encouraging more private cars onto the roads. There are fewer parking facilities as against the number of vehicles in Cairo, which leads to most of the vehicles being parked on the sides of the roads, and thereby reduce road capacity. Although there are around five million people who use public transportation on a daily basis in Cairo, the low capacity, quality and limited coverage of the public transportation drives the citizens to use other means of transportations (e.g. private cars, taxis). The bad planning of road intersections, road crossings, U-turns and traffic lights also contribute to the congestion. In addition to the social behaviour of pedestrians crossing the streets, roadside hawkers contribute to the congestion. The huge investments in highways will not improve the speed of vehicles as the traffic congestion keeps on increasing. [2]

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[1] http://www.capmas.gov.eg/

[2] http://www.worldbank.org/content/dam/Worldbank/document/Cairo-Traffic-Congestion-Study-Overview-Final.pdf

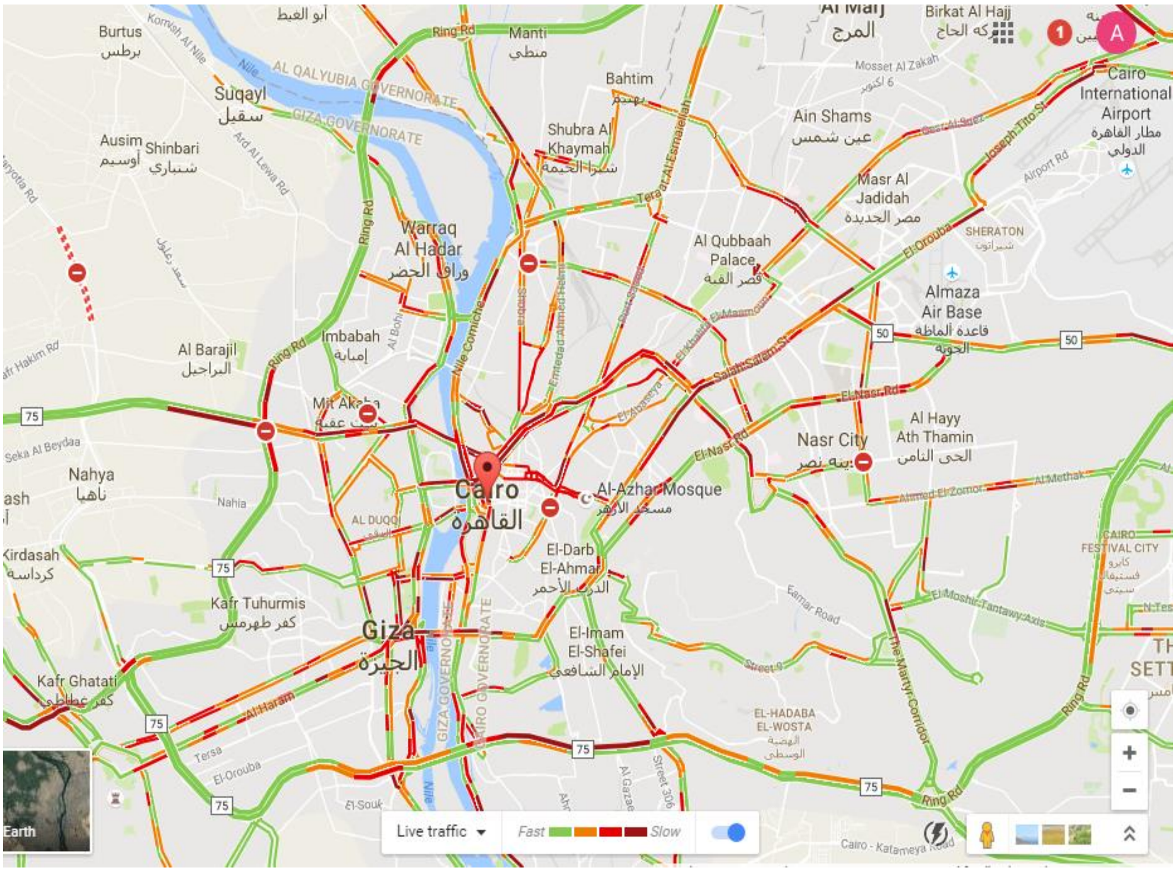

Figure 1: The traffic in Cairo city centre at 4 PM on Wednesday, 23 November 2016

2.2.3 Congestion solutions

The congestion solutions come as proposals in the planning stage, which is the second stage of urban fright transport management. The congestion solutions are classified into two categories, the immediate solutions and complex solutions. The immediate solutions are easy to implement and have immediate impacts. The complex solutions are not so easy to implement, and it is very hard to predict their impacts.

2.2.3.1 Immediate solutions to congestion

There are many solutions that might help to reduce the congestion immediately as well as easy to implement in Cairo. These include improving the traffic design, starting to use many digital traffic lights, and improving the intersections. Also, introducing parking areas for each business district and making it imperative for each building to build parking spaces in accordance with the building's needs. Making the crossing of roads easier for pedestrians by building bridges and tunnels or earmarking the normal crossing areas, and improving the capacity of sidewalks by removing hawkers to reduce the traffic disturbance. Improving the drivers' behaviours by improving the legal provisions against errant drivers and creating some tough parking rules. Organizing the routes and the transit stations for taxis and microbuses is another solution. [3]

2.2.3.2 Complex solutions to congestion

The global tendency to solve complex congestion problems in cities is by focusing on two basic solutions: improving public transportation and making the use of private vehicles expensive by applying the congestion pricing system. Public transportation should be well designed regarding coverage, capacity, and quality. All modes of transports should be well integrated, in addition to being clean, safe, and appropriately priced. The main goal of public transportation is to maximize the coverage area to travel almost anywhere in a city. When public transportation is good, the use of private vehicles during peak hours becomes more expensive by virtue of the road congestion pricing system. The congestion pricing system is aimed towards drivers who choose to use their private vehicles during peak hours by making them pay a large price through parking charges and congestion pricing system. (Richardson et al., 2008)

2.2.3.2.1 Congestion pricing systems

Some countries apply the road pricing system to reduce road congestion. Singapore introduced the so called Area Licensing Scheme (ALS) in 1975. As per the ALS, cars with one or two occupants should pay fees when entering Singapore’s central business district, while handcars with three or more occupants and trucks are exempt from the fees. London introduced a pricing system that is fully electronic and more complex than the Singaporean system for the central business district; cameras catch traffic scofflaws and criminals. All the countries that apply the road pricing system follow the London pricing system.[4]

2.2.4 Ability of the congestion pricing system

The congestion pricing system will not eliminate congestion altogether, but it will certainly reduce congestion. The congestion pricing system in Stockholm has been successful since its inception, and has attracted huge attention worldwide. There are several reasons that prove the investments in the congestion pricing system are not enough to eliminate

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[3] http://www.worldbank.org/content/dam/Worldbank/document/Cairo-Traffic-Congestion-Study-Overview-Final.pdf

[4] http://thisbigcity.net/five-cities-with-congestion-pricing/

congestion on roads. There are two main reasons that are determined as leading to congestion, with the first being shortage of urban land and the second is limited public resources. The urban transport system must integrate four strategies: attractive public transportation, walkability, compact spatial planning, and restraints on car traffic. (Eliasson, 2014)

2.2.5 The acceptance of the congestion pricing system

The public attitude towards the congestion pricing system will pass through six stages. The first stage will be very low support for the new idea. At the second stage, the people will start supporting the idea. The support at the third stage will be sufficient to continue with the idea. When it comes to emerging details, the support will fall off at the fourth stage. At the fifth stage, the support will be very low just before implementation due to panic. At the final stage, the support will increase again due to the benefits gained by the people. (Goodwin, 2006)

2.3 Problem objectives

2.3.1 The congestion pricing system on Al Qasr Al Ayni Street

The congestion pricing system has an impact on increasing the demand for public transportation, and this consequently requires the expansion of the modes of public transportation that pass through Al Qasr Al Ayni Street. Some drivers will switch from using their own vehicles to use the public transportation, and that will not only require increasing the number of public transport vehicles, but also require increasing the transit stations of public transportation. The ministry of transport can easily measure the crowding in public transports by the number of standing passengers. The speed of public transportation will increase due to the reduction of congestion due to the road congestion pricing system. (Eliasson, 2009)

The author settled for discussing the demand for public transportation in the previous paragraph to highlight the impact of congestion pricing system on private vehicles. The congestion pricing system on Al Qasr Al Ayni Street consists of two charging points, with one at the entrance of the street and the other at the exit. The objective of the charging points is to collect tolls from each vehicle each time. The entrance charging point registers a vehicle’s number plate and the exit charging point checks that the number plate has been already registered. Each charging point counts the number of vehicles each time, and calculates the travel time for each trip. The toll values imposed by the congestion pricing system vary from time to time depending on the congestion level. For example, the toll is cheaper in the early morning from 6 am to 7 am than that from 10 am to 11 am. A driver pays the maximum amount only during peak hours in weekdays, and he does not need to pay during the night and weekends. There are exceptions that exempt some vehicles from paying tolls, for example in Stockholm, the exceptions are given to 15% of buses, foreign cars and many other vehicles (Eliasson and Mattsson, 2006). The author has proved in this study that the congestion pricing system makes drivers to choose another route as long as they do not create congestion on the other route, which means that they will choose the routes that have a free capacity for them without creating congestion. The results are presented in Chapter Six.

2.3.1.1 The benefits of congestion pricing

Traffic in urban areas can increase due to external factors such as inflation, but the congestion pricing system can control the traffic. In case the congestion pricing system succeeds, the impact on the traffic will be effective from day one. For example, the traffic in Stockholm’s central business district had decreased by 22% after the application of the congestion pricing system during the peak period. The congestion pricing system affects the traffic flow inside the charging area as well as outside the charging area because some of the drivers travelling from outside to somewhere inside the charging area will stop driving, and some of the drivers travelling through the charging area will find alternative roads. (Eliasson, 2014)

The road pricing system improves travel time by way of some drivers switching to other routes as well as some drivers preferring to use the public transport instead of their private vehicles. The road pricing system not only improves the travel time inside the charging area but also affects the travel time outside the charging area, because of the drivers, who travel through the inner city, find alternative routes or modes of transport. The reduction of travel time comes from the drivers who start to change routes, the drivers who start to share vehicles, and the drivers who go on to use the public transport. (Eliasson et al., 2006)

The congestion pricing system plays an important role in reducing vehicular emissions by reducing congestion, as vehicles produce more emissions during congestion. Cairo is one of the top 10 cities in environmental pollution, and the Al Qasr Al Ayni congestion-pricing system will be an indicator to the application of the congestion pricing system in Cairo, which will help a lot in reducing vehicular emissions in the city. Congestion reduction tackles vehicular emissions effectively by virtue of the vehicles that go off the roads. The road pricing system improves the air quality inside the charging area. From the point of view of health, the reduction in traffic and the consequent reduction in vehicular emissions will help to reduce ailments such as cardiovascular diseases and lung cancer as well as help ambulances to travel faster. (Sean, and Carslaw, 2005)

The congestion pricing system enables the government to earn revenues through toll collection, and it can assign these revenues to improve roads and the public transportation. In Chapter Six, the computational answers of Al Qasr Al Ayni congestion pricing system estimate the daily revenues. The tolls in Cairo should have a positive relationship with the income. The toll values have a direct relationship with the travel speed; for example, when the toll value is four EGP, it will make travel speed 30 km/h, and when the toll value is two EGP, it will make travel speed 21 km/h. (Eliasson, 2014)

Reducing congestion by the successful implementation of a congestion pricing system will have a good impact on the GDP because the economic costs of Cairo's congestion amounts to around 4% of the annual GDP, which makes for a very high percentage. The economic costs of congestion arise due to travel delays, wasted fuel, health impacts due to poor air quality and accidents, and impacts on economic productivity. The yearly economic cost of traffic congestion could reach up to 4% of Egypt's GDP, when all congestion impacts are combined. This comes to an annual economic cost of up to 50 billion EGP to Egypt.[5]

2.3.1.2 Shortcomings of congestion pricing system

Applying the congestion pricing system require avoiding the shortcoming. The shortcomings in the congestion pricing system are not that clear, such as the political restriction. To avoid the shortcomings of the congestion pricing system, the net social surplus should be positive. The social surplus should involve the political, technical, and physical restrictions for designing the charging system so as to introduce the optimal charge. The transport economics should care about the labour market and the effect of the crowded transit stations. (Eliasson, 2009)

2.3.2 Al Qasr Al Ayni Street

Due to the limitations of time and data, the author introduced the study of congestion pricing system for one of the most congested streets in the city centre of Great Cairo (Figure 2). The

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[5] http://www.worldbank.org/content/dam/Worldbank/document/Cairo-Traffic-Congestion-Study-Overview-Final.pdf

study of the application of the congestion pricing system on Al Qasr Al Ayni Street focuses on the impacts on the two aspects of travel time and wasted fuel; the study will show the amount of wasted fuel and travel time both before and after applying the congestion pricing system.

The study of the application of the congestion pricing system on Al Qasr Al Ayni Street will initiate the system's application on all the streets of Great Cairo's city centre. The success of the trial of Al Qasr Al Ayni Street, however, does not mean that it will succeed on all the streets of Great Cairo's city centre, because the trial has external impacts as well. For example, in this thesis, the congestion on Al Qasr Al Ayni Street will decrease, but it may increase on other streets if the toll values are high. On the other hand, the success of the trial of Al Qasr Al Ayni congestion pricing system may lead to its application on some other streets in the city centre.

Figure 2: Traffic on Al Qasr Al Ayni Street on Wednesday, 27 April 2016

3.0 Chapter Three

Methodology and data collection

3.1 Methodology

The methodology of applying the congestion pricing system on Al Qasr Al Ayni Street mainly contain the collected data, Al Qasr Al Ayni mathematical model, and cost benefit analysis. The collected data classified into secondary and primary data. The secondary data is the data found on Google, the primary data is the data the calculated by the author. Al Qasr Al Ayni mathematical model is an improvement of the transhipment model in order to fit the study. The cost benefit analysis is the theory that analyse the results. The methodology of applying the congestion pricing system on Al Qasr Al Ayni Street is applying the collected data to the Al Qasr Al Ayni mathematical model by using AMPL, and then analyses the computational answers by the cost-benefit analysis theory.

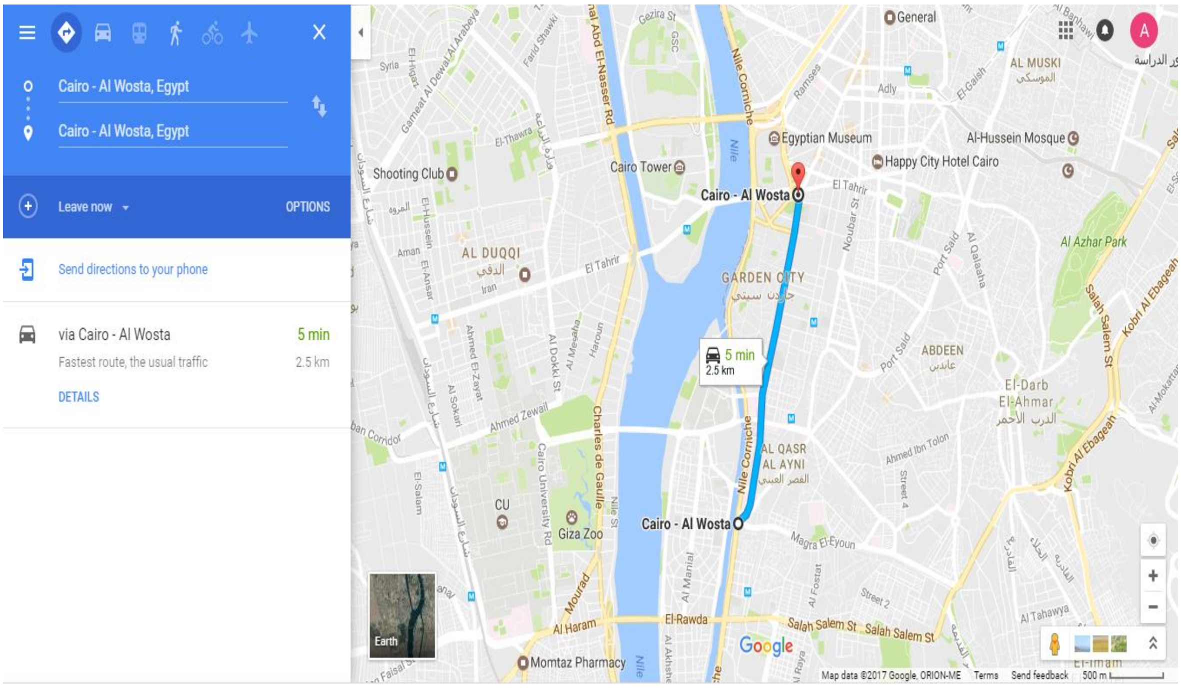
3.2 The data collection

In this chapter, the author will introduce the reader as to how he built the data used in his model. The author classified the data into two types—the secondary data and the primary data. The secondary data comprise the data found on Google, and they are provided in this chapter's first and second sections, which are the travel time and the travel distance. The primary data include the data that are based on equations and assumptions. The calculated data comprise traffic speed, road capacity, demand, congestion level, travel time congestion factor, and the congestion toll values of Al Qasr Al Ayni Street, followed by the value of travel time saving and the rate of fuel consumptions, and finally the demand of Nile Street.

3.2.1 The secondary data

3.2.1.1 The travel time

The author used Google traffic to find out the travel time on Al Qasr Al Ayni Street at different times during working hours on weekdays. The travel time on Al Qasr Al Ayni Street was calculated during a period starting at 7 am on Thursday, 9 February 2017 and ending at 7 pm on Wednesday, 15 February 2017. The author checked the travel time on Al Qasr Al Ayni Street in 25 different times for each day by Google traffic. The travel time on Al Qasr Al Ayni Street was checked every half hour each day from 7 am to 7 pm as shown in Table 1. Figures 3 and 4 show the traffic conditions—indicated by four colours ranged from fastest to slowest—on Al Qasr Al Ayni Street at different times, with blue representing the fastest traffic followed by orange, red, and finally dark red indicating the slowest traffic.



Cairo - Al Wosta, Egypt

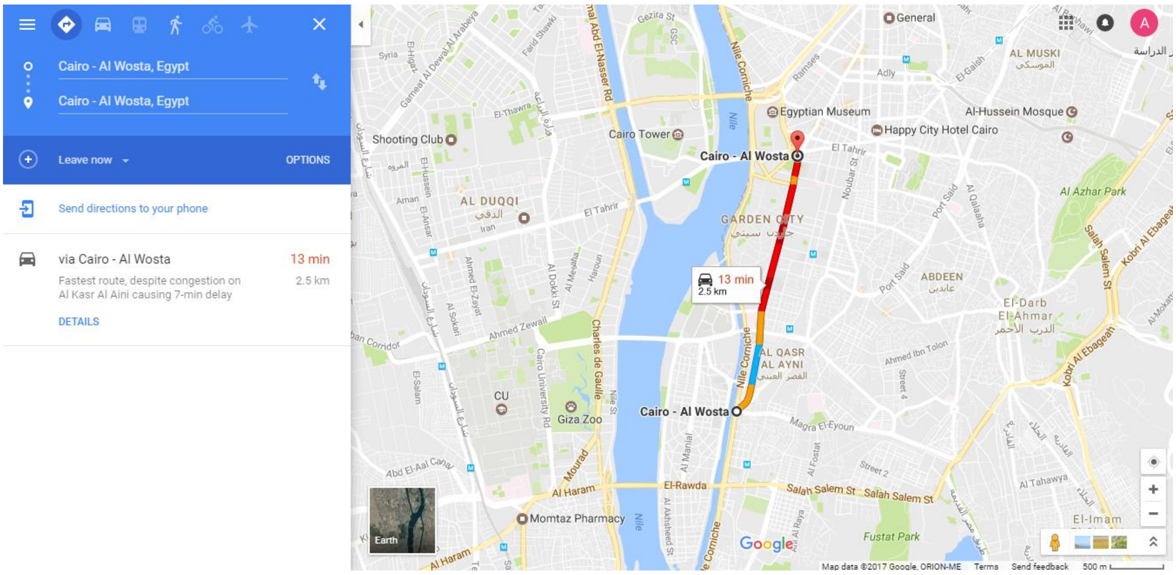
Cairo - Al Wosta, Egypt

Leave now

via Cairo - Al Wosta 5 min

Fastest route, the usual traffic 2.5 km

Figure 3: Al Qasr Al Ayni Street traffic condition at 7 am on Thursday, 9-February 2017



Cairo - Al Wosta, Egypt

Cairo - Al Wosta, Egypt

Leave now

via Cairo - Al Wosta 13 min

Fastest route, despite congestion on Al Kasr Al Aini causing 7-min delay 2.5 km

Figure 4: Al Qasr Al Ayni Street traffic condition at 3 pm on Thursday, 9-February 2017

	Thursday 09/02/2017	Sunday 12/02/2017	Monday 13/02/2017	Tuesday 14/02/2017	Wednesday 15/02/2017
7:00	5	6	6	5	6
7:30	6	6	7	7	7
8:00	8	10	9	7	9
8:30	8	10	12	13	11
9:00	8	11	12	11	10
9:30	10	11	12	11	13

10:00	9	11	12	12	13
10:30	10	13	16	13	14
11:00	10	13	15	14	14
11:30	12	13	14	14	15
12:00	11	13	16	15	15
12:30	11	13	16	17	13
13:00	11	11	15	19	12
13:30	9	12	16	15	12
14:00	9	13	16	13	15
14:30	9	12	23	11	17
15:00	13	10	29	14	18
15:30	10	19	26	12	17
16:00	8	19	23	9	16
16:30	8	10	22	9	9
17:00	7	12	17	10	8
17:30	7	9	13	10	9
18:00	7	8	9	11	10
18:30	7	8	8	10	9
19:00	7	8	7	9	8

Table 1: The travel time on Al Qasr Al Ayni Street at different times

3.2.1.2 The travel distance

The travel distance of each street was found by Google maps. The author created nodes for many intersections in GC, and then used Google maps to find out the travel distance of the links between those nodes. Every node has less than four links with the other nodes, for example, node 3 has three different links with nodes 4, 2 and 5. Figure 5 illustrates the nodes of these intersections, and Table 2 presents the travel distances for each link for the nine nodes used in Al Qasr Al Ayni mathematical model. Al Qasr Al Ayni Street is shown as the link between nodes 3 and 4, which is evident in Figure 6. As per Table 2, the distances of some links were considered as 1000 km, and these link distances could be explained by the fact that there was no link between two nodes. The reader may get confused by seeing the distance between nodes 3 and 5 as 1000 km, but only 2.5 km between nodes 5 and 3 on the same street; this means that the street is one way from node 5 to node 3, and Al Qasr Al Ayni Street is also in one direction.

Nodes	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1	.	0.4	1000	1000	1000	0.7	1000	1000	1000
2	0.4	.	0.8	1000	1000	1000	1000	1000	1000
3	1000	0.8	.	2.5	1000	1000	1000	1000	1000
4	1000	1000	1000	.	0.4	1000	1000	1000	1000
5	1000	1000	2.5	0.4	.	1000	1000	1000	0.6
6	0.7	1000	1000	1000	1000	.	3	1000	1000
7	1000	1000	1000	1000	1000	3	.	1	1000
8	1000	1000	1000	1000	1000	1000	1	.	1.3
9	1000	1000	1000	1000	0.6	1000	1000	1.3	.

Table 2: The distances between nodes

3.2.2 The primary data

According to the data found from Google traffic, the author could easily find out the average travel time and the speed for each vehicle for each time horizon. On the other hand, it was quite a challenge to find out the average number of vehicles on the road (road demand) and the capacity of the road for each time horizon. The author put in some assumptions to find out the capacity of the road, with the assumptions being that the maximum capacity was the result of the road level of service F and the normal capacity was the result of the road level of service C.

3.2.2.1 The speed on Al Qasr Al Ayni Street

Speed equals to distance over time$\left(speed = \frac{distance}{travel\ time}\right)$. The author could easily calculate the average speed of the vehicles on Al Qasr Al Ayni Street for each hour in the time horizon, and the results are presented in Table 3. For example, if the distance is 2.5 km and the travel time is six minutes, the speed of the vehicle will be 25 km/h.

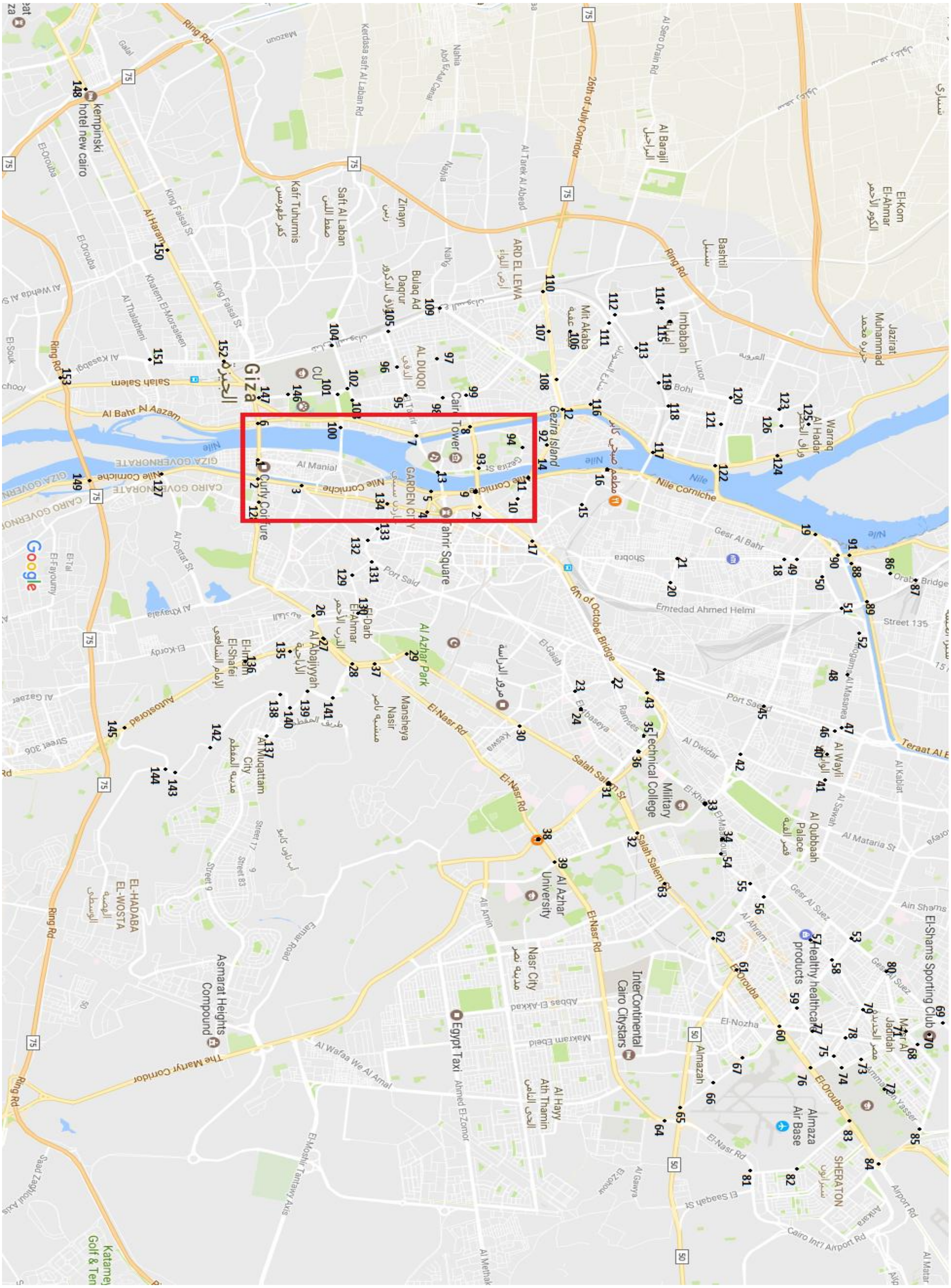


Figure 5: The nodes on the map of GC

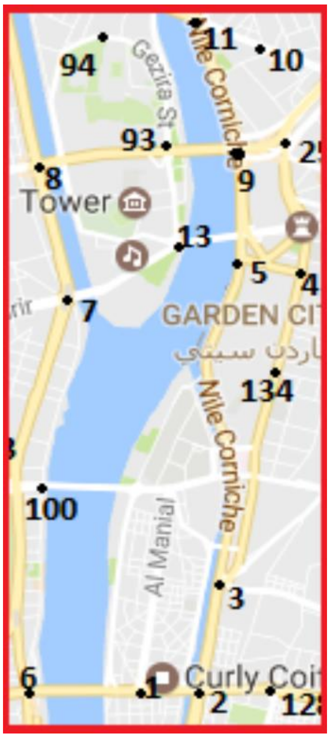


Figure 6: The link between nodes 3 and 4 on Al Qasr Al Ayni Street

3.2.2.2 The road capacity

The capacity of the road is not easy to find, and that is why the author assumed that the result of the road level of service is the capacity of the roads. There are four types of road level of service (A, B, C, F) based on the different speeds of vehicles. For example, the road level of service C only works when the speed of vehicles is around 20 km/h, and the road level of service F only works when the speed of vehicles is around 0 km/h. The calculations of the road capacity for all types of road level of service have the same formula: $\frac{lane\ lenght\ * number\ of\ lanes}{(the\ vehicle\ legnth + the\ free\ space\ between\ the\ vehicles)}$. The only difference between all the types of road level of service comes in the practical part (free space between the vehicles). For example, the free space between the vehicles is 0 meter in the level of service F, but it is 0.8 meter in the level of service C. The author took into his consideration just the two levels of service C and F due to the speed found in the previous section, which didn't exceed 30 km/h, and since the level of service B only works when the speed is around 60 km/h. (Garber et al., 2014)

3.2.2.3 The demand on Al Qasr Al Ayni Street

It was more difficult to find out the number of vehicles on the road as per the only found data pertaining to the travel time, the travel distance (the link length), and the speed of the vehicles. For this purpose, the author took advantage of the inverse relationship between the speed and the number of vehicles on the road, which means that there is an increase in the travel speed when there is a decrease in the number of vehicles on the road, and vice versa. The author developed the formula for road level of service by taking advantage of this relationship to find out the number of vehicles on the road by multiplying the free space between the vehicles by the actual speed over the level of service speed as the actual speed on that road, with the level of service speed being calculated as: $\frac{lane\ lenght\ * number\ of\ lanes}{(the\ vehicle\ legnth + (the\ free\ space\ between\ the\ vehicles * (\frac{the\ actual\ speed}{the\ level\ of\ service\ speed}))}$. For example, when the actual speed on the road is 7km/hour, the lane length is 2500 meters, the number of lanes is four, the vehicle length is 3 meters, and the free space between vehicles is 0.8

meter for the level of service C that has a speed of 20km/hour, then the number of vehicles on the road will be $\frac{2500*4}{(3+(0.8*(\frac{7}{20}))} = 3048$ vehicles on the road at that time. The actual numbers of vehicles (the demand) on Al Qasr Al Ayni Street (the demand) are shown in Table 3.

3.2.2.4 Congestion level

The author assumed that the congestion level should be accepted when the number of vehicles was below the level of service C. The congestion level calculated as the number of vehicles that exceeded the level of service C divided by the capacity of level of service F minus the capacity of level of service C: $(\frac{number\ of\ vehicles\ on\ the\ road - capacity\ of\ level\ of\ service\ C}{capacity\ of\ level\ of\ service\ F - capacity\ of\ level\ of\ service\ C})$. The congestion levels on Al Qasr Al Ayni Street are given in Table 3.

Time horizon	Speed	Number of vehicles	Congestion level	Average travel time
7:00–8:00	24.7 km/h	2506 vehicles	0	6.1
8:00–9:00	15.6 km/h	2757 vehicles	17.9%	9.7
9:00–10:00	13.8 km/h	2816 vehicles	26.2%	10.9
10:00–11:00	12.3 km/h	2865 vehicles	33.2%	12.3
11:00–12:00	11.2 km/h	2900 vehicles	38.2%	13.4
12:00–13:00	10.7 km/h	2917 vehicles	40.5%	14
13:00–14:00	11.4 km/h	2894 vehicles	37.4%	13.2
14:00–15:00	10.9 km/h	2911 vehicles	39.7%	13.8
15:00–16:00	9.00 km/h	2979 vehicles	49.4%	16.8
16:00–17:00	11.5 km/h	2891 vehicles	36.9%	13.3
17:00–18:00	14.0 km/h	2785 vehicles	21.8%	10.2
18:00–19:00	17.3 km/h	2710 vehicles	11.0%	8.7
19:00–20:00	19.2 km/h	2653 vehicles	3.00%	7.8

Table 3: The average speed, number of vehicles, congestion level, and travel time on Al Qasr Al Ayni Street

3.2.2.5 Travel time congestion factor

The congestion factor is calculated to find the travel time during congestion. The author assumed that the travel speed of the free flow of traffic was 25 km/h based on the average travel time found between 7 am and 8 am; which means that if the congestion level is 0%

and the distance is 2.5 km, the travel time will be $\frac{2.5}{25} * 60 = 6$ minutes. On the other hand, if there is congestion, the travel time will increase by different amounts of time due to the addition of the congestion level to the travel time of the free flow of traffic. The travel time congestion factor plays an important role in calculating the amount of increase in the travel time due to congestion. The value of the travel congestion factor is found by the following equation:

$$\begin{aligned} &total\ travel\ time\ found\ by\ Google \\ &\quad = the\ travel\ time\ of\ the\ traffic\ free\ flow \\ &\quad + travel\ time\ of\ the\ traffic\ free\ flow * level\ of\ congestion \\ &\quad * congestion\ factor \end{aligned}$$

Which means that:

$$\begin{aligned} &travel\ time\ congestion\ factor \\ &= \frac{total\ travel\ time\ found\ by\ Google - the\ travel\ time\ of\ the\ traffic\ free\ flow}{the\ travel\ time\ of\ the\ traffic\ free\ flow * level\ of\ congestion} \end{aligned}$$

The travel time congestion factor values were calculated for each time horizon and it was found that the values were between three and four for each time horizon except for the period between 19:00 and 20:00. The average congestion factor value was equal to 3.61. Table 4 presents the calculated congestion factor values.

Time horizon	The calculation	The travel time congestion factor value
7:00–8:00	As long as the congestion level is 0%, the congestion factor will be 0	0
8:00–9:00	$\frac{9.7 - 6}{6 * 17.9\%}$	3.45
9:00–10:00	$\frac{10.9 - 6}{6 * 26.2\%}$	3.12
10:00–11:00	$\frac{12.3 - 6}{6 * 33.2\%}$	3.16
11:00–12:00	$\frac{13.4 - 6}{6 * 38.2}$	3.23
12:00–13:00	$\frac{14 - 6}{6 * 40.5}$	3.29

13:00–14:00	$\frac{13.2-6}{6*37.4\%}$	3.21
14:00–15:00	$\frac{13.8-6}{6*39.7\%}$	3.27
15:00–16:00	$\frac{16.8-6}{6*49.4\%}$	3.64
16:00–17:00	$\frac{13.3-6}{6*36.9\%}$	3.30
17:00–18:00	$\frac{10.2-6}{6*21.8\%}$	3.21
18:00–19:00	$\frac{8.7-6}{6*11.0\%}$	4.1
19:00–20:00	$\frac{7.8-6}{6*3.00\%}$	10
average		3.61

Table 4: The congestion factor values

3.2.2.6 Congestion tolls

The congestion tolls values were found after many trails of running the program through the mathematical model. The author assumed that the value of the congestion tolls should be less than the cost of creating congestion on any other route, and more than or equal to the cost of congestion on the same route. Al Qasr Al Ayni Street congestion tolls values are less than the cost of creating congestion on Nile Street and more than the cost of congestion on Al Qasr Al Ayni Street. Al Qasr Al Ayni Street congestion tolls values for each time horizon are shown in Table 5.

Time horizon	Al Qasr Al Ayni Street congestion tolls values
7:00–8:00	0
8:00–9:00	2
9:00–10:00	3
10:00–11:00	3
11:00–12:00	3
12:00–13:00	3
13:00–14:00	3
14:00–15:00	3
15:00–16:00	3

16:00–17:00	3
17:00–18:00	3
18:00–19:00	2
19:00–20:00	2

Table 5: Al Qasr Al Ayni Street congestion tolls values

3.2.2.7 The value of travel time saving

There are three basic aims behind the desire for reducing travel time—the time saved can be spent for more production, it could be spent on having fun or leisure, and because the time spent in travelling makes a traveller to feel discomfort. The author assumed all the travellers' trips from 7 am to 8 pm, with 50% of trips comprising business purposes and 50% of the trips accounting for personal purposes. The category of travel in Cairo is local travel. As per the US department of transport, the recommended values of travel time saving per person-hour as a percentage of the total income are 50% for personal travel and 100% for business travel.[6] The average weekly income in Egypt is 641 EGP ($92) according to a World Bank report in 2013. The value of travel time saving in Cairo is 75% per person-hour as a percentage of the total income. Since the income is 641 EGP per week, which comes to 16 EGP per hour, the VTTS will be 12 EGP per hour.

3.2.2.8 Fuel consumption

A 2014 study on fuel consumption in Canada showed that a private car consumes 9.2 litres for every 100 kilometres.[7] Since the fuel cost in Egypt is 3.5 EGP per litre, and a private car consumes 0.092 litres per kilometre, the cost comes to around 0.322 EGP for free flow traffic. The author assumed that the fuel consumption would increase by 33% in the case of congestion, meaning that the cost will increase by 0.106 EGP per kilometre. Figure 7 shows the fuel consumption as per the study in Canada.

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[6] https://www.transportation.gov/sites/dot.dev/files/docs/vot_guidance_092811c.pdf

[7] https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/oee/pdf/transportation/tools/fuelratings/FCG2014WCAG_e.pdf

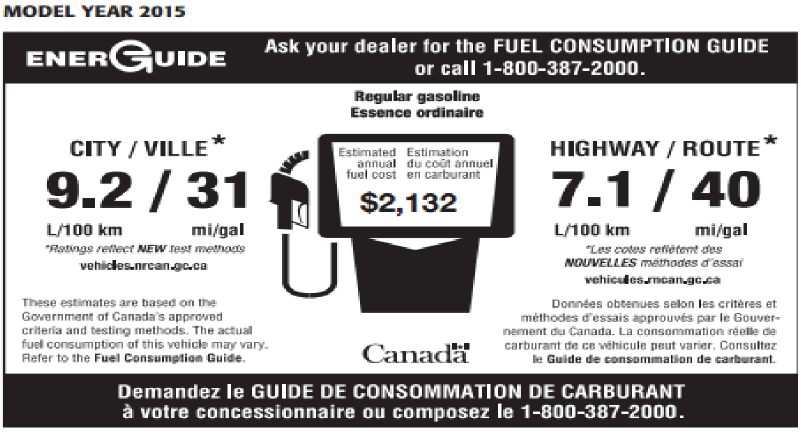

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Figure 7: The fuel consumption in Canada

3.2.2.9 The demand on Nile Street

The demands on Al Qasr Al Ayni Street and Nile Street are shown in Table 6. The demand on Al Qasr Al Ayni Street has already been introduced, and the author assumed that the demand on Nile Street (the link between nodes 6 and 7) was not congested and it has free capacity; however, free capacity was not enough to eliminate congestion on Al Qasr Al Ayni Street.

Time horizon	Demand ON Nile street (nodes 6 & 7)	Demand on Al Qasr Al Ayni street (nodes 3 & 4)
7:00–8:00	2368 vehicles	2506 vehicles
8:00–9:00	3032 vehicles	2757 vehicles
9:00–10:00	2974 vehicles	2816 vehicles
10:00–11:00	2925 vehicles	2865 vehicles
11:00–12:00	2890 vehicles	2900 vehicles
12:00–13:00	2873 vehicles	2917 vehicles
13:00–14:00	2896 vehicles	2894 vehicles
14:00–15:00	2879 vehicles	2911 vehicles
15:00–16:00	2811 vehicles	2979 vehicles
16:00–17:00	2883 vehicles	2891 vehicles
17:00–18:00	3005 vehicle	2785 vehicle
18:00–19:00	3080 vehicle	2710 vehicle
19:00–20:00	3136 vehicles	2653 vehicles

Table 6: The demands on Al Qasr Al Ayni Street and Nile Street

4.0 Chapter Four

Cost-benefit analysis theory

In this chapter, the author will explain how the cost-benefit analysis theory is implemented in the transportation sector. First, a brief general description of the cost-benefit analysis is given, followed by a detailed description of the cost-benefit analysis from the point of view of transportation. In the chapter, the cost-benefit analysis will focus on determining whether the congestion pricing system should be considered for the improvement of transport in Cairo or not.

4.1 Cost-benefit analysis

The cost-benefit analysis (CBA) answers the following questions: Whether the project should be undertaken or not, which project should be taken up in the case of limited funds, and how to determine of which planet should be made operational. The CBA not just measuring the benefits for the shareholders but it also pertains to measuring the benefits and costs to personnel. The CBA is unlikely to coincide with the benefits of individuals, and that is why it is directed towards the economy of a whole country. (Mishan et al., 2007; Bryde et al., 2013)

A private or a public enterprise is driven by the motive of profits for the shareholders, but it also incorporates benefits for its employee, consumers, as well as the government by paying taxes. An enterprise survives only if it is makes profit, otherwise it will not survive without receiving subsidies. The pursuance of profitable acts affects the welfare of all individuals and leads to perfect competition in economic activities. (Mishan et al., 2007; Torriti et al., 2014)

4.1.1 The appraisal of the cost-benefit analysis

The appraisal of a project by the CBA is not at the core of the exercise since the questions answered by the analysis can also be answered by the accountants of a private firm. However, in the case of CBA, it is rather the people who comprise society asking the same questions, but more searchingly. The CBA is better suited for the owner to select the activities to be undertaken for the enterprise as it helps to show the net benefits of each activity. For a more precise concept of revenues, economists have replaced the concept of social benefit with that of excess benefits over cost or net social benefit. Economists have proved that the CBA estimates the excess benefits over cost or net social benefit. (Mishan et al.,2007; Johansson et al., 2015)

The cost effectiveness can be easily calculated by the cost benefit techniques. The CBA simply calculates the net value, and so if there is a project with two values which are affected, the first value equals to +100 and the second one equals to -80. For this project, the cost benefit will equal to 100-80, which is +20. In this case, however, the cost effectiveness analysis will be conducted just for -80 as it is the part that accounts for the loss from the project. The CBA also calculates the effectiveness of benefits, but it is more commonly used to calculate the cost effectiveness. Simply put, the CBA calculates the summation of all valuations in the project. (Mishan et al., 2007; Dunn and William, 2015)

4.1.2 The valuations of utility and money

Large investment projects have an impact on the CBA when the aggregate gains of utility exceed the aggregate losses instead of the aggregate gains of money. There is an inverse relationship between the respective valuations of utility and money. There are three methods to weigh this relationship. The first one is that an increased income of 1 per cent will face a 2 per cent fall in the level of utility, the second one is that the marginal rates of income tax is 80 cents for the rich people and 10 cents for those who are not so rich, and the third method is based on the average national income, whereby the income of rich people is four times that of the average national income, while the income of poor people is 1/5 of the average national income. (Marglin and Stephen, 2014; Mishan et al., 2007)

4.1.3 The enterprise challenges

The acceptance rate is hard to find because several difficulties are faced in calculating the valuation of other goods and non-goods. And depending on the risk and the project length, the return might change as well. The taxes may be paid as per a proposed discount, and that makes calculating the valuation more difficult. Political constraint is another difficulty which is faced in calculating the valuation as it might include the project location, the level of production, and the product’s export. (Coates and John, 2014; Mishan, et al., 2007)

In calculating the cost-benefit, an economist poses the following question to himself: ‘What difference does it make to the economy if, given the constraints likely to be operative over the relevant time period, the specific investment project is introduced?’ It means whether the project is going to make a Pareto improvement. (Mishan et al., 2007)

For instance, if someone is willing to pay $25 for a product and that person buys the product for $15, then that means there is +$10 in his surplus. A person’s consumer surplus is measured by ‘the most he would pay for a thing less the amount he actually pays for it.’ The consumer surplus measures the maximum number of units a customer should buy for his need according to the demand curve by a given price for a specific period. That means there is a relationship between the price and the quantity sold, which is measured by the consumer surplus. (Mishan et al., 2007)

4.2 CBA of transport economics

There are few consumers of transport who want to get more information about all the costs and the benefits. For instance, when a consumer decides to buy a new vehicle, he is more concerned with its fuel consumption, maintenance, insurance, and repair costs. Similarly, consumers do the same when they buy airline or train tickets for travelling as they just want good price, reliable, safe, and comfortable trip. On the other hand, a country's government needs all the exact details and information for planning and making decisions on transports policies. Most of the transport consumers are concerned with the availability and the safety of their trips with a good price without high taxes, but they have very limited information about all these because their trips are indeed expensive and complex. The growing in the motor vehicles market needs to expand in the roads and parking capacities. For instances, the growing number of motor vehicle increases the risk of accidents and also affect the environment by their emissions. Most of the consumers do not know that the taxes and the fees they pay are not enough to cover all these costs. (Mishan et al., 2007; Glaeser et al., 2001)

The governmental transport policies and planning have an impact on everything in life as their objectives include conflict impacts. For instance, the strategy of increasing the speed limit on a road will reduce travel time, but will increase the risk of accidents as well. The strategy to reduce emissions by using electric vehicles will increase the cost of a vehicle for the consumer as well as increase the cost of building charging stations. The widening of parking facilities and roads will increase building costs. Whether these objectives are considered or not is determined by the CBA. (Pearce and David, 1998; Johansson et al., 2014)

The CBA evaluates and gives the guidelines for the objectives of transport economic decisions. For example, the travel time values and the vehicle operating cost have been studied well, and this enables a decision maker to be more aware of the costs and benefits of these two factors in order to help him make his decision. On the other hand, it is very difficult to evaluate and quantify the gas emissions or the greenhouse effect as gas emission is intangible. The two examples above illustrate the difference between factors that are easy to measure and those that are not, which makes the decision maker to always depend more on the factors that are easy to estimate. (Marglin and Stephen, 2014)

The next section will provide the benefits and the costs of the transport economic impacts. Indeed, the benefits and the costs vary from one mode of travel to another, but this thesis will only consider personal land transport. The analysis of the costs and the benefits will be provided for travel condition (urban peak) for land transport (motor vehicle). The values that are going to be provided will be differently used in different travel conditions such as faster and safer. The CBA will analyse the costs and the benefits of applying the Al Qasr Al Ayni congestion pricing system in Cairo. (Wingo and Lowdon, 2016)

4.2.1 The transportation costs and benefits

Most of the costs and the benefits in the transportation sector will be introduced by the following factors (Greene et al., 1997):

1. Vehicle ownership.
2. Vehicle operation.
3. Operating subsidies.
4. Travel time.
5. Internal crash.
6. External crash.
7. Healthy activity.
8. Internal parking.
9. External parking.
10. Congestion.
11. Road facilities.
12. Roadway land value.
13. Traffic services.
14. Transport diversity value.
15. Air pollution.
16. Greenhouse gas emissions.
17. Noise.
18. Resource consumption.
19. Barrier effect.
20. Land use impacts.
21. Water pollution.
22. Waste disposal.

4.2.2 Transport Means

The information on modifying the default values to reflect the specific conditions will help users to develop more suitable cost values for a specific means as 11 modes of transport are in use at a specific time at a specific location. The following part will cover the most common modes of transport (Knibbs et al., 2010).

1. Average automobile.
2. Compact (fuel efficient) car.
3. Electric car.
4. Van or light truck.
5. Rideshare passenger vehicle.
6. Diesel bus.
7. Electric bus/trolley.
8. Motorcycle.
9. Bicycle.
10. Walk.
11. Telework.

The planning and decision of the transport policy will include the analysis to provide the costs and the benefits. The evaluation of the impacts should be accurate in order to avoid the results from being misleading. In this section, the reader will be able to evaluate the full costs and benefits of a specific mode of transport. One of the economics principles is marginal costs, which have been inverted by the prices. The cost analysis helps the decisions makers to price the service. The management of transport demand needs universal analysis for planning and decisions as its impacts include changes in the travel time and the travel impacts. (Magnanti et al., 1984)

4.2.3 Transport definition

Transport refers to mobility and it is defined as ‘the movement of goods and people, measured in terms of distance and speed.’ (Litman and Todd, 2009). The travel goals in general are the abilities to address the demands for goods, services, activities, and destinations. The performance of a transport system is measured by the vehicular traffic conditions. This makes the planning of and decisions on transport policies to support improvements in automobile travel. At the same time, the planners should also consider that they need to reduce the need for travel. For example, telework is one of the solutions against traffic costs (problems), as it means working from home by making use of the internet, email, and telephone. (Litman and Todd, 2009)

4.2.4 Accessibility

The evaluation of accessibility differs from person to person as every individual has many different destinations. The quality of accessibility is measured by the time and the cost needed to visit to all the destinations by a person. The quality of accessibility relies on individual factors such as the person’s economic status (poor or rich) and traffic factors such as the road capacity or the transit services. There are some destinations whose accessibilities are difficult to improve, for instance a friend’s home, and the only way to improve it is a general improvement in mobility. On the other hand, there are some destinations that are easier to access, such as nearby places, and the accessibility to such destinations improves with the occurrence of any improvement. (Litman and Todd, 2008; Geurs et al., 2004)

4.2.5 Transport costs

Whenever a consumer faces a traffic problem, an economist terms it as traffic cost, since a problem means that there is something wrong and it should be corrected. Economists are aware enough to understand that the cost is a problem, which can be solved by sacrificing one or more of its benefits. Congestion is a traffic cost that always comes with a level of acceptance, but once it exceeds that limit, it should be solved by sacrificing, for example, the free use of the road. In other words, if a consumer wants time as a benefit, he should pay for that and vice versa. All the factors that affect traffic can be both costs and benefits; for example, travel time will be a cost if there is congestion and it will be a benefit if there is no congestion. (Lee and Douglass, 1995)

4.2.5.1 Internal, external, and social costs

The social costs are the total internal, external, and other costs. The internal costs are the costs that can be controlled by a user, such as fuel. The external costs are the costs that cannot be controlled by a user, such as congestion and accidents. The external cost could become an internal cost as well, for instance, if a group of users decide to take a roundabout on some roads and thus create congestion. This makes the internal and external costs to be different in each case. The efficient use of resources should make each person to calculate his share of use as a part of the social cost. For each person who pays the cost of his use should calculate his use as a marginal cost. (Verhoef, 1994; Delucchi and Mark, 1996)

The external costs among automobile users can be described by the following example. If a person own a car and most of the people who live in the same district own cars, that does not mean there is no external cost. As there may be some drivers who may endanger others by reckless driving or use the road more than normal and so on, they then make for external impact, which is a cost for the others. On the other hand, if a car owner does not use his car, then that makes for an external impact, which is a benefit for the others. The people who create the external cost for others should compensate the others and vice versa. (Forkenbrock and David, 1999)

4.2.5.2 Variable and fixed costs

There are two types of costs, which are variable costs (marginal costs) and fixed costs (sunk costs). The variable cost has a positive relationship with consumption, meaning that any increase in consumption effects an equal increase in variable costs and vice versa. The fixed costs are not affected by consumption, and this type of cost can be sold and part of its value, though not all of its value, can be recovered. For instance, fuel, travel time, and risk of accidents are variable costs, while insurance and fees are fixed costs. There are some costs that are a mix of variable and fixed costs. For example, a vehicle's operating life is affected by its consumption, and if it is sold, then it will recover part of its value. (Billheimer et al., 1973; Osborne and Richard, 1995)

4.2.5.3 Market and non-market costs

Costs are also classified as market and nonmarket costs. The market costs are tangible costs such as fuel, land, and vehicle. The non-market costs are intangible costs such as pollution, risk of accidents, and noise. Most consumers are not aware of the actual costs such as those pertaining to insurance, repair and maintenance, residential parking, travel time, fuel, parking fees, and traveller fees. But they are aware of the perceived costs that comprise part of the actual costs such as travel time, fuel, parking fees, and traveller fees. (Litman et al., 2006; Small and Kenneth, 2013)

4.2.5.4 Direct and indirect costs

Costs can also be classified as direct and indirect costs. The indirect costs are difficult to quantify, and to do so, one should be aware of the all the steps that connect an activity. For example, the reduction in transport due to the people who stop driving will affect the economic, social, and environmental costs. (Daley et al., 1998; Ostrom et al., 1993)

4.2.5.5 Economic transfer

There is something called economic transfer, which includes benefits or costs, and its transfer will not affect the available resources. The congestion pricing is an economic transfer as it is a cost for the users and a benefit for the government, but the toll points that scan the number plates of vehicles in order to collect fees is a resource cost. The non-market cost is an economic transfer as the drivers who have big vehicles equipped with safety measures for passengers, increase the risk for the other drivers, and thus termed as transfer of risk. The evaluation should consider the costs and the benefits. (Winebrake et al., 2008; Saaty et al., 2013)

4.2.5.6 Taxes

It is quite difficult to analyse the taxes as most of the taxes are not involved in the costs and the benefits of the transport economics. It could be considered as an economic transfer from the users to the government. On the other hand, there are some taxes that could be involved in the costs and the benefits, such as fuel taxes, as external costs. (Homburger et al., 1982; Mayeres et al., 1996)

4.2.5.7 Cost summary

The transport economic costs could be categorized as the following: the internal variable costs pertaining to fuel, parking, and part of maintenance, user accident risk, and the stress and the time of the user. The internal fixed costs relate to purchasing a vehicle, the fees for the vehicle’s documentation and registration, insurance payments, residential parking, and the other part of maintenance. The external variable costs pertain to congestion, pollution, accident risk of the other drivers, insurance expenditure, road maintenance, and traffic services. The external fixed costs are concerned with traffic planning, constructions, subsidies, land impacts, and social unfairness. (Litman and Todd, 1999)

4.2.6 Transport benefits

Benefits and costs have the same elements, but share an inverse relationship; an economist defines benefits as the decrease in costs, and costs as the decrease in benefits. Some people think that all the researches on the transportation sector are against automobiles, and deny the benefits of transport. Indeed, these people misunderstand the researches. For example, congestion pricing is one of the successful strategies to reduce travel time as well as vehicular emissions by reducing the number of drivers; however, the naysayers focus on the part of reducing the number of drivers and fail to see the other part of reducing travel time and vehicular emissions. (Litman and Todd, 2009)

4.2.7 Uncertainty

There is a percentage of uncertainty and variability in the costs and the benefits of transportation. When an economist calculates the costs for the first time, he applies the general values for each cost, but of course it is different from case to another. For example, land value differs from one city to another. Later on, the economist removes the general values and modifies them by incorporating the actual values. There is an accepted level of uncertainty, but it differs from one location to another as also from case to another. The uncertainty arises out of limited data. (Ottinger and Richard, 1993)

The cost estimation should consider all the impacts, and not just the impacts that are easy to measure (market and direct costs). For instance, if an economist estimates the costs that are easy to measure such as travel time and operating cost, but ignores the costs that are hard to measure (indirect and nonmarket costs) such as the environment impact, then this will lead to a harmful effect for the environment. Cost estimation requires an economist to be fair enough with each impact for each person. In his estimation, an economist should consider all aspects of a society such as the poor and rich people, the future and the present, and so on to avoid losses. (Litman and Todd, 2009)

The uncertainty could have a cost range to find the worst-case scenario and the best-case scenario in the analysis by a decision maker. The sensitivity analysis plays an important role in the cost range by showing the results and the effects. This leads to the use of the cost range and the sensitivity analysis for costs that have high uncertainties. (Jordan et al., 1995; Hanley, et al., 1993)

4.2.8 The social surplus

The social surplus consists of consumer surplus, externalities, government costs and revenues, and tax effects. The consumer surplus contains shorter travel times, more reliable travel times, loss for evicted car drivers, gain for new car drivers, congestion charges paid, and increased transit crowding. Externalities contain reduced greenhouse gas emissions, health and environmental effects, and increased traffic safety. The government costs and revenues contain congestion charges paid, increased public transit revenues, decreased revenues from fuel taxes, increased public transportation capacity, and operational costs for the charging system. Tax effects contain marginal costs of public fund, and correction for indirect taxes (Eliasson, 2014).

5.0 Chapter Five

The Mathematical Model

This chapter provides a brief description of the Urban Transportation Network Design Problems (UTNDP), followed by the linear network programs. The UTNDP classifications are provided in the first section. The general transhipment model is provided in the second section, followed by Al Qasr Al Ayni mathematical model, which has been improved the general transhipment model to fit the problem.

5.1 Urban Transportation Network Design Problems (UTNDP)

Transportation is important as it makes travelling from place to another much easier. The demand for transportation is directly affected by the population, which means that an increase in population increases transportation and a decrease in population decreases transportation. When the demand for transportation increases, the cost increases as well. In transportation economics, the cost not only refers to the monetary cost, but it also includes impacts such as congestion, air pollution, and noise. The improvement of transportation is a governmental responsibility in most countries around the world. The government always plans for a transport network that would decrease the costs. The transport network plan should always be flexible so as to accommodate increases or decreases in the population. Such a transportation network plan is called Urban Transportation Network Design Problems (UTNDP). (Farahani et al., 2013)

UTNDP has been created to improve transportation networks. It contains most of the strategic, operational and tactical decisions attached to the network topology. The following problems are considered as UTNDP sub-problems: traffic signal setting, toll setting, parking pricing, and public transit pricing. For example, the decisions on networks formation have a strong relationship with traffic signal setting. (Cantarella et al., 1991; Meneguzzer, 1995; Wong and Yang, 1999; Wey, 2000; Cascetta et al., 2006)

5.1.1 Types of UTNDP decisions

In transportation planning, the UTNDP decision making process involves three types of decisions (Figure 8). The first pertains to long-term decisions, which are related to the infrastructure of the transportation networks, such as building new roads, and these decisions

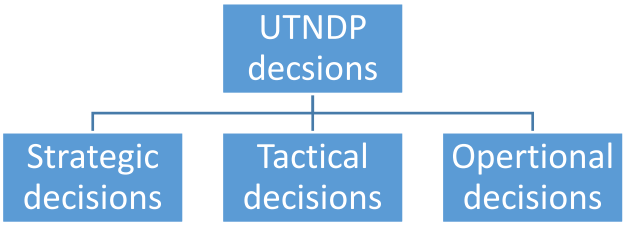

Figure 8: Types of UTNDP decisions

are addressed as strategic decisions. The second type are the decisions that are related to the efficient utilization of roads, such as determining the transit service frequency, and these decisions are referred to as tactical decisions. The last type are the decisions pertaining to the control of traffic flow, such as scheduling of traffic lights, and these decisions are known as operational decisions. (Magnanti and Wong, 1984)

5.1.2 Bi-level UTNDP

The mathematical model formulation for UTNDP has two levels of problems or bi-level problems. The first level (upper level) relates to the person or persons responsible for planning the transport network, such as the government. The planner of the transport network has goals such as the reduction of travel time, and restrictions such as political restrictions, and he also predicts the consumer behaviour. The second level (lower level) pertains to the travellers, who select the routes and their modes of travel. This type comprises nonlinear problems which are not easily solved. (LeBlanc et al., 1986)

5.1.2.1 Upper level of UTNDP

Many network design decisions and policies are categorized under UTNDP (Figure 9). Mainly, roads network design problems (RNDP), and transit network design and scheduling problems (TNDSP) are the most common categories of UTNDP. The Multi-Modal Network Design Problem (MMNDP) is used when there is more than one mode of transport. (Farahani et al., 2013)

5.1.2.1.1 Roads Network Design Problems (RNDP)

RNDP cannot recognize the difference between public vehicles and private vehicles. RNDP is classified into three types of network designs, which are namely Discrete Network Design Problem (DNDP), Continuous Network Design Problem (CNDP), and Mixed Network Design Problem (MNDP). DNDP only deals with design decisions that have the following characteristics: countable, nothing in between, and digital, such as building new roads, adding new lanes, deciding the orientation of one-way streets, and locating intersections and U-turns. CNDP only deals with design decisions that have the following characteristics: infinite, always something in between, and analogous, such as expanding road capacity, scheduling the traffic lights, and deciding the toll systems for some streets. MNDP only deals with design decisions that have combined discrete and continuous characteristics. If there is time planning horizon, then the classifications will be DNDP-T, CNDP-T, and

MNDP-T. (O'Brien and Szeto, 2007; Farahani et al., 2013; Long et al., 2010; Mathew and Sharma, 2009; Lo and Szeto, 2009)

5.1.2.1.2 Transit Network Design and Scheduling Problems (TNDSP)

TNDSP mainly comprises the service frequency, the time tables, and the structure of public transit networks. TNDSP is classified into five types of network designs, which are TNDP, TNDFSP, TNFSP, TNTP, and TNSP. The Transit Network Design Problems (TNDP) only deal with the routes design of transit lines involving the origin and the destination of the transit routes and the links visited. The Transit Network Design and Frequency Setting Problems (TNDFSP) only deal with deciding the service frequency for each bus line and route design. Transit Network Frequencies Setting Problem (TNFSP) only deals with the given route topology frequency setting. Transit Network Timetable Problem (TNTP) deals only with timetable issues pertaining to service frequency and routes. Transit Network Scheduling Problem (TNSP) deals with both frequency and time-table decisions pertaining to the route structure. (Farahani et al., 2013; Barra et al., 2007; Szeto and Wu, 2011)

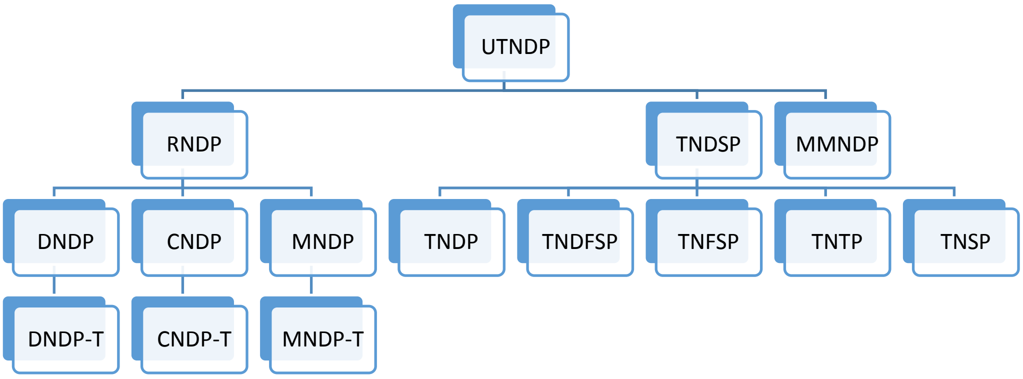

Figure 9: The classification of the UTNDP's upper level

5.1.2.2 Lower level of UTNDP

The lower level of the network design and policies pertains to the travellers. The lower limit always depends on the choice of dimensions and the assumptions about the traveller's choice of route. The flow unit in road network problems are the vehicles. On the other hand, the flow unit in the public transit network are the occupants. The user equilibrium (UE) is provided to determine the flows of the road and the transit network. Some transport economists refer to this kind of problem as combined travel choice problems (CTCP). (Daganzo and Sheffi, 1977; Luo et al., 1996)

5.1.3 UTNDP demand

Demand is one of the UTNDP components, and there are two types of demands for all the problems. The first one is fixed demand, which means that the number of travellers and vehicles will not change. The second one is elastic demand, which means that the number of travellers will not change, but the number of vehicles will change. In fixed demand, the travellers have a variety of choices of routes and they will choose the route which is appropriate for them. Elastic demand considers other factors such as travel time. In this type of demand, the travellers have a variety of choices of routes and modes, and they will choose the route that is appropriate for them. (Arnott et al., 1993)

5.2 Network linear programs

The Urban Transportation Network Design Problems (UTNDP) classify congestion tolls or pricing as a Continuous Network Design Problem (CNDP), which is one of the Roads Network Design Problems (RNDP). These types of problems are used as a nonlinear problem, but in this thesis, it will be treated as a linear problem due to the program and data limitation. The model is applied on one of the city centre streets, which is named Al Qasr Al Ayni. The author will show that this model is an improvement of the general transhipment model. The computational answers will show whether the congestion pricing system is an effective system to reduce congestion or not.

5.2.1 General transhipment model

The mathematical model, which is going to be provided in this section, is a linear networks model, and it is called the general transhipment model. The general transhipment model represents cities and the flow between those cites, with the supply being in the origins and the demand being in the destinations. The cities between the origins and the destinations will be provided as transit cities to make the flow reach each destination. There is a travel cost between the cities, which could be the distance, the travel time, noise, and so on. Each flow cannot exceed the road capacity. Consider the network is represented by G (N, A), where N represents the cities and A represents the streets connecting the cities. (Robert et al., 2003)

Figure 10 shows a simple topology of the urban transport network. Assuming that the six nodes on the left-hand side are the origins (supply cities), the three nodes on the right-hand side are the destinations (demand cities), all the other nodes are transit cities, and there are different travel costs between all the links between the cities. The general transhipment model will be able to minimize the total costs and satisfy the demand.

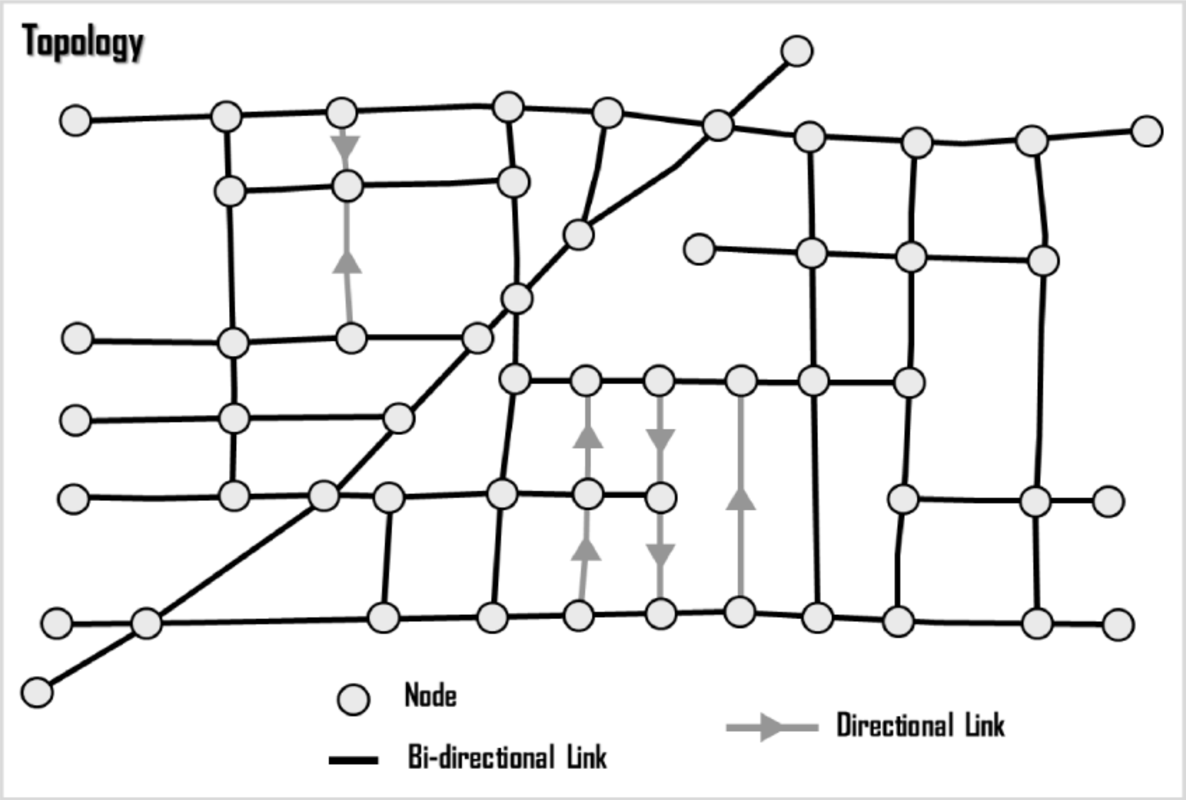

Figure 10: City topology

Notations:

N	Set of cities
A_{ij}	Set of streets between the cities
c	Travel cost between the cities
S_n	Supply of each city
D_n	Demand of each city
cap_{ij}	The street capacity between city i and city j of each arc in A
X_{ij}	The variable of total number of vehicles on each arc (i, j)

The general transhipment model

$$Min\ Tot.cost = \sum_{(i,j)\epsilon A} X_{ij} * c \tag{1}$$

$$S_{nt} + \sum_{(i,n)\in A} X_{in} = D_{nt} + \sum_{(n,j)\in A} X_{nj} \qquad n \ \epsilon \ N \tag{2}$$

$$X_{ijt} \leq cap_{ij} \qquad (i,j) \ \epsilon \ A \tag{3}$$

In this model, the first equation is the objective function that represents the sum of the travel costs over all the arcs. The second equation describes that in each city, the vehicles supplied plus the vehicles arrived must balance the vehicles demanded plus vehicles departed. The third equation prescribes that the total number of vehicles on each street cannot exceed the street capacity.

5.2.2 Mathematical model of Al Qasr al Ayni congestion pricing system

As it is an improvement of the general transhipment model, *G* (*A*, *N*) will be the network in the model, with *N* as the set of nodes (intersections) denoted by n, and *A* is the set of arcs (roads) between all the nodes denoted by (i, j). Set *T* is the set of time horizon denoted by t. There are three more sets, which are parts of the two main sets *A* and *N*. The first set *O* is the origins set, and it is part of the nodes set *N*. The second set *D* is the destinations set, and it is part of the nodes set *N*. The index o denotes set *O*, and d denoted set *D*. The third set *OD* is the pairs of origins and destinations denoted by (*o*, *d*), and it is part of the set of arcs *A*.

Notations:

Sets

N	Set of intersections
A_{ij}	Set of streets between the cities

Parameters:

c	Cost of fuel per kilometre without congestion
cc	Cost of wasted fuel due to congestion
tc_{ij}	The toll vehicle cost of each arc (i, j) at time t
S_n	Supply of each node
D_n	Demand of each node
odt_{odt}	Demand of each pair of origin and destination at time t
M	Big number
dis_{ij}	Distance between node i and node j of each arc in *A*
tt_{ij}	Travel time between node i and node j of each arc in *A* without congestion
cap_{ij}	Capacity between node i and node j of each arc in *A* according to the road design C
$maxcap_{ij}$	Capacity between node i and node j of each arc in *A* according to the road design F
cf	The travel time congestion factor of travel time

Variables:

X_{ijt}	The variable of total number of vehicles on each arc (i, j) at time t

Y_{ijt}	The variable of number of vehicles on each arc (i, j) at time t within the capacity of the road design C
V_{ijt}	The variable of number of vehicles on each arc (i, j) at time t which makes the capacity exceed the limit of the capacity of the road design C and makes the capacity to be within the capacity of road design F
W_{ijt}	The variable which is equal to 1 if there is congestion on arc (i, j) at time t, or otherwise 0
Z_{ijt}	The variable which is equal to 1 if there is congestion on each arc (i, j) at time t, or otherwise 0
R_{ijt}	The variable which is equal to the actual travel time for each vehicle on each arc (i, j) at time t

$$Min\ Tot.cost = \sum_{(i,j)\epsilon A} \sum_{t\ in\ T} X_{ijt} dis_{ij} c + \sum_{(i,j)\epsilon A} \sum_{t\ in\ T} W_{ijt} Y_{ijt} dis_{ij} cc + \sum_{(i,j)\epsilon A} \sum_{t\ in\ T} V_{ijt} dis_{ij} cc + \sum_{(i,j)\epsilon A} \sum_{t\ in\ T} X_{ijt} tc_{ijt} \tag{1}$$

Subject to

$$S_{nt} + \sum_{(i,n)\in A} X_{int} = D_{nt} + \sum_{(n,j)\in A} X_{njt} \qquad n\ \epsilon\ N, t\ \epsilon\ T \tag{2}$$

$$\sum_{(i,j)\epsilon A} X_{ijt} \geq\ odt_{odt} \qquad (o,d)\ \epsilon\ OD, t\ \epsilon\ T \tag{3}$$

$$X_{ijt} = Y_{ijt} + V_{ijt} \qquad (i,j)\ \epsilon\ A, t\ \epsilon\ T \tag{4}$$

$$Y_{ijt} \leq cap_{ij} \qquad (i,j)\ \epsilon\ A, t\ \epsilon\ T \tag{5}$$

$$V_{ijt} \leq maxcap_{ij} - cap_{ij} \qquad (i,j)\ \epsilon\ A, t\ \epsilon\ T \tag{6}$$

$$X_{ijt} \geq Y_{ijt} + W_{ijt} \qquad (i,j)\ \epsilon\ A, t\ \epsilon\ T \tag{7}$$

$$V_{ijt} \leq W_{ijt} M \qquad (i,j)\ \epsilon\ A, t\ \epsilon\ T \tag{8}$$

$$X_{ijt} \leq Z_{ijt} M \qquad (i,j)\ \epsilon\ A, t\ \epsilon\ T \tag{9}$$

$$X_{ijt} \geq Z_{ijt} \qquad (i,j)\ \epsilon\ A, t\ \epsilon\ T \tag{10}$$

$$Z_{ijt} tt_{ij} + tt_{ij} cf\left(\frac{V_{ijt}}{maxcap_{ij} - cap_{ij}}\right) = R_{ijt} \qquad (i,j)\ \epsilon\ A, t\ \epsilon\ T \tag{11}$$

$$X_{ijt} \geq 0 \qquad (i,j)\ \epsilon\ A, t\ \epsilon\ T \tag{12}$$

$$Y_{ijt} \geq 0 \qquad (i,j)\ \epsilon\ A, t\ \epsilon\ T \tag{13}$$

$$V_{ijt} \geq 0 \qquad (i,j)\ \epsilon\ A, t\ \epsilon\ T \tag{14}$$

$$W_{ijt} \geq 0 \qquad (i,j)\ \epsilon\ A, t\ \epsilon\ T \tag{15}$$

$$Z_{ijt} \geq 0 \qquad (i,j)\ \epsilon\ A, t\ \epsilon\ T \tag{16}$$

$$R_{ijt} \geq 0 \qquad (i,j)\ \epsilon\ A, t\ \epsilon\ T \tag{17}$$

The objective function of this problem is to minimize the total cost of fuel and tolls charge. The objective function contains three parts. The first part is the cost of the total amount of vehicular fuel consumed without congestion, even though there is congestion, where $\sum_{(i,j)\epsilon A}\sum_{t\ in\ T} X_{ijt}dis_{ij}c$ is the total number of vehicles on each arc multiplied by the distance on each arc multiplied by the cost of fuel per kilometre. The second part is the cost of the amount of vehicular fuel wasted due to congestion, and it works just as if there is congestion, where $\sum_{(i,j)\epsilon A}\sum_{t\ in\ T} W_{ijt}Y_{ijt}dis_{ij}cc + \sum_{(i,j)\epsilon A}\sum_{t\ in\ T} V_{ijt}dis_{ij}cc$ is the binary variable of congestion on each arc multiplied by the total number of vehicles on each arc multiplied by the distance on each arc multiplied by the cost of wasted fuel per hour. The third part is the charge cost of tolls, where $\sum_{(i,j)\epsilon A}\sum_{t\ in\ T} X_{ijt}tc_{ijt}$ is the total number of vehicles on each arc at each time multiplied by the tolls charge on each arc at each time.

Equation number (2) is the balance constraint, where the dummy index is n, and it represents the summation of the nodes where the vehicle path go from the supply node to the demand node, and that is called indexing convention. The left-hand side of the constraint $S_{nt} + \sum_{(i,n)\in A} X_{int}$ means that all the vehicles going in at intersection n equal the right-hand side of the constraint $D_{nt} + \sum_{(n,j)\in A} X_{int}$ means that all the vehicles go out of intersection n. Simply put, at each n intersection, the in vehicles minus the out vehicles equals to the supply minus the demand.

Equation number (3) is the demand of each pair of OD. The left-hand side is the summation of the vehicles on arcs (roads) at time t, and it should be more than or equal to the demand of each pair of origin and destination. This constraint has been created to make sure that each vehicle going out of its origin has a specific destination.

Equation number (4) shows that the total number of vehicles (flow) on each arc at each time has two components. The first component Y_{ijt} represents the number of vehicles on each arc at each time t within the capacity of the road design C (speed 20 km/hour). The second one V_{ijt} represents the number of vehicles on each arc at each time t added to the first component Y_{ijt} within the capacity of the road design F (speed 0 km/hour).

Equation number (5) is the capacity constraint showing that the number of vehicles Y_{ijt} on each arc at each time should be less than or equal to the capacity of the road design C. Equation number (6) is the capacity constraint showing that the number of vehicles V_{ijt} on each arc at each time should be less than or equal to the capacity of the road design F minus the capacity of the road design C. There is no need for a capacity constraint to show that the total number of vehicles X_{ijt} on each arc at each time should be less than or equal to the capacity of the road design F as X_{ijt} equals to Y_{ijt} $+V_{ijt}$, which already have capacity constraints.

Equation number (7) is the upper bound of the binary variable link constraint so that the total number of vehicles on each arc at each time should be more than or equal to the binary variable, and if the arc is not used by the vehicles, then that means the binary variable should be zero.

Equation number (8) is the lower bound of the binary variable link constraint so that if there is congestion, it should be equal to 1 multiplied by big number to be more than or equal to the number of vehicles V_{ijt} on each arc at each time.

Equation numbers (9, 10) are the binary variable link constraint lower and upper bounds as if the arc is used, the binary variable should equal to one, or otherwise equal to 0.

Equation number (11) is the constraint of the travel time on each arc at each time, which contains two parts. The first part $Z_{ijt}tt_{ij}$ is the travel time without congestion, and the second part $tt_{ij}cf(\frac{V_{ijt}}{maxcap_{ij}-cap_{ij}})$ is the travel time with the congestion as cf is the congestion factor multiplied by the congestion level $(\frac{V_{ijt}}{maxcap_{ij}-cap_{ij}})$.

Equation numbers (12, 13, 14, 15, 16, 17) ensure that the all the variables are non-negative variables.

6.0 Chapter Six

Computational Answers and Analysis

6.1 Computational study

AMPL has been used to formulate and program the model in this thesis, and it works by an algebraic modelling language for mathematical programming (Fourer et al., 2003). The cost benefit analysis theory will determine if the congestion tolls on Al Qasr Al Ayni Street should be applied or not; if the social surplus is positive, then the congestion tolls should be applied on Al Qasr Al Ayni Street and vice versa. The following computational answers that were derived by AMPL will be used in the next section to find out the social surplus values.

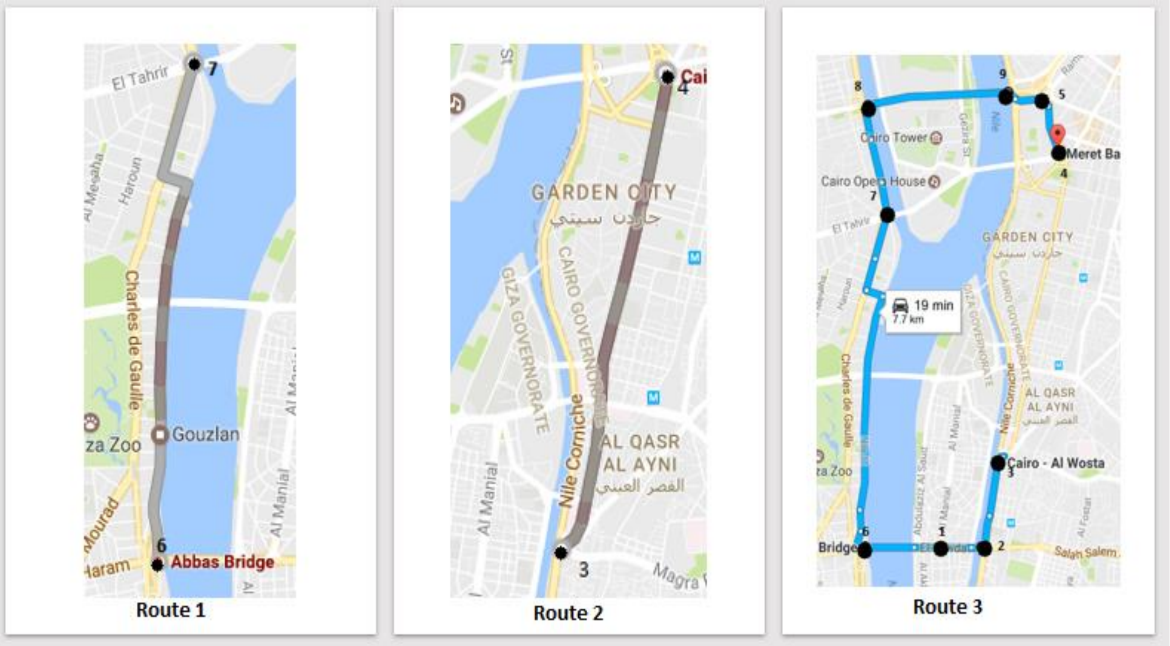

Figure 11: Routes 1, 2, and 3

Time horizon	Number of vehicles before the introduction of congestion tolls		Number of vehicles after the introduction of congestion tolls		
	Route 1	Route 2	Route 1	Route 2	Route 3
7:00–8:00	2368	2506	2368	2506	0
8:00–9:00	3032	2757	3157	2631	125
9:00–10:00	2974	2816	3157	2631	183
10:00–11:00	2925	2865	3157	2631	232
11:00–12:00	2890	2900	3157	2631	267
12:00–13:00	2873	2917	3157	2631	284
13:00–14:00	2896	2894	3157	2631	261
14:00–15:00	2879	2911	3157	2631	28

15:00–16:00	2811	2979	3157	2631	346
16:00–17:00	2883	2907	3157	2631	274
17:00–18:00	3005	2785	3157	2631	152
18:00–19:00	3080	2710	3157	2631	77
19:00–20:00	3136	2653	3157	2631	32

Table 7: The number of vehicles on routes before and after the introduction of congestion tolls

Time horizon	Travel time before the introduction of congestion tolls		Travel time after the introduction of congestion tolls		
	Route 1	Route 2	Route 1	Route 2	Route 3
7:00–8:00	6	7.2	6	7.2	19.68
8:00–9:00	9.889	7.2	6.03087	7.2	19.68
9:00–10:00	11.7101	7.2	6.06173	7.2	19.68
10:00–11:00	13.2225	7.2	6.06173	7.2	19.68
11:00–12:00	14.3028	7.2	6.06173	7.2	19.68
12:00–13:00	14.8275	7.2	6.06173	7.2	19.68
13:00–14:00	14.1176	7.2	6.06173	7.2	19.68
14:00–15:00	14.6423	7.2	6.06173	7.2	19.68
15:00–16:00	6.7412	7.2	6.06173	7.2	19.68
16:00–17:00	14.5189	7.2	6.06173	7.2	19.68
17:00–18:00	10.7533	7.2	6.06173	7.2	19.68
18:00–19:00	8.43837	7.2	6.06173	7.2	19.68
19:00–20:00	6.679	7.2	6.03087	7.2	19.68

Table 8: the travel time on routes before and after the introduction of congestion tolls

As mentioned in Chapter Three, there are two pairs of origin and destination ([6,7] and [3,4]). The demand of each pair of origin and destination are satisfied when the vehicles choose the shortest path (Route 1, 2) because it's the cheapest path even if there is congestion on it. After the introduction of congestion tolls on Al Qasr Al Ayni Street (Route 2, Figure 11), some vehicles found out that it was cheaper to choose another route (Route 3) even if it was longer than Al Qasr Al Ayni Street (Route 2). The vehicles chose Route 3 because it had free capacity and thus it would not lead to congestion. Nile Street (Route 1) is part of Route 3, which means that the number of vehicles would increase on Nile Street (Route 1) by the same number of vehicles on Route 3. Table 7 shows the difference between the number of vehicles on the routes before and after the introduction of congestion tolls. Table 8 shows the difference between travel time for each vehicle on the routes before and after the introduction of congestion tolls. The demand in this case is fixed demand, which means that the number of travellers and vehicles do not change.

Consumer	Before the introduction of congestion tolls	After the introduction of congestion tolls
Cost of fuel without congestion	64498.1	68986.9
Cost of added fuel due to congestion	9120.15	8451.39
Cost of congestion tolls	0	86885
Total cost	73618.3	164323

Table 9: the total cost before and after the introduction of congestion tolls

The total monetary cost in the model for the average number of vehicles on road per hour, for daily working hours from 7 am to 8 pm, is 164323 EGP. This cost consists of the congestion tolls cost of 86885 EGP, the fuel cost without congestion is 68986.9 EGP, and the extra cost fuel due to congestion is 8451.39 EGP. On the other hand, the total cost of the same model before the introduction of the congestion tolls (before adding the congestion tolls to the objective function) was 73618.3 EGP, which consisted of the fuel cost without congestion of 64498.1 EGP, and the extra cost of fuel due to congestion of 9120.15 EGP. The difference between the fuel cost before and after the introduction of the congestion tolls is 3819.7 EGP, which shows that the introduction of congestion tolls added 3819.7 EGP to fuel costs. The respective costs before and after the introduction of the congestion tolls are presented in Table 9.

Consumer	Before the introduction of congestion tolls	After the introduction of congestion tolls
Travel time consumed	715797	527402
Travel time without congestion	491414	491414
Wasted travel time	2243823	35988
The value of wasted travel time	44876.5	7197

Table 10: The travel time values before and after the introduction of congestion tolls

The result of the wasted travel time value before the introduction of congestion tolls is estimated to be 44876.5 EGP, and after the introduction of congestion tolls, it is estimated to be 7197.6 EGP. The difference between the wasted travel time value before and after the introduction of congestion tolls is 44876.5 EGP, thereby showing that introducing the congestion tolls saved travel time costs by 37679 EGP. The travel time values before and after the introduction of congestion tolls are provided in Table 10.

6.2 The costs analysis

The social costs are the total internal and external costs. Part of the fuel cost is internal cost and the other part is external cost. The fuel cost in general is an internal cost, but in this thesis, there are two fuel costs—the first cost is the internal cost of normal fuel consumption, which has been estimated to be 68986.9 EGP, while the second is the external added cost of fuel due to congestion, which has been estimated to be 8451.39 EGP. The paid congestion is an internal cost because the drivers are willing to pay to drive through street congestion, and this cost has been estimated to be 86885 EGP, which could be economic transfer from the travellers to the government. The drivers who switched to Route 3 created external benefits or impacts for the others as they reduced the travel time for the others by 37679 EGP, but they incurred internal travel time cost of 3297.37 EGP, and internal fuel cost of 3977 EGP. On the other hand, the drivers who switched to Route 3 saved 1351 EGP on wasted fuel in congestion and 6549 EGP from paid congestion.

The variable costs are the costs that have a positive relationship with consumption, such as the travel time cost of 527402 EGP, the fuel consumption cost of 77438 EGP, and the paid congestion tolls of 86885 EGP. This means the total variable costs is 691725 EGP. The author didn’t mention the fixed costs such as fees and insurance in this study.

The economic transfer is clear in this thesis as the drivers who switched to Route 3 themselves incurred travel time cost of 3297.37 EGP and fuel cost of 3977 EGP, but saved travel time cost of 37679 EGP and fuel cost of 669 EGP for the others. The congestion tolls have been estimated to be 86885 EGP as the drivers incurred it, but the government earn that amount.

The direct cost like the congestion tolls of 86885 EGP was considered in this study. However, the indirect cost such as how the shops would be affected on that street was not considered. The non-market costs were not considered as well, but the market costs were considered such as the travel time and fuel consumption.

The social surplus consists of consumer surplus, externalities, government costs and revenues, and tax effects. The consumer surplus contains shorter travel times, more reliable travel times, loss for evicted car drivers, gain for new car drivers, congestion charges paid, and increased transit crowding. Externalities contain reduced greenhouse gas emissions, health and environmental effects, and increased traffic safety. The government costs and revenues contain congestion charges paid, increased public transit revenues, decreased revenues from fuel taxes, increased public transportation capacity, and operational costs for the charging system. Tax effects contain marginal costs of public fund, and correction for indirect taxes (Eliasson, 2014). The net social benefit in this study is more than 33860 EGP per day as the author considered the shorter travel time and the cost of fuel. The social surplus in this study is not yet complete as some costs are missed, such as emissions and taxes.

The social surplus of Al Qasr Al Ayni Street after the introducing congestion tolls	*The values loss/gain*
Consumer surplus	
Shorter travel time	37679
Paid congestion	-86885
The cost of fuel	-3819
Government revenues	
Paid congestion	86885
Net social benefit	33860

Table 11: The net social benefit of Al Qasr Al Ayni Congestion pricing system

(Table 11)

The net social benefit is positive by 33860 EGP, which means that the study has met success and should be continued to add the other costs in order to implement it and make it a reality.

7.0 Chapter Seven

Conclusion and further research

Conclusion and further research

Road congestion is one of the most common problems (costs) around the world that occurs when the numbers of vehicles on the road exceed the road capacity. There are six main reasons for Cairo’s congestion, which are governmental fuel subsidies, few parking facilities, public transportation, bad planning, social behaviour, and large investment in highways. The global tendency to solve complex congestion problems in cities is by focusing on two basic solutions: improving public transportation and making the use of private vehicles expensive by applying the congestion pricing system.

The methodology of that research was applying the collected data to the mathematical model by using AMPL to get results, those results analysed by the cost-benefit analysis theory.

The data collected classified into two secondary and primary data. The secondary data comprise the data found on Google, such as travel time, and travel distance. The primary data include the data that are based on equations and assumptions, such as road capacity and road demand.

The cost benefit analysis illustrate all the costs and benefits, and calculate the net social benefit. Benefits and costs have the same elements, but share an inverse relationship; an economist defines benefits as the decrease in costs, and costs as the decrease in benefits. The social surplus consists of consumer surplus, externalities, government costs and revenues, and tax effects. The consumer surplus contains shorter travel times, more reliable travel times, loss for evicted car drivers, gain for new car drivers, congestion charges paid, and increased transit crowding. Externalities contain reduced greenhouse gas emissions, health and environmental effects, and increased traffic safety.

Al Qasr Al Ayni mathematical model is an improvement of general transhipment model, which is one of the Roads Network Design Problems (RNDP) dealing with fixed demand. Where the objective function minimize the fuel and congestion tolls costs for the travellers. The social net benefit of the flow per hour, for daily working hours from 7 am to 8 pm, is 33860 EGP. Some travellers switched from Al Qasr Al Ayni Street to use the free capacity on Nile Street. The success of the trial of Al Qasr Al Ayni Street, however, does not mean that it will succeed on all the streets of Great Cairo’s city centre, because the trial has external impacts as well. On the other hand, the success of the trial of Al Qasr Al Ayni congestion pricing system may lead to its application on some other streets in the city centre.

For further research, all the costs will be included such as emissions, all the types of road vehicles, the congestion pricing system start-up costs and operational costs. The application of the congestion pricing system will be on many streets in the city centre. The mathematical model should be Multi-Modal Network Design Problem (MMNDP) to involve more than one mean of transport.

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