

ECONOMIC IMPACT OF URBAN TRAFFIC CONGESTION ON THE MAIN ROUTES IN MANSOURA CITY, EGYPT

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Abstract: Traffic congestion is a major problem in most of the large Egyptian cities. This research paper focused on estimating the economic impact of the traffic congestion in Mansoura city. A traffic questionnaire was formulated and handed to various vehicle drivers and passengers. The questionnaire inquired about ideal travel time, actual travel time for each mode of transport, fuel consumption, non-recurring travel delay due to crashes and road restrictions, percentage of injured people due to road congestion accidents, and traffic offenses due to traffic congestion pressure. A field study was also conducted on some of the main arterials in the city (Suez canal street, El-Gesh street, El-Gomhoria street and Al-Mashaya street) to measure the geometric design elements, traffic volume, and speeds. Traffic volume was counted over 16 hours in a working day and the average vehicle operating speed was measured during free-flowing and peak periods. These measurements were used in the calculation of travel time delay cost, excess fuel consumption cost, and excess emissions cost due to congestion. Results showed that traffic congestion on the studied links costs about 184.5 million Egyptian Pounds (EGP) annually. This result shows that the chronic congestion problem in the city not only influence the daily life of the people but also drastically affects the economy of the country.

Keywords: traffic congestion, Mansoura, delay, cost, travel time, transport mode.

1. Introduction

Traffic congestion is a major problem in Mansoura city, the capital of Al-Dakahlia governorate. Mansoura with an area of 371 km² is located about 120 km northeast of Cairo on the east bank of the Damietta branch of the Nile in the Delta region. Approximately 480,500 capita live in the city (CAPMAS, 2015; Shoaeb et al., 2016). The city hosts Mansoura University with its educational/research institutions and hospitals, which attracts more than 150,000 students/employees/patients daily. In

addition to the educational and medical services, Mansoura city introduces social, business, and recreational activities to the society in the Nile Delta region. These activities and the distinctive location of the city in the Delta region bring more traffic pressure in most days over the year. CAPMAS (2015) reported that Al-Dakahlia governorate is the fourth Egyptian governorate in the number of licensed vehicles ($\approx 421,748$ vehicles) and grows each year which causes traffic congestions especially at peak periods in the main arterial streets.

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2. Literature Review

During the morning, there are much stress on passengers going to work due to delays caused by traffic congestion. In addition, the afternoon rush hour is again a frustrating time because the workday is done and people want to get home for relaxation. Downs (2004) and Weisbrod and Reno (2009) defined congestion as the situation when traffic is moving at speeds below the speeds at designed capacity of a roadway, and hence the number of vehicles trying to use the road exceeds the traffic network capacity. El-Shourbagy and Abo-Hashema (2000) measured the travel time, delay, and speed on two different arterials in Mansoura city by field trips at the morning and afternoon peaks. They found that the running speed decreased due to traffic congestion by 60% and 45% for the different arterials. Hansen (2001) stated that the total congestion time loss on Dutch motorways and principal highways was 19 million vehicle-hours.

Traffic congestion increases travel time and consequently the cost due to delays increases for different transport modes. These delays are divided into two main categories, the first is the recurring (daily or usual) travel time delay, which is defined as the amount of extra time spent traveling when traffic volume exceeds road capacity at a particular location during a predictable and repeated time of day. The second is the non-recurring delay which is defined as the delay due to unexpected events such as road maintenance, accidents and bad behavior of road drivers. The associated costs due to the two main traffic delay categories are illustrated in the subsequent sections.

2.1. Travel Time Delay Costs

World Bank (2010) estimated the traffic congestion cost on 11 corridors in Cairo city (over 15 million people). The annual recurring and non-recurring cost for the 11 corridors was 2.6 billion Egyptian Pounds (EGP). For greater Toronto and Hamilton area with a total population of over 6 million people, these costs were found, in 2006, to be 2.25 billion Canadian \$ for auto users and 337.104 million Canadian \$ for transit users (GTTA, 2008). Chang and Xiang (2003) selected some arterial roads for measuring accident frequency at peak and free-flowing hours. They found that the average accident frequency during peak hours was higher than that during off-peak hours on all sample arterials. An increase of accident frequency is associated with increase of non-recurring travel time delay, and hence an increase of overall travel time delay cost. BITRE (2009) selected different major urban metropolitan and non-metropolitan areas in all states in Australia and calculated the delay costs for different transport modes. In a complement study to BITRE (2009), Risbey et al. (2010) estimated the cost of non-recurring travel delay due to accidents for 122,000 reported crashes in 2006 in metropolitan areas and freeway crashes in non-metropolitan areas in Australia. Crash location, time of day, severity outcome and traffic flows by road type were used for the non-recurring delay estimation. The estimated cost was 792 million Australian \$, which was about 4.5% of the crash cost.

2.2. Vehicle Operating Cost due to Delays

As traffic congestion occurs on roads, more fuel is being consumed. This wasted quantity of fuel leads to extra

costs. Additionally, vehicle maintenance costs increase due to more depreciation, which also occurs at peak periods (World Bank, 2010). TAG (2014) concluded that at low speeds (during peak periods) the fuel consumption increased to about 15 liters/100 km travelled and reduced gradually with increase of speed. The World Bank (2010) study on Cairo's 11 corridors, estimated the total excess gasoline, diesel consumption and excess fuel subsidy costs to be 2.85 billion EGP yearly. In another study conducted by (Khan and Islam, 2013), the total annual cost of burnt fuel due to congestion in Dhaka city was estimated to be 178.6 million US Dollars (USD). Barnes and Langworthy (2003) estimated the maintenance cost for the new brands of passenger cars, light, and commercial trucks based on five-year life-cycle costs. They used the available data from the manufacturers' recommended maintenance schedule, national labor-rate averages, and manufacturers suggested list price for spare parts. They found that the maintenance cost values were 0.17, 0.22, and 0.49 USD per mile for passenger cars, light trucks and trucks, respectively. RACQ (2015) found that the average repair cost for different private vehicles that passed 15,000 km annually was 8.8 cents/mile. AAA (2015) estimated the average cost for owning and operating automobiles over a five-year personal use of a vehicle or 75,000-mile ownership period. The average maintenance cost included oil cost was 5.1 cents/mile based on the prices in 2013. Litman (2013) concluded that the vehicle maintenance cost in Melbourne city, Australia for urban peak travel was 15% more than the urban off-peak travel.

2.3. Excess Emission Cost due to Traffic Delay

There are five main pollutants emitted from vehicle operations such as carbon dioxide (CO_2), carbon monoxide (CO), PM_{10} ; particles with a diameter of 10 micrometers or less that can be suspended in air, nitrogen dioxide (NO) and sulfur dioxide (SO) (Mallela and Sadasivam, 2011). Ali (2010) conducted a study on 20 air-quality monitoring stations in Greater Cairo to measure pollutants such as PM_{10} . He found that the concentration of PM_{10} in air ranged from 114 to 162 $\mu\text{g}/\text{m}^3$. Ibrahiem (2015) found that the marginal damage costs to human health because of SO, NO, PM_{10} , and $\text{PM}_{2.5}$ (fine particles with a diameter of 2.5 micrometers or less) pollutants were 5446, 7261, 22102, and 34037 USD/ton, respectively. RWDI (2006) estimated the marginal damage costs to human health due to CO, $\text{PM}_{2.5}$, and O_3 in Vancouver BC region, Canada to be 205, 317000, and 1086 Canadian\$/ton, respectively. Mallela and Sadasivam (2011) adopted the EMFAC (EMission FACTors) model that was developed by the California Air Resource Board (CARB) to estimate the emission rates in gm/mile for most pollutants (CO, SO, NO, Vehicle Operating Cost (VOC), PM_{10}) generated in California from auto and trucks based on the vehicle average speed.

2.4. Traffic Offenses Cost

TAC (2014) conducted a study on congestion cost related offenses in Hong Kong. Authorities applied fixed penalty charges that were set at 320 USD or 450 USD for illegal parking, loading and unloading of

goods or picking up passengers in restricted zones. When there are traffic jams or lack of parking spots, drivers in Egypt, commit more traffic offenses due to congestion. The new Egyptian traffic rules that were released by (The Parliament, 2008) regulate the misbehavior of drivers by applying an offense of at least 1000 EGP and 200 EGP to whoever drives in opposite direction and parks illegally.

2.5. Waiting Time Delay Cost

Waiting and transferring are perceived more burdensome than travelling. Indeed, out-of-vehicle times appear longer than in-vehicle time (IVT). Wardman (2004) conducted a study on waiting time effect and found that trip length and trip purpose affect waiting time values. Wait time value increases slightly with trip duration for transit walk and wait and appears longer for cars than other transit riders. Waiting time was estimated to be about 2.5 times the value of IVT during congestion. Lagune-Reutler et al. (2016) conducted a questionnaire with 822 responses regarding observed wait times in urban study area. Approximately half of respondents actually waited less than 5 minutes, a third waited between 5 and 10 minutes, 8% waited between 10 and 15 minutes, and the rest waited between 15 and 30 minutes.

3. Objectives

The main objective of this study is to estimate the total (direct and indirect) annual traffic congestion costs on the main urban corridors in Mansoura city, Egypt for home based work (HBW) trips. A secondary aim was to suggest recommendations to Dakahlia governorate on the short and

long-terms for diminishing the economic impact of traffic congestion in Mansoura city. The direct costs are related to travel time delays such as traffic delays cost, excess fuel consumption cost, excess emissions cost due to traffic congestion. The indirect traffic congestion costs are associated to road safety, health and environmental impacts as vehicle maintenance cost, lost productivity of injured people due to traffic congestion crashes, waiting delay time cost and traffic offenses cost.

4. Site Selection

Mansoura University introduces many services to society in different fields. Thus, the campus and its surrounding area are considered the main traffic generators in the city. Most of the work/education trips end at Mansoura University through El-Gesh, El-Gomhoria, Al-Mashya, and Suez Canal streets, which represent the main corridors in Mansoura city. Therefore, this path (from Gedella to Mansoura University) as shown in Fig. 1 was chosen as a case study, since it accommodates a great deal of attraction for the HBW trips in Mansoura. The investigated path starts from Suez Canal street as origin to Mansoura University as destination through El-Gesh, El-Gomhoria and Al-Mashaya streets with a total length of about 5.5 km. This link has a very high volume of traffic, and different transport modes (private cars, taxis, micro/mini buses, light commercial vehicles and motorcycles). In addition, this link accommodates traffic coming from the east direction of the city from other governorates. The opposite direction from Mansoura University to Gedelya represents the work-home trips, which are not studied in this research study.

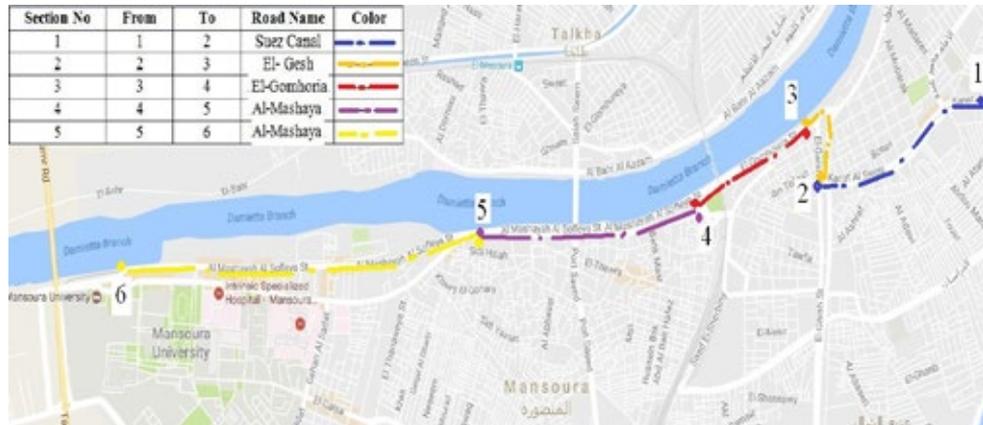


Fig. 1.
Study Area and Corridors
Source: (Google maps)

5. Research Methodology

Fig. 2 illustrates the methodology followed in this study. The work plan was divided into three main parts:

First part describes the traffic questionnaire conducted on road users (drivers and passengers) within the study area to determine Value Of Time (VOT) of each road user, delays at the same locations during congestion, delays due to unexpected events, fuel economy of each fuel type used by vehicles, average monthly maintenance cost of vehicles, percentage of drivers committing traffic offenses at peak periods, and percentage of injured people due to traffic congestion crashes and its corresponding injury level. Second part refers to the collected data for the studied corridors such as cross section elements, traffic volumes at morning and afternoon peaks, traffic flow characteristics at each period, average speed at peak and off-peak periods, the 85th percentile speed and hence free-flow speed at each studied corridor.

6. Data Collection

Traffic questionnaire was designed in Arabic language and delivered to various drivers and passengers in Mansoura city to collect data needed to achieve the study objectives. The questionnaire forms were handed during the 2015/2016 academic year between September and December, since traffic congestion increases during the academic season. The questionnaire forms were distributed during working hours at stations around studied path. Some forms were posted online using Google forms. The total number of surveyed persons was 613 representing a confidence level of about 95% according to the formula found in (Bartlett et al., 2001) Eq. (1):

$$n = (Z^2 * p * (1 - p)) / d^2 \tag{1}$$

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 sections as follows:

- First section refers to general introduction about passenger and driver profession, and transport mode to work.
- Second section covers the extent of suffering from the traffic congestion problem and its causes on the studied path. It also inquiries about the recurring and non-recurring delays, average waiting times and applied penalties on salary due to delays to work
- Third section evaluates the monthly income, monthly working hours, and recurring travel delays to calculate time value for different drivers and passengers
- Fourth section includes vehicle operating costs such as fuel consumption and maintenance
- Fifth section asks about accident rates, causes, collision types, and traffic offenses that may be applied due to congestion. It also covers the injured people due to traffic accidents and the corresponding injury level

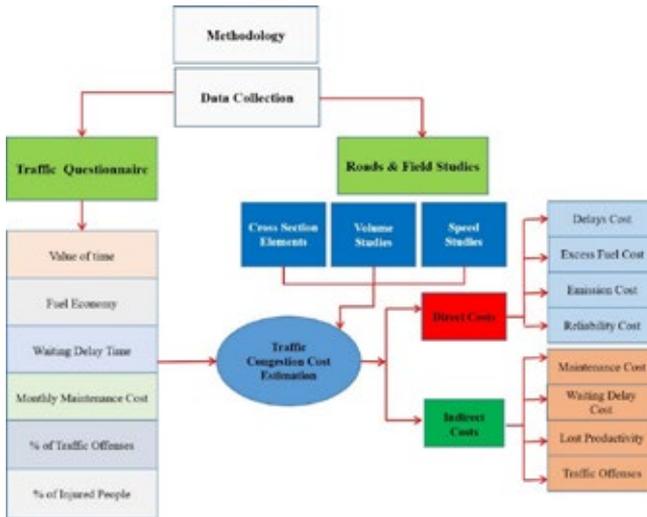


Fig. 2.
Research Methodology Flow Chart

It was also important to collect field data regarding the cross section elements of the studied corridors, traffic volumes, average peak speed, and average speed at free-flowing periods. Traffic volume counts were conducted on the four main links over 16 hours in an ordinary day using a video camera. Average speeds were measured during peak and free-flowing periods using

the pavement marking (Manual method) for each road corridor (HCM, 2010). Two lines 33 meters apart were marked on the surface of the pavement and the elapsed time by each vehicle to cross the two marks was measured using a stopwatch (pen and paper technique), and hence the travel speed was estimated. The legal speed limit on each corridor was determined as the speed of 8 km/hr

above the 85th percentile speed according to Forbes, (2012). Design speeds are the speeds of (8 to 16) km/hr above legal speed limit based on NCHRP (2003). Measurements of speeds during the peak and free-flowing periods were used further in estimating traffic congestion costs. The floating car technique (average 10 runs for each corridor) was used on all sections to determine travel time at peak and free-flowing periods as well as estimate the travel time reliability and scheduling. Reliability of travel time is the standard deviation of the travel time divided by the average travel time (AustRoads, 2016). While, scheduling is defined as the 90th percentile travel time divided by the average travel time (AustRoads, 2016).

7. Results and Analysis

The questionnaire discussed three types of delays as follows:

- Recurring or systematic delays of working trips which vary between transport modes. As shown in Fig. 3, the minibuses had the maximum recurring delay (about 23 min./trip/day) due to systematic stops, large number of passengers, and minibuses' drivers bad

driving behavior. In average, recurring delay for other transport modes was about 16 min./trip/day as shown in Fig. 3. The symbol (I) in the Figure represent the standard deviation of delay time

- Average non-recurring travel delay time due to unexpected events ranged between 7 and 10 minutes for different transport modes
- Passenger responses related to waiting delay time showed that 45.5% of road passengers waited at stations during peak periods for 5 to 15 minutes, 20.2% of passengers waited about 16 to 25 minutes, 5.8% of passengers waited for 26 to 35 minutes, 7.5% of passengers waited for more than 35 minutes, and only 12.7% of passengers waited less than 5 minutes

Table 1 presents the data of the cross-section elements for each corridor, traffic volume, and speed. Based on HCM (2010), traffic density, Peak Hour Factor (PHF), flow rate and level of service (LOS) were calculated for each studied section. Daily traffic was computed by adding all the 16 hours traffic volumes plus the 8 hours traffic volumes, which were assumed to be about 2 to 3% of the whole day for urban routes (FHWA, 2014).

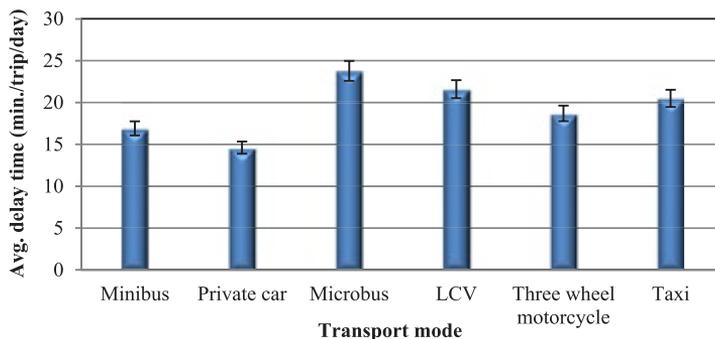


Fig. 3. Observed Average Recurring Travel Time Delay for Each Transport Mode

Table 1
Data of the Field Study for Each Corridor

Property	Suez Canal st.	El-Gesh st.	El-Gomhoria st.	Al-Mashaya	
				Sec. 1	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
Right lateral clearance (m)	2	1	0.8	1	1.5
Left lateral clearance (m)	1	1	0.8	1	1.5
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
Peak traffic volume, veh/hr	3071	3218	3343	3515	
Daily traffic (veh/day)	40067	44580	39989	30267	
Peak hour factor	0.95	0.97	0.99	0.96	
Peak flow rate (pcu/hr)	3233	3318	3377	3661	
Road density (pcu/km/ln)	41.4	25.7	34.8	50.3	33.9
Average speed (km/hr)	14.5	14.1	22	14.2	8
off-peak 85 th percentile speed (km/hr)	20	24	32	22	20
Design speed (km/hr)	40	45	50	40	40
Speed limit (km/hr)	30	35	40	30	30
Base free flow speed (km/hr)	41.2	46.2	51.2	41.2	41.2
Free flow speed (km/hr)	39.1	43	48.5	36.4	36

Fig. 4 presents an example of the 15-minute traffic flow rate for each vehicle class at morning peak on Suez Canal street. Looking at Table 1, flow rate was calculated based on HCM (2010) by dividing the observed traffic volume at peak period over the corresponding PHF for each section. Density was calculated by dividing the flow rate over corresponding average travel speed. The LOS was determined for each corridor based on the HCM (2010) according to the average travel speed and density values, which was found to be “F” for all corridors. This was due to the high traffic density values on all studied corridors and the unstable and variable flow rate. As given in Table 1, average travel speed was found to be 14.5 km/hr, 14.1 km/hr, 22 km/hr, 14.2 km/hr and 8 km/hr for Suez Canal street, El-Gesh, El-Gomhoria, Al-Mashaya Sec. (1) and

Al-Mashaya Sec. (2), respectively. FFSs were determined in accordance with the HCM (2010) for urban multilane highways. Furthermore as seen in Fig. 4, passenger cars represent more than 60% of the traffic volume, followed by taxis, which represent more than 20% of the traffic volume at peak periods on Suez Canal street. Microbuses and minibuses have 6% to 9% of the traffic volume at daily peak periods. Three wheel motorcycle represented about 7% of traffic volume and light commercial vehicles have the least percentage (4%). Thus, private cars and taxis had high impact on congestion costs due to their high percentages and the corresponding high daily working trips especially at rush hours. This also indicates the poor public transportation system in the city and the high dependency on private cars and taxis, which contribute more to the congestion problem in the city.

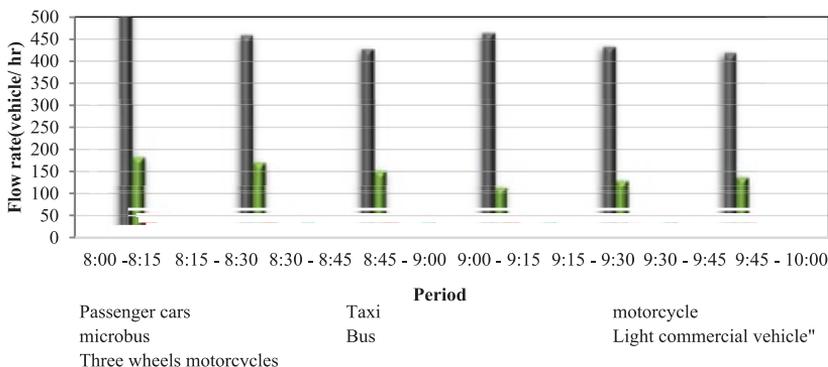


Fig. 4. Flow Rate by Vehicle Class on Suez Canal Street at (8-10) AM

7.1. Direct Congestion Costs

Measurements of traffic volumes, speeds, and the geometry of the cross-section as well as the questionnaire results were employed to estimate the direct congestion costs for the path from Gedyla to Mansoura University. These costs include costs of recurring and non-recurring travel time delay, vehicle operation, fuel consumption, and excess emission. The following sections present the approaches used to estimate these costs based on the collected data for the studied path.

7.1.1. Working-Trips Recurring and Non-Recurring Travel Time Delay Costs

By knowing the monthly income and number of working hours per month from the traffic questionnaire, the VOT for passengers and drivers using different transport modes was calculated.

Fig. 5 shows the calculated VOT for both drivers and passengers for each transport mode. The symbol (I) in the Figure represent the standard deviation of VOT values.

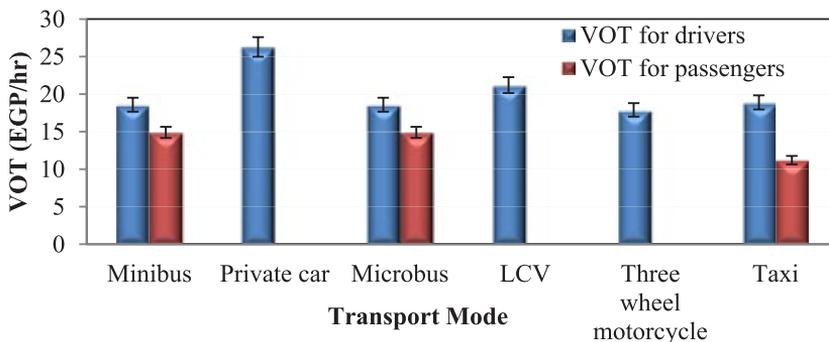


Fig. 5. VOT for Passengers and Drivers of Each Transport Mode

It can be seen from Fig. 5 that the average hourly VOT for each passenger and driver per each transport mode was within the range of 15 to 25 EGP/hr. The highest value of time was for private car owners due to their high level of income (27 EGP/

hr in average). CAPMAS (2015), reported the average VOT for public and private employees as 14.1 EGP/hr in Egypt. Eq. (2) (World Bank, 2010) was used to calculate the recurring business travel time delay as follows:

$$\text{Recurring vehicle hour delay/day} = \frac{\text{Peak period congested DVKT}}{\text{Average peak period speed}} - \frac{\text{Peak period congested DVKT}}{\text{Average off - peak speed}} \quad (2)$$

Where; DVKT: daily vehicle kilometer travelled at peak periods, which equals traffic volume at peak period multiplied by road length in kilometers.

Recurring travel time delay values were found to be 1.49, 0.48, 0.51, 1.2, 8.5 minutes/trip for Suez canal st., El-Gesh st., El-Gomhoria, Al-Mashaya (sec. 1) and Al-Mashaya (sec. 2), respectively. Average number of working trips per one work shift was estimated based on the questionnaire results by calculating the number of daily working hours and trip time (at peak and free-flowing periods) for each driver of microbus, minibus and taxi. Microbus and minibus are using specific path, which is the studied link, while taxis

make trips all over the city. Therefore, a specific question was asked to taxi drivers about how many trips they make on the studied link to determine the number of trips per day. The average number of working trips were found to be 22, 22, 8, and 71 trip per day for minibus, microbus, taxi, and three-wheel motorcycle, respectively assuming two work shifts per day. The number of trips for the three-wheel motorcycle was higher than other transport modes because three-wheel motorcycle drivers makes only short trips on Suez Canal street. Fig. 6 presents the expected recurring travel time delay cost due to congestion using Eq. (3) (Khan and Islam, 2013) for each section and each transport mode.

$$\text{TTC per day} = \% W.T * (\sum TT * VOT * O_i * N_i) + \% N.W.T * (\sum TT * VOT * O_i * N_i) \quad (3)$$

Where; TTC: travel 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 VOT for a particular vehicle type, i; TT travel time delay, hr; O is the passenger occupancy of the vehicle, i and N is the number of vehicles, i.

That cost was estimated based on the conducted field measurements, traffic composition for each corridor, VOT for each transport mode, and the calculated

travel time delay from Eq. (2). This cost was calculated for each mode by multiplying the DVKT at peak periods per day by the percentage of each transport mode by the VOT for transport users (drivers or passengers) by the number of daily work trips for each mode on the studied section over 250 days per year. Both taxi and private car modes showed the highest delay cost, respectively due to the highest number of taxi and private cars, their relatively high VOT. Al-Mashaya corridor had the highest

annual travel time delay cost with a value of about 43.2 million EGP due to the higher value of delay time. The delay costs for the three wheel motorcycle and LCV were very low compared to cost values of other

transport modes as most drivers of three wheel motorcycles take illegal paths during peak periods. The total annual recurring delay cost for all corridors was about 56.2 million EGP.

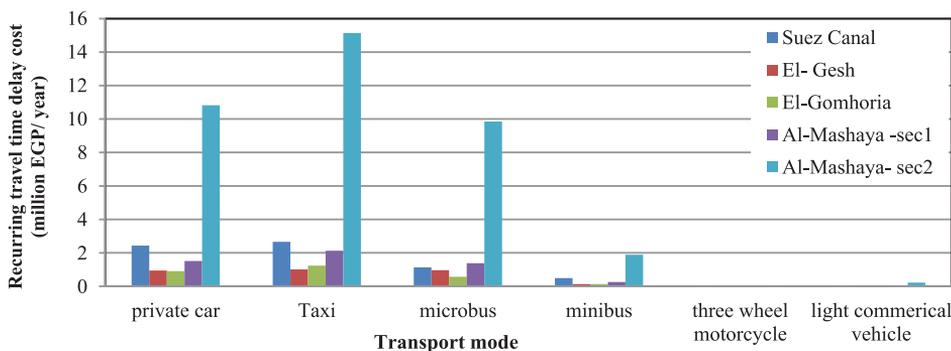


Fig. 6. Recurring Travel Time Delay Cost for All Transport Modes for Each Corridor

The non-recurring travel time delays due to crashes, and unexpected events were computed from the conducted traffic questionnaire 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, minibus, microbus, light commercial vehicles and private cars, respectively. Due to the lack of data on crash locations, times, and severity outcomes, Eq. (3) 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 st., El-Gesh st., El-Gomhoria st, and Al-Mashaya st., respectively.

7.1.2. Reliability Cost

Reliability is a variation around trip travel time at peak period whether one arrives early

or late (World Bank, 2010). World Bank (2013) assumed a monetization factor that is used for converting variation of travel time at peak periods to equivalent value of travel time. This factor varies according to transport mode as follows:

- Passenger cars and motorcycles: 1.0-minute travel time variation is equivalent to 0.9 minute in travel time.
- Public transport including taxis: 1.0-minute travel time variation is equivalent to 1.1 minutes in travel time.

Eq. (4) was used to calculate the economic cost of reliability using the average peak-speed and the volume of vehicles at peak periods (World Bank, 2013). The annual reliability cost was calculated for each studied corridor at peak periods, which were 2.73, 1.64, 2.96, and 6.57 million EGP for Suez canal, El-Gesh, El-Gomhoria and Al-Mashaya streets, respectively.

$$\text{Reliability cost} = \text{Monetization factor} * \text{Coefficient of variation} * \frac{\text{Length of corridor}}{\text{average peak speed}} * \text{vehicle occupancy} * \text{VOT} * 250 \text{ working days} * \text{volume of vehicles at peak period} \quad (4)$$

7.1.3. Excess Fuel Consumption Cost

Based on the traffic questionnaire, the fuel consumption rate was estimated for gasoline, diesel and natural gas and found

to be 0.123, 0.122 liter/km and 0.113 m³/km, respectively. The annual excess fuel consumption was then calculated for each fuel type using Eq. (5) (World Bank, 2010) as follows:

$$\text{Daily fuel wasted (liter)} = \frac{DVKT}{\text{Free flow travel speed}} * \frac{FFS - \text{Peak congested speed}}{\text{Average fuel economy}} \quad (5)$$

Where, FFS is the free flow speed that represents the desired speed of drivers in low volume conditions and in the absence of traffic control devices; Average fuel economy represents the rate of consumption of fuel type during the day.

The annual excess fuel cost can then be calculated for each kind of fuel as the daily fuel wasted multiplied by liter cost (gasoline or diesel) multiplied by number of working days. The estimated total annual excess fuel consumption costs from Eq. (5) based on the fuel prices in 2017 were 1.76, 0.6, and 0.11 for gasoline, diesel, and natural gas, respectively. Moreover, the annual excess fuel consumption for each corridor was calculated based on Khan and Islam (2013) using Eq. (6) as follows:

$$\text{Cost per day} = \sum(N * A * FE * FC) \quad (6)$$

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

The values of annual excess fuel consumption cost were 0.748, 0.167, 0.297, and 1.27 million EGP for Suez Canal, El-Gesh, El-Gomhoria,

and Al-Mashaya streets, respectively based on Eq. (6).

7.1.4. Excess Emission Costs

The annual excess weight of carbon dioxide, CO₂ can be calculated from Eq. (7) as described in (World Bank, 2010). Thus, the total annual excess emission cost can be determined from Eq. (8).

$$W_{CO_2} = GW * 2.40 + DW * 2.41 \quad (7)$$

$$C_{CO_2} = W_{CO_2} * U_{CO_2} \quad (8)$$

Where; GW: Annual weight of wasted gasoline (kg), DW: Annual weight of wasted Diesel (kg), U_{co2}: unit cost of CO₂.

The estimated unit cost of CO₂ by (World Bank, 2010) was 57 EGP per ton, which requires a modification based on 2017 prices. Assuming that the annual increase in global unit price of CO₂ is 1%, thus the predicted price is 60.5 EGP/ton. The Co₂ emissions cost was estimated based on Eq.s (7) and (8) (World Bank, 2010), while the costs of other pollutants, CO, NO, SO, and PM₁₀ were estimated based on the emission rates detailed in (Mallela and Sadasivam, 2011).

7.2. Indirect Congestion Costs

The indirect traffic congestion cost is composed of four main components as follows:

- Vehicle maintenance cost due to vehicle breakdowns that may happen at peak periods
- Waiting delay time cost of passengers at stations which proportionally increases with traffic volume increase
- Traffic offenses cost which occurred especially at peak periods due to bad behavior of road drivers, and
- Lost productivity of injured people who may be injured due to accidents

7.2.1. Vehicle Maintenance Cost

In accordance with the analysis of the conducted traffic surveys for the different transport modes, the average monthly vehicle maintenance cost was calculated and found to be 231, 270, 249, 188 and 241 EGP/month for taxi, minibus, microbus, private cars and light commercial vehicles, respectively. These average monthly estimated costs represent the total maintenance cost during peak and off-peak periods. Litman (2013) found that the maintenance vehicle cost during peak periods was more than that during free-flowing periods by 15%. In Egypt, this percentage was also confirmed by the World Bank (2013), which showed the relationship between Vehicle Operating Cost (VOC) (EGP/VKT) and average speed

(km/hour). The vehicle maintenance cost during peak periods was more than that at free-flowing periods by 11%, 20%, 30%, and 9% for medium cars (taxis and private cars), minibuses, minibuses, and motorcycles, respectively. The weighted average excess maintenance cost due to congestion was found to be about 15% more than that during free-flowing period. Therefore, the average vehicle maintenance cost values due to traffic congestion were corrected to be 123.6, 144.4, 133.2, 100.6, and 128.9 EGP/month for taxi, minibus, microbus, private cars and light commercial vehicles, respectively. Subsequently, the annual vehicle maintenance cost due to congestion was estimated by the summation of the multiplication of the monthly average maintenance cost during peak periods by number of months per year by the annual peak traffic volumes for each transport mode. The total annual maintenance costs were 12.4, 14.7, 14, and 10.5 million EGP for Suez Canal, El-Gesh, El-Gomhoria, and Al-Mashaya streets, respectively.

7.2.2. Waiting Time Delay Cost

Delays due to waiting at stations during peak periods were computed from questionnaires as 8.7, 7.25, and 10.2 minutes for taxi, minibus and microbus, respectively. Waiting time delay cost can be determined using Eq. (9). The total annual waiting time delay costs were 1.8, 2.79 2.51, and 2.14 million EGP for Suez canal, El-Gesh, El-Gomhoria, and Al-Mashaya streets, respectively.

$$W_c = \sum MDPHV \times \%TC \times Avg.Wt \times V_o \times VOT \times No.Wd \quad (9)$$

Where; W_c : Annual waiting time delay cost; $MDPHV$: Maximum daily peak hour volume; $\%TC$: Percentage of each mode in traffic composition; $Avg.Wt$: Average waiting time delay for each transport mode, V_o : Vehicle occupancy of each transport mode; VOT : Value of time

of passengers for each mode; and No.Wd: Number of working days per year (250 days).

7.2.3. Traffic Offenses Cost

According to the traffic questionnaires, about 55% of drivers violated the traffic rules due to congestion. About 21% of them drove in opposite direction, 28% illegally parked, and 6% violated other rules i.e., defects in car, exceeding the speed limit...etc. As mentioned previously in the literature, a penalty of 1000 EGP must be applied to anyone drives in opposite direction and a fine of 200 EGP must be applied to drivers who park illegally (The Parliament, 2008). Based on that, the annual traffic offenses cost due to traffic congestion were estimated as 1.66, 1.8, 1.71, and 1.31 million EGP for Suez canal, El-Gesh, El-Gomhoria, and Al-Mashaya streets, respectively.

7.2.4. Lost Productivity of Injured People due to Traffic Congestion Accidents

Lost productivity of injured people due to traffic congestion crashes represents a decrease or loss of annual income per person due to injury. It is related to accident severity and percentage of injured people obtained from the questionnaire results. Lost productivity cost per injury can be calculated by the multiplication of the average annual income per person by the average consumption per person by the subtracting of the average age minus productive age per person (NIT, 2016). The average computed monthly income per person from the questionnaire was found to be 2000 EGP. NIT (2016) assumed that the

average age and the productive age per injury are 69 and 30 years, respectively. It was also assumed that the average consumption per person is 92 EGP per month. Consequently, the lost productivity cost was found to be 1.95, 2.47, 2.22, and 1.69 million EGP/year for Suez Canal, El-Gesh, El-Gomhoria and Al-Mashaya streets, respectively.

7.3. Final Traffic Congestion Costs

Table 2 gives a summary of all the estimated costs due to traffic congestion for each corridor as well as the overall annual congestion cost for the studied link. The total annual direct congestion cost was about 59% of the total cost with a value of 108.9 million EGP, while the total annual indirect congestion cost was 75.6 million EGP. The annual cost of delays including recurring, non-recurring travel time and waiting delays were about 55% of the total cost. The reason for that was due to the fact that the traffic volume had the most significant contribution on the calculation of the delay cost in particular the volumes of taxis. Regardless the largest road width of Al-Mashaya section, it was observed that it had the highest total annual cost owing to the high traffic volume and road length. Vehicle operating costs for minibuses and minibuses were higher compared with other transport modes due to the higher daily number of working trips. Consequently, the annual maintenance costs ranked in second position after delays costs with 28% of the annual total cost. In short sections i.e., El-Gesh and El-Gomhoria sections, vehicle maintenance cost had slightly higher impact on traffic congestion costs rather

than travel time delay cost especially when many minibuses stop and traffic volume increase. The annual traffic offenses costs were about 3.5% of the total annual cost. Excess fuel consumption and emissions had the lowest influence on the estimation of congestion cost. In general, the total annual cost due to traffic congestion may surpass billion EGP for all Mansoura city, since the total annual cost of only the studied link was 184.5 million EGP.

8. Conclusions

A total of 613 traffic questionnaires were designed and delivered to passengers and drivers to answer questions about business travel time, actual congested travel time for each vehicle type, fuel consumption, non-recurring travel time due to crashes, percentage of injured people, and value of traffic offenses. Field studies including geometric design elements, traffic volumes, and traffic speeds during peaks and off-peaks were conducted. Based on these studies, the economic impact of traffic congestion on the main path in Mansoura city was studied in terms of the estimation of the costs of recurring and non-recurring business travel time delay, excess fuel consumption, vehicle maintenance, excess emission, waiting time delay, traffic offenses, and lost productivity of injured passengers and drivers. Based on the results and analyses of this research, the following conclusions are drawn:

- About 184.5 million EGP is wasted annually due to traffic congestion on the

studied path from Gedyla to Mansoura University. The highest cost of traffic congestion in the study area was due to recurring, non-recurring and waiting time delays with a share of 55% of the total annual cost. Traffic volumes and VOT showed the most impact on the estimation of delay costs. The annual maintenance cost was ranked second with 28% of the total annual cost due to the high operating cost of minibuses and minibuses

- Illegal stops of some transport modes such as taxis, minibuses and minibuses in addition to the bad behavior of some drivers increased the bottlenecks and subsequently the delay cost
- Reliability cost was about 6% of the total annual cost. Reliability cost is related to the total travel time (including delays) and road length. The reliability cost on El-Gesh street was about 4.1% of the total cost on this corridor, while it was about 8.7% of the total cost on Al-Mashaya street due to the lower delay and the shorter length of El-Gesh road
- Traffic offenses if applicable cost about 3.5% of the total annual cost and the other costs i.e., fuel consumption, emissions, lost productivity of injured people costs were about 6%

In short corridors i.e., El-Gesh and El-Gomhoria corridors, vehicle maintenance cost had higher impact on the traffic congestion costs rather than travel time delay cost especially when many minibuses stop and traffic pressure increased.

Table 2
Summary of Traffic Congestion Costs on Studied Corridors

Section	Suez Canal St.	EL-Gesh St.	EL-Gomhoria St.	AL-Mashaya St.
Direct congestion costs (million EGP/year)				
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
Reliability cost	2.73	1.64	2.96	6.57
Excess fuel consumption cost	0.748	0.167	0.297	1.270
Excess emission cost	0.0344	0.0092	0.024	0.071
Sum of average direct traffic congestion cost	17.64	16.67	15.77	58.79
Indirect congestion costs (million EGP/year)				
Vehicle maintenance cost	12.4	14.7	14.0	10.5
Waiting time delay cost	1.804	2.791	2.509	2.138
Traffic offenses cost	1.659	1.796	1.707	1.311
Lost productivity	1.95	2.47	2.22	1.69
Sum of indirect traffic congestion cost	17.81	21.76	20.41	15.64
Total traffic congestion cost for each corridor (million EGP /Year)	35.45	38.43	36.18	74.43
Total average traffic congestion cost (million EGP/Year)	184.5			

9. Further Work

In this study, most of the parameters related to traffic congestion were studied such as vehicle speed, traffic volume, average daily traffic volume, level of service, traffic density, ... etc. More parameters should be studied in the future such as impact of faulty design of intersections on generation of traffic bottlenecks. Emission rates and noise levels should be measured as well as the incident delay factor of roads for accurate determination of excess emission, noise, and non-recurring travel time delay costs, respectively. Finally, the impact of applying some solutions regarding the regulation of traffic demand and supply on the estimation of traffic congestion costs in Mansoura city should be studied. These solutions are for example are:

- Changing days of weekly vacation and daily shift timings (staggered shifts times) for employees

- Using river transport as a good alternative to the land transport especially that most of the attraction areas are located next to the Nile River
- Adapting of natural gas as a fuel for most vehicles, since it's environmentally friendly and safe on human health rather than other fuel types, and
- Implementing of parking garages and smart techniques of parking in the areas that attract traffic based on the land use, etc

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