Direct Costs of Urban Traffic Congestion Case Study: Main Corridors in Mansoura City

A. Shoaeb[1], S. El-Badawy[2], and A. Gabr[3]

***Abstract*—**Traffic congestion extends the travel time leading to increased cost for most people especially business men and stakeholders. More fuel is consumed, which reduces the air quality, decreases the people's health and increases the emissions. In addition, the noise level is increased due to the traffic congestion. Mansoura city is directly affected by this problem due to the large number of private cars on the streets and the lack of efficient public transportation system. The lack of parking spaces make drivers to park incorrectly on the streets or turn back, resulting in further traffic jams. This research paper focused on estimating the direct costs of the traffic congestion in Mansoura city. Field study was conducted on Mansoura city main corridors to measure the geometric design elements, traffic volume, and speeds. Traffic volume was counted over one day and the average vehicle speed was measured during free-flowing and peak periods. These measurements were used for the calculation of travel time delay cost, excess fuel consumption cost, excess emission cost and excess noise cost due to congestion. Moreover, a questionnaire was designed and handed to vehicle drivers and passengers on the studied corridor. The questionnaire focused on travel time, actual congested travel time, fuel consumption and non- recurring travel delay due to crashes and road restrictions. The annual direct traffic congestion cost was estimated to be 150.37 million Egyptian Pounds (EGP) for the studied link.

***Keywords*—**Traffic congestion, delay, direct cost, emission, noise.

I. INTRODUCTION

DOWNS [1] defined congestion as the situation when traffic is moving at speeds below the speeds at the designed capacity of a roadway. Traffic congestion is a major problem in urban arterial streets in Mansoura city, the capital of Dakahlia governorate. Mansoura city has broad land use areas which includes social, business, educational, industrial, and recreational activities that serves not only the city but the whole Delta region. These activities and the location of the city in the Delta region attract more traffic to the city. CAPMAS [2] stated that Dakahlia governorate is ranked as the fourth Egyptian governorate in number of licensed vehicles (≈398,300 vehicles). The number of licensed vehicles grows each year and cause traffic bottlenecks especially at peak periods in the main arterial streets.

Several research studies have been conducted worldwide to estimate the cost of delays due to the traffic congestion. In 2006 for greater Toronto and Hamilton area, the annual recurring and non-recurring cost was 2.25 billion Canadian $ for auto users and 337.104 million Canadian $ for transit users [3]. Hansen [4] stated that the total congestion time loss was 19 million vehicle-hours on the Dutch motorways and principal highways. El-Shourbagy and Abo-Hashema [5] measured the travel time, delay, and speed on two different arterials in Mansoura city in the morning and afternoon peaks and reported about 60% and 45% decrease in the running speed due to traffic congestion. World Bank [6] estimated the traffic congestion cost of 11 corridors in Cairo city, Egypt. The annual recurring and non-recurring cost for the 11 corridors was found to be 2.6 billion EGP. This study applied collective assessment based on the measured average peak speed, daily traffic counts and the road section length. This approach defined travel delay as the difference between the amount of time it takes to travel at average speed at peak period and at free flow speed as presented in equation 1:

[1]Demonstrator, Nile Academy for Engineering; Mansoura, Egypt.
[2]Associate Professor, Public Works Engineering Dept., Faculty of Engineering, Mansoura University, Mansoura, Egypt.
[3]Assistant Professor, Public Works Engineering Dept., Faculty of Engineering, Mansoura University, Mansoura, Egypt.

$$\text{Recurring vehicle hour delay/day} = \frac{\text{Peak period congested DVKT}}{\text{Avgerage peak period speed}} - \frac{\text{Peak period congested DVKT}}{\text{Avgerage off-peak speed}} \quad (1)$$

where, DVKT is the daily vehicle kilometer travelled at peak periods, which equals traffic volume at peak period multiplied by road length in kilometers).

Khan and Rashedul [7] calculated the travel time cost due to the congestion delays in Dhaka city, Bangladesh for working and personal trips according to the following equation:

$$TTC\ per\ day = \%W.T * (\Sigma TT * VOT * Oi * Ni) + \%N.W.T * (\Sigma TT * VOT * Oi * Ni) \quad (2)$$

where, TTC is the ravel time cost; W.T is the working trips (assumed to occur during peaks only); N.W.T is the non-working trips calculated from surveys with different values of time (VOT) for a particular vehicle type i; TT is the travel time delay, hour; O is the passenger occupancy of the vehicle i; and N is the number of vehicles.

Non-recurring delays happen due to road crashes, road maintenance, and unexpected events that cause more traffic bottlenecks and time-wasting. Chang and Xiang [8] selected some arterial roads as samples for measuring accident frequency at peak hours and free-flowing hours. They found that the average accident frequency during peak hours was higher than the accident frequency during off-peak hours on all arterials. They also observed some approximate linear relationship between accident frequency and traffic volume per lane. The accident frequency increased with the increase in number of intersections per unit length of the arterial link.

BITRE [9] selected different major urban metropolitan and non-metropolitan areas in all the states in Australia and calculated the delay costs for each vehicle type. There was slight difference in delay cost between the metropolitan and non-metropolitan areas for each vehicle type. In a complement study, Risbey et al. [10] estimated the cost of non-recurring travel delay due to accidents for 122000 reported crashes in metropolitan areas and non-metropolitan areas (freeways) in Australia in 2006 . Crash location, time of day, severity outcome and traffic flows by road type were used in the non-recurring delay estimation. The estimated cost was 792 million Australian Dollars (AUD) which was about 4.5% of total crash cost.

Vehicle operating cost is the excess fuel consumption cost and additional maintenance costs due to more depreciation at peak periods. The World Bank study [6] for Cairo, estimated the total excess gasoline and diesel consumption and excess fuel subsidy costs by about 2.85 billion EGP yearly. In another study conducted by [7], the total annual cost of burnt fuel due to congestion in Dhaka city was 178.6 million USD. According to [6], the daily fuel wasted can be estimated using equation 3 as follows:

$$Daily\ fuel\ wasted\ (litre) = \frac{DVKT}{Free\ flow\ travel\ speed} * \frac{FFS - Peak\ congested\ speed}{Avgerage\ fuel\ economy} \quad (3)$$

where, FFS is the free flow speed. The FFS term represents the desired speed of drivers in low volume conditions and in the absence of traffic control devices. Average fuel economy is the rate of consumption of fuel type during the day. The annual excess fuel cost can be calculated as daily fuel wasted multiplied by the litre cost (gasoline or diesel) multiplied by the number of working days.

Khan and Rashedul [7] estimated the excess fuel cost due to congestion using equation 4:

$$Cost\ per\ day = \Sigma(N * A * FE * FC) \quad (4)$$

where, N is the number of vehicles of a specific fuel type; A is the average run per day; FE is fuel efficiency (fuel Economy); and FC is the fuel cost.

The World Bank [6] estimated the fuel subsidy cost for both gasoline and diesel depending on wasted liters of each fuel type as described in the following equations:

$$EGS = EGW * 2.2 \quad (5)$$

$$EDS = EDW * 1.1 \quad (6)$$

In 2015, RACQ [11] found that the average repair cost for different private vehicles that passed 15,000 km annually was 8.8 cents/mile. AAA [12] studied the estimation of the average cost for owning and operating automobiles over a five-year personal use of a vehicle and 75,000-mile ownership period. The average maintenance cost included oil cost was 5.1 cents/mile based on the prices in 2013. Litman [13] concluded that the vehicle maintenance cost in Melbourne city, Australia for urban peak travel was more than the urban off-peak travel by 15%.

There are five main pollutants emit from vehicle operation. They are CO_2, CO, PM_{10}, NO, SO [14]. Ali [15] conducted a study on air-quality monitoring stations in Greater Cairo to measure pollutants such as PM_{10} in 20 stations. The term PM_{10} includes particles with a diameter of 10 micrometers or less that can be suspended in air. Ali [15] found that the concentration of PM_{10} in air ranged from 114 to 162 $\mu g/m^3$. Ibrahim [16] found that the marginal damage costs to human health of SO, NO, PM_{10}, $PM_{2.5}$ were 5446, 7261, 22102, and 34037 USD/ton, respectively. The $PM_{2.5}$ is the fine particles with a diameter of 2.5 micrometers or less. VTPI [17] stated that the marginal damage costs to human health due to CO, $PM_{2.5}$, O_3 in Vancouver BC region, Canada were 205, 317000, and 1086 Canadian$/ton, respectively. FHWA [14] suggests the following equation for the calculation of emission cost:

$$\text{Emissions Cost} = \sum(\text{VMT x Emissions Rate x Cost (\$/ton)) by Emissions Type} \quad (7)$$

where, VMT is the vehicles miles travelled representing the traffic volume at certain period multiplied by road length (mile). The emission rate is expressed in gm/mile.

The annual excess weight of carbon dioxide, CO_2 can be calculated from equation 8 as described in [6] as follows:

$$W_{CO2} = GW * 2.40 + DW * 2.41 \quad (8)$$

where, GW is the annual weight of wasted gasoline (kg); and DW is the annual weight of wasted Diesel (kg).

Thus, the total annual excess emission cost can be determined as follows:

$$C_{CO2} = W_{CO2} * U_{CO2} \quad (9)$$

where, U_{CO2} is the unit cost of CO_2, EGP, which was assumed to be 57 EGP per ton in the world bank study [6].

Noise level has direct relationship with traffic volume that increases especially at peak periods. van Essen and Sutter [18] compared between noise costs for urban roads for each transport system at day and night. They found that the noise cost was doubled at night. They also found the noise costs values for cars and heavy trucks at night were 1.39 Euro cent/km and 12.78 Euro cent/km, respectively. Maître [19] suggested yearly noise unit costs values per each person at each corresponded noise level. Reyad [20] and Reyad et al., [21] measured the noise levels in Mansoura city, Egypt by a noise level meter for four main urban arterial roads (Gehan street, Abd El-Sallam Aref, El Gesh street, El Gomhoria street). A relationship between the traffic volume, cross-section elements of road and the noise level was recommended as follows:

$$Leq = 61.54 + 0.65Q^{0.47} + 0.113W - 1.664M \quad (10)$$

where, L_{eq} is the noise level (dB); Q is the traffic volume; W is the carriageway width; and M is the median width. The coefficient of determination, R^2 was excellent of 0.89.

II. Objectives

The main objective of this paper was to estimate the total annual direct traffic congestion costs on the main corridor in Mansoura city, Egypt. These costs included recurring and non-recurring business travel time delay costs, excess fuel consumption cost, excess vehicle emission cost, noise cost, and vehicle maintenance cost.

III. Site Selection

Mansoura University introduces many services to society i.e., education, medication and consultation in different specialties. Most of the services in Mansoura city are also around the university campus, this includes, small shops, big shopping malls, social clubs and so on. Thus, University campus and its surroundings represent the central business district of the city. Most of the working trips end at Mansoura University through El Gesh, El Gomhoria, Al Mashya, and Suez canal streets, which represent the main corridors in Mansoura city. The path shown in Figure 1 [22] was chosen as a case study to investigate the traffic congestion costs for working trips. The path starts from the beginning of the Suez canal street as origin to Mansoura University as destination through El Gesh, EL Gomhoria and Al Mashaya streets with a length of 5.5 km. The reasons of that selection are due to the high volume of traffic on this link and most of transport modes (private car, taxi, micro/mini bus, light commercial vehicles and motorcycles) are flowing through this link daily. In addition, this link accommodates the traffic coming from the east direction of the city from other governorates and cities.

IV. Methodology

Figure 2 illustrates the methodology that was followed to achieve the objectives of the study. First data was collection from field and traffic survey was conducted on different drivers and passengers for different transport modes. Then direct congestion costs were estimated by different approaches based on the collected data.

V. Data Collection

Traffic questionnaire was designed and handed to various drivers and passengers in Mansoura city. The total number of surveyed persons was 613 representing a confidence level of about 95% according to the following formula [23]:

$$n = (Z^2 * p * (1-p)) / d^2 \quad (11)$$

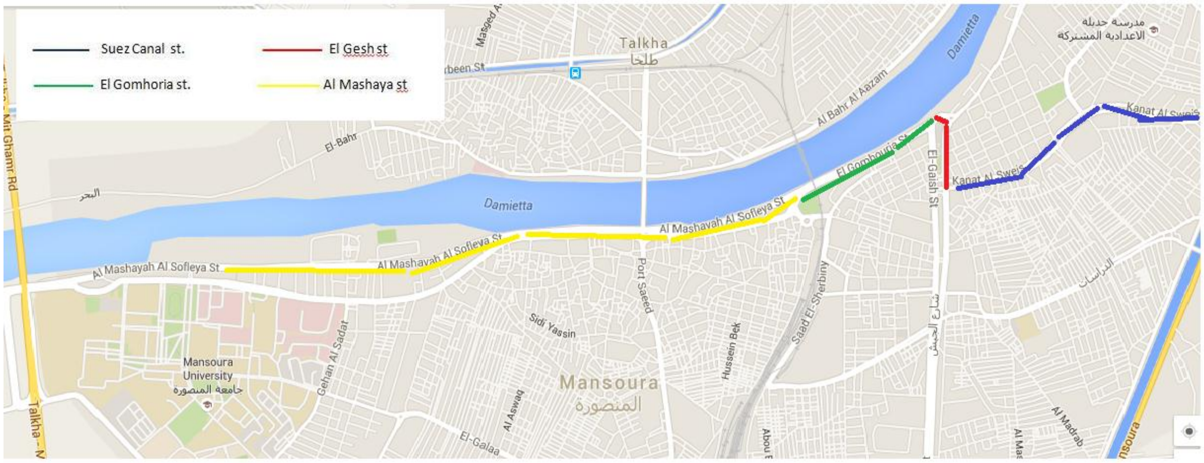

Fig. 1: The studied corridor in Mansoura city, Egypt [22]

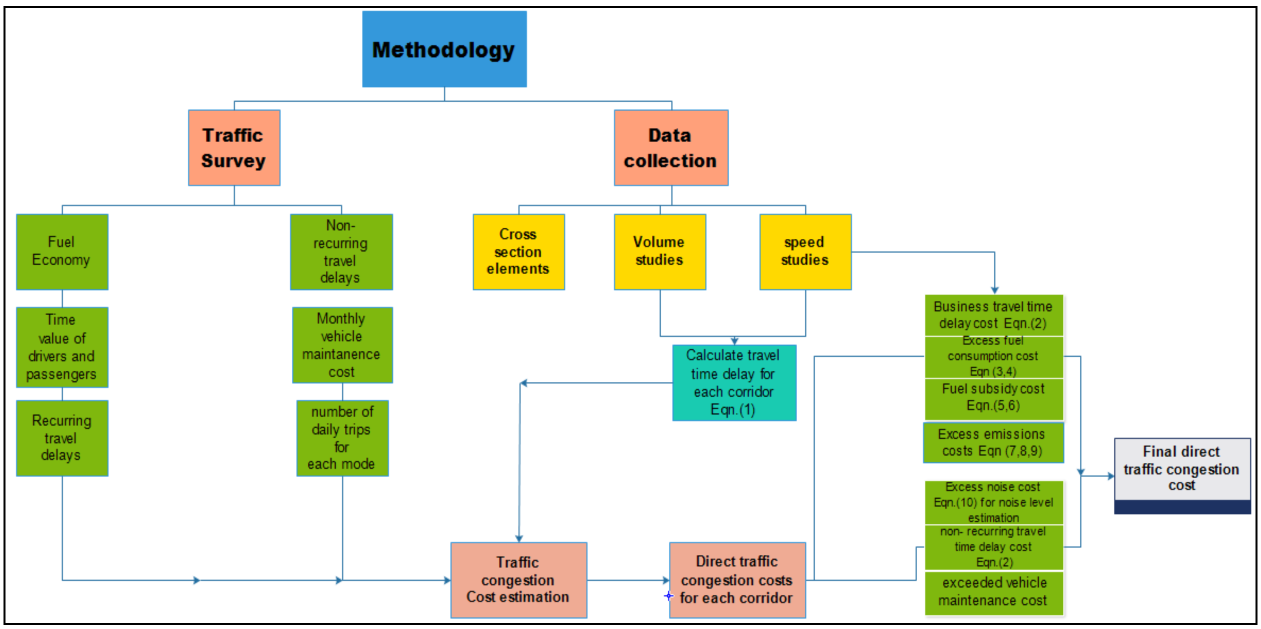

Fig. 2: Outline of the Research Methodology

where, n is the sample size; Z is the standard normal derivative value (1.96 for 95% confidence level); p is the percentage picking a choice in decimal; and d is the confidence interval in decimal.

The questionnaire was divided into five main categories as follow:

- Vehicle passenger's and driver's profession,
- Transport mode for working trips,
- The extent of suffering from traffic congestion problem and its causes on the studied link, Recurring and non-recurring delay values and the wage penalties that may be applied due to delays,
- Monthly income, number of monthly working hours and recurring travel delays for drivers and passengers,
- Vehicle operating costs from fuel consumption and vehicle maintenance.

The cross section elements of the studied road link, traffic volumes, average peak speed, and average speed at free-flowing period were collected from field measurements. Speeds measured during the peak and free-flowing periods were used further in the estimation of travel time delays and hence the calculation of excess wasted fuel consumption, and the vehicle depreciation rate that causes more maintenance and excess emissions due to traffic congestion. Tables 1 to 3 give a summary of the cross-section elements for each corridor, traffic volume, and speed measurements, respectively.

Traffic volumes were counted in the four main roads using video camera at daily peak periods (8-10) am & (2-4) pm and over 16 hours in a congested day. Based on [24], traffic density, PHF, Flow rate and road capacity were calculated for each corridor in the study area as given in table 2. Daily traffic was computed by adding all the 16 hours traffic volumes plus the 8 hours traffic volumes, which were measured as a percentage of 2 to 3% approximately of the whole day for urban routes [25]. The daily traffic was fixed over the week owing to security issues. Average speeds during peak period and free-flowing period were measured by using pavement marking method in each road corridor. Legal posted speed limit on each corridor was determined as the speed of 8 km/hr above the 85th percentile speed according to [26]. Design speeds were the speeds of (8 to 16) km/hr above legal posted speed limit based on [27]. Free flow speeds were determined in accordance with the [24] for urban multilane highway. The level of service, LOS was determined for each corridor based on the [24] and was F for all the studied corridors.

TABLE I: CROSS SECTION ELEMENTS FOR THE STUDIED ROAD LINK

Road Name	Suez Canal st.	El Gesh st.	El Gomhoria st.	Al Mashaya – Sec 1	Al Mashaya – Sec 2
Length (m)	1600	300	700	900	2000
Lane width (m)	3.75	3.65	3.5	3.75	3.75
No. of lanes/direction	2	3	2	2	3
On street parking width (m)	4	2	-	-	4
Sidewalk width (m)	1	1.5	2	1.5	1.5
Right lateral clearance (m)	2	1	0.8	1	1.5
Left lateral clearance (m)	1	1	0.8	1	1.5
Total lateral clearance (m)	3	2	1.6	2	3
Road type	Urban Major Arterial				
Median type	Raised	Raised	Raised	None	None
Median width (m)	17	30	0.6	-	-
Access points/km	6	3	1	1	5

TABLE II: DATA OF TRAFFIC VOLUME STUDIES FOR EACH SECTION

Road name	Suez canal street	El Gesh street	El Gomhoria street	Al Mashaya street	
				Section 1	Section 2
Peak hourly traffic volume, veh/hr (am)	3071	3218	3343	3515	
Peak hourly traffic volume, veh/hr (pm)	2612	3013	2471	1820	
Daily traffic (veh/day)	40067	44580	39989	30267	
Peak Hour Factor (PHF)	0.95	0.97	0.99	0.96	
Flow rate (veh/hr/ln)	1617	1106	1689	1831	1221
Road density (veh/km/ln)	108	79	77	129	153
Spacing /lane (metre)	9.25	12.65	12.98	7.75	6.53
Road capacity (veh/hr/ ln/dir)	1486	1534	1602	1452	1447

TABLE III: SUMMARY OF SPEED MEASUREMENTS

Road name	Suez canal	El Gesh	El Gomhoria	Al Mashaya- sec (1)	Al Mashaya- Sec (2)
Average peak speed (km/hr)	15	14.1	22	14.2	8
85th percentile off-peak speed (km/hr)	20	24	32	22	20
Design speed (km/hr)	40	45	50	40	40
Posted limit speed (km/hr)	30	35	40	30	30
BFFS (km/hr)	41.2	46.2	51.2	41.2	41.2
FFS (km/hr)	39.1	43	48.5	36.4	36
Space mean speed (km/hr)	5.3	6.2	8.5	6	5

VI. RESULTS AND DISCUSSION

By using the speed plot method conducted by [6] as presented previously in equation 1, recurring travel time delay can be calculated for each corridor as given in Table 4.

TABLE IV: CALCULATED RECURRING BUSINESS TRAVEL TIME DELAY FOR EACH CORRIDOR

Road name	Suez canal	El Gesh	El Gomhoria	Al Mashaya-Sec (1)	Al Mashaya- Sec (2)
Travel time delay (minutes/ trip)	1.49	0.48	0.51	1.2	8.5

Regression analyses were performed on the actual travel time data during congestion and the target (expected) travel time that should be taken outside the congestion periods. The data of the actual time and target time were estimated from the questionnaires for all users (passengers or drivers) using different transport modes on the studied link. Figure 3 exemplifies the relationship between the two times for the studied link for mini-bus users showing a good accuracy in terms of coefficient of determination, R^2 of 0.83 between the two times. Table 5 gives a summary of the relationships between the two times for the other transport modes. In this table Y represents the actual travel time in minutes while x represents the target time in minutes.

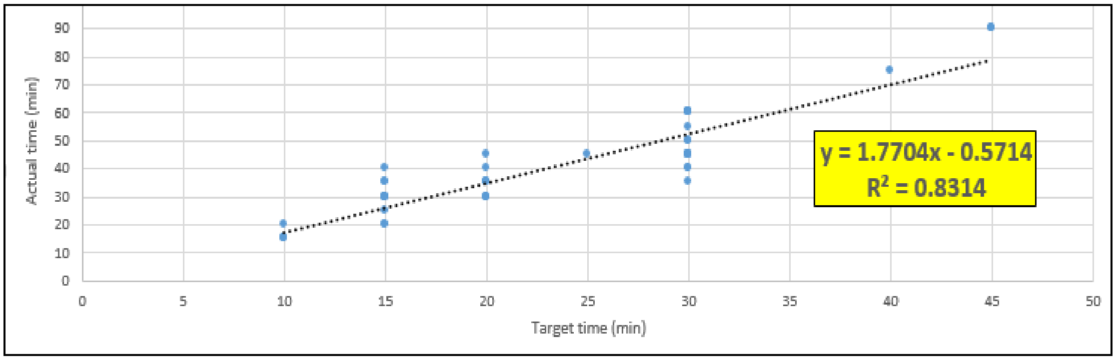

Fig. 3: Relationship between target time and actual time for mini-bus users

TABLE V: SUMMARY OF THE RELATIONSHIPS BETWEEN THE TRAVEL TIME AND ACTUAL TIME FOR DIFFERENT USERS

User	Equation	R^2
Private car users	$y= -0.003x^3 + 0.101x^2 + 1.22x -1.967$	0.71
Microbus users	y= 1.31x + 18.34	0.63
Minibus users	y= 1.77x - 0.57	0.83
Taxi users	y= 2.08x – 1.36	0.71
Light commercial vehicles users	y= 1.31x + 13.79	0.73

The non-recurring travel time delays due to crashes, unexpected events…etc, were computed from the conducted traffic questionnaires for each transport mode. The non-recurring travel time delays were found to be 7, 9.6, 9.1, 8.9 and 5 minutes for taxi, mini-bus, microbus, light commercial vehicles and private cars, respectively. Due to the lack of crash data, equation 2 was used to determine the non-recurring travel time delay cost in a similar way to the calculation of recurring travel time delay cost. The total estimated annual non-recurring travel time delay costs were 6.96, 11.44, 9.72, and 7.64 million EGP for Suez canal street, El Gesh street, El Gomhoria street, and Al Mashaya street, respectively.

Based on the traffic questionnaires, the fuel economy was estimated for gasoline, diesel and natural gas and found to be 0.123, 0.122 litre/km and 0.113 m^3/km, respectively. The annual excess fuel consumption cost was then calculated for each fuel type using equations 3 [6] and 4 [7] and given in Table 6.

TABLE VI: ESTIMATION OF ANNUAL EXCESS FUEL CONSUMPTION COST BASED ON EQUATIONS 3 AND 4

Fuel type	Equation 3 [6] (million EGP/year)	Equation 4 [7] (million EGP/year)
Gasoline	1.76	1.20
Diesel	0.60	0.41
Natural Gas	0.11	0.07

It can be seen from the table that the estimation of annual excess fuel consumption cost based on equation 3 was significantly higher than that obtained from equation 4.The calculated annual excess fuel consumption costs were 0.748, 0.167, 0.297, and 1.27 million EGP for Suez canal, El Gesh, El Gomhoria, and Al Mashaya streets, respectively.

Using equations 5 and 6 [6], the annual fuel subsidy costs were calculated for gasoline and diesel for each corridor. The annual fuel subsidy cost values were 0.54, 0.12, 0.21, and 0.93 million EGP for Suez canal, El Gesh, El Gomhoria, and Al Mashaya streets, respectively.

Costs of emissions due to traffic congestion i.e., Co_2, CO, NO, SO, and PM_{10} were calculated for each corridor as given in Table 7. The Co_2 emissions cost was estimated based on equations 8 and 9 [6], while the other pollutants costs, CO, NO, SO, PM_{10} were estimated according to the emission rates using equation 7 [14].

TABLE VII: POLLUTANTS COST DUE TO CONGESTION FOR THE STUDIED ROADS (EGP/YEAR)

Road name	CO	NO	SO	PM_{10}
Suez Canal street	1404	745	1.23	341.36
El Gesh street	406	142	0.02	27.1
El Gomhoria street	652	203	10.6	135.9
Al Mashaya street	1650	783	0.72	471.5

According to Equation 10 [20], the noise levels for each corridor at both peak and free-flowing periods were estimated as shown in Figure 4. By knowing the noise level, the unit cost of noise can be determined according to [19] and hence the noise costs can be calculated. The annual noise costs were found to be 0.234, 1.258, 0.309, 0.255 million EGP for Suez canal, El Gesh, El Gomhoria, and Al Mashaya streets, respectively.

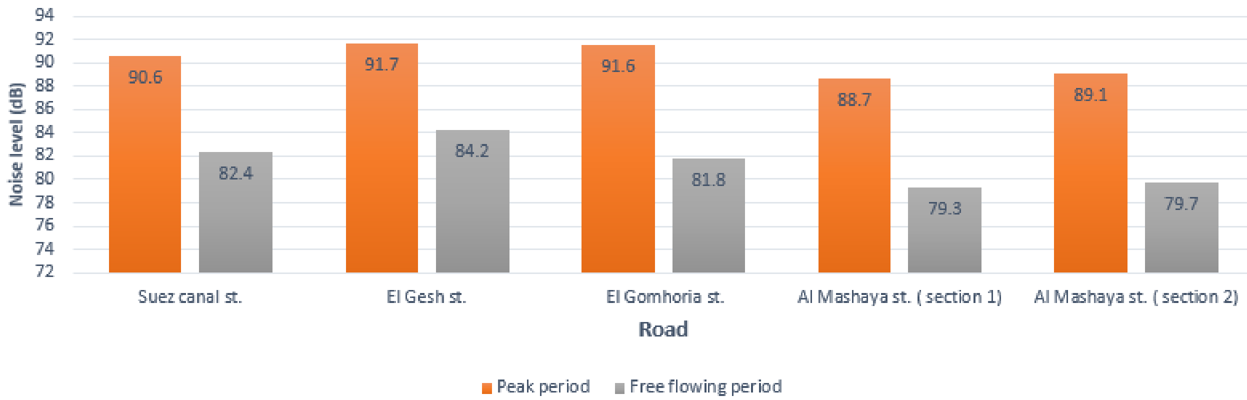

Fig. 4: Estimated noise levels at peak periods and free- flowing periods for each corridor using Equation 10

Table 8 gives a summary of the estimated direct costs due to traffic congestion for each corridor. It can be seen from the table that the total annual direct congestion cost was about 150.4 million EGP for all corridors. The annual cost of delays including recurring, and non-recurring travel time delays were about 61% of the total direct cost. This is because traffic volume had the most significant contribution to delays cost in particular the volumes of taxis, the speeds at peak period were very low of about 8 km/hr and the delay value was about 8 minutes per trip per vehicle. Regardless the largest road width of Al Mashaya corridor, it was observed that it had the highest total annual cost owing to the high traffic volume, illegal stops of microbuses and bad behavior of some drivers. Vehicle operating costs for microbuses and minibuses were higher compared with other transport modes due to the higher daily number of trips. Consequently, the annual maintenance costs ranked in second position after delays costs with a 34.3% of the annual total direct cost. It is expected that the annual total cost due to traffic congestion for all Mansoura city will surpass a billion EGP/year, which needs further research in the future.

TABLE VIII: TOTAL DIRECT CONGESTION COSTS FOR THE STUDIED LINK (MILLION EGP/YEAR)

Road name	Suez Canal St.	El Gesh St.	El Gomhoria St.	Al Mashaya St.
Recurring travel time delay cost	6.86	3.10	2.91	43.26
Non- recurring travel time delay cost	6.962	11.437	9.715	7.641
Excess fuel consumption cost	0.748	0.167	0.297	1.270
Vehicle maintenance cost	12.4	14.7	14.0	10.5
Fuel subsidy cost	0.547	0.122	0.216	0.935
Excess Emission cost	0.0334	0.0082	0.0137	0.0606
Noise cost	0.234	1.258	0.309	0.255
Sum of average direct congestion cost	28.07	31.1	27.32	63.88
Total average traffic congestion cost				150.37

VII. SUMMARY AND CONCLUSIONS

A total of 613 drivers and passengers were interviewed to answer questions about travel time, actual congested travel time, fuel consumption, and non-recurring travel time due to crashes. Field data were collected on geometric design elements, traffic volumes, and traffic speeds during peaks and off-peaks were conducted. The costs of recurring and non-recurring travel time delay, excess fuel consumption, vehicle maintenance, fuel subsidy, excess emission and noise were estimated. Based on the results and analyses of this research the following conclusions are drawn:

- The highest cost was due to recurring, and non-recurring delays with a value of 61% of the total annual direct cost. Traffic volumes and value of time showed the most impact on the delays costs.
- Illegal stops of some transport modes and bad behavior of drivers increased the bottlenecks and subsequently increased the cost and that was clear from the highest cost of Al Mashaya corridor.

The annual maintenance costs were about 34% of the total annual direct cost due to the high cost of vehicle operating in particular microbuses and minibuses

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