Annex 10: Equations used for Direct Cost Calculation

In this section, the formulas that are used to estimate the direct economic costs of traffic congestion in the following themes are presented:

- Travel time delay
- Travel time reliability
- Excess gasoline consumption
- CO_2 emission

Travel Time Delay

In order to estimate delay from recurrent traffic congestion, determining the congestion threshold is essential. In order to determine the congestion threshold two different approaches have been applied as follows:

- Approach 1: Applying Principal Corridors Collective Assessment for corridors' speed plot
- Approach 2: Applying V/C based on traffic counts and useable road capacity

Delay Estimation Causing By Recurrent Congestion

Approach 1: Applying Principal Corridors Collective Assessment for corridors' speed plot

The consultant uses the speed indices plots to determine the corridors' level of service and thus the congestion level. The hours that the speed indices show the average speed below 0.6 is considered as congested hours.

Travel delay from recurrent traffic congestion is estimated by equations relating vehicle traffic volume per lane and traffic speed. The calculation proceeds through the following simplified steps based on the method proposed by Texas Transportation Institute (TTI Method):

1. Estimate the daily volume of vehicles per lane corresponding to congested peak hours
2. Calculate Daily Vehicle Kilometer of Travel (DVKT) for each roadway section as the average daily traffic (ADT) of a section of roadway multiplied by the length of that section of roadway. The Daily Vehicle-Kilometers of travel (DVKT) is the average daily traffic (ADT) of a section of roadway multiplied by the length (in Kilometers) of that section of roadway. This allows the daily volume of all urban facilities to be presented in terms that can be utilized in cost calculations. DVKT was estimated for the freeways and principal arterial streets located in each urbanized study area.
3. Determine average freeway speeds based on data collected from travel time and speed surveys in the region.

4. *Estimate Travel Delay:* The difference between the amount of time it takes to travel during the peak-period at the average speed and at free-flow speeds in a the segments is termed delay.
5. Calculate daily recurring vehicle-hour delay by using the following formula:

$$\frac{\text{Recurring vehicle hour delay}}{\text{Day}} = \frac{\text{Peak Period Congested DVKT}}{\text{Avg. Peak Period Speed}} - \frac{\text{Peak Period Congested DVKT}}{\text{Avg. Off Peak Period Speed}}$$

The amount of delay incurred in the peak period is the difference between the time to travel at the average speed and the travel time at the free-flow speed, multiplied by the distance traveled in the peak period.

Approach 2: Applying V/C based on traffic counts and useable road capacity

By this approach the consultant applied the following multistep method to identify congested peak hours and segments for the corridors:

1. Divide each corridor into segments based on the useable segment's capacity
2. Calculate V/C for each segment during peak hours
3. Identify congested segments when V/C >0.77.

The FHWA model used 0.77 V/C ratio as the threshold marker for traffic congestion. In fact, in 1991, the FHWA completed additional research in the area of quantifying congestion. The focus of this work was on recurring congestion on urban area freeways and the development of a congestion indicator combining both the duration and extent of congestion in a single measure (Cottrell, 1991), (Texas Transportation Institute, 1992), and (Epps et al. 1993). The only impact of congestion considered in this work was recurring congestion-induced delay expressed in terms of both its duration and physical extent by a newly developed indicator called the lane-mile duration index.

Given description above, the consultant applied the following steps to estimate the delay from recurrent congestion:

- Calculate capacity based on number of lanes, an adjustment factor for lane width, lateral clearance, the presence of trucks, and type of terrain, and a value of 2,200 vehicles per lane per hour for the basic lane capacity assuming a roadway design speed of at least 60 Km per hour (kph)
- Calculate volume-to-capacity ratio (V/C) for each hour of a typical day based on new counts
- Determine which hours of the day are to be classified as congested. A V/C ratio of 0.77 was used to indicate the onset of congested travel conditions (boundary between LOS C and LOS D).
- Calculate total annual congested vehicle Kms of travel (DVKT) based on AADT, roadway section length, and percentage of daily traffic experiencing congested conditions, which is the sum of the percentages of traffic occurring during those hours of the day with a V/C ratio greater than or equal to 0.77.
- *Estimate Travel Delay:* The difference between the amount of time it takes to travel the peak-period vehicle-Kilometers at the average speed and at free-flow speeds is termed delay.
- Calculate daily recurring vehicle-hour delay by the following formula:

$$\frac{Recurring\ vehicle\ hour\ delay}{Day} = \frac{Peak\ Period\ Congested\ DVKT}{Avg.\ Peak\ Period\ Speed} - \frac{Peak\ Period\ Congested\ DVKT}{Avg.\ Off\ Peak\ Speed}$$

Delay Estimation due to Nonrecurring Events

Another type of delay encountered by travelers is the delay that results from incidents, Security Checks, Vehicle Breakdowns, Random Minibus Stops, and finally Random Pedestrian Crossings. Incident delay is related to the frequency of crashes or vehicle breakdowns, how easily those incidents are removed from the traffic lanes and shoulders and the "normal" amount of recurring congestion. The basic procedure used to estimate incident delay in this study is to multiply the recurring delay by a ratio.
The process used to develop the delay factor ratio is a detailed examination of the freeway characteristics and volumes. In addition, a methodology developed by FHWA is used to model the effect of incidents based on the design characteristics and estimated volume patterns.

Delay from non-recurring congestion-Summary Version:
Calculate vehicle hours of delay due to incidents by the following formula:

$$Daily\ Non\ Recurring\ VHD = Daily\ Recurring\ VHD \times \alpha$$

Where:
α: Road incident delay factor

Total VHD= Daily Recurring VHD+ Daily Nonrecurring VHD

The road incident delay factor is derived from the TTI Urban Mobility Report Methodology. The process used to develop the delay factor ratio is a detailed examination of the road characteristics and volumes. The consultant uses daily traffic influencing events in the car floating survey to estimate the incident delay factor.
Incident delay occurs in different ways on streets than freeways. While there are driveways that can be used to remove incidents, the crash rate is higher and the recurring delay is lower on streets. Arterial street designs are more consistent from city to city than freeway designs. For the purpose of this study, the road incident delay factor for arterial streets is ranges between 110 to 160 percent of arterial street recurring delay depending on:

- No. of accidents;
- Security checks;
- Vehicle breakdowns;
- Random Microbus stops;
- Random pedestrian crossings

Table A10.1 outlines the road incident delay factor for diverse US states provided by the Texas Transportation Institute and stated in the TTI Urban Mobility Report Methodology.

Table A10.1: TTI incident delay factor

Urban Area	Freeway Incident Delay Ratio	Arterial Street Incident Delay Ratio	Urban Area	Freeway Incident Delay Ratio	Arterial Street Incident Delay Ratio
Very Large			Medium		
Atlanta, GA	1.2	1.1	Akron, OH	1.4	1.1
Boston, MA-NH-RI	1.6	1.1	Albany-Schenectady, NY	2.3	1.1
Chicago, IL-IN	0.8	1.1	Albuquerque, NM	1.1	1.1
Dallas-Fort Worth-Arlington, TX	1.3	1.1	Allentown-Bethlehem, PA-NJ	1.6	1.1
Detroit, MI	1.2	1.1	Bakersfield, CA	1.8	1.1
Houston, TX	0.9	1.1	Birmingham, AL	2.0	1.1
Los Angeles-LBch-Santa Ana, CA	0.7	1.1	Bridgeport-Stamford, CT-NY	1.5	1.1
Miami, FL	1.0	1.1	Colorado Springs, CO	2.2	1.1
New York-Newark, NY-NJ-CT	2.5	1.1	Dayton, OH	1.4	1.1
Philadelphia, PA-NJ-DE-MD	2.2	1.1	El Paso, TX-NM	1.7	1.1
Phoenix, AZ	0.9	1.1	Fresno, CA	2.3	1.1
San Francisco-Oakland, CA	0.9	1.1	Grand Rapids, MI	2.1	1.1
Seattle, WA	1.2	1.1	Hartford, CT	2.1	1.1
Washington, DC-VA-MD	1.0	1.1	Honolulu, HI	1.3	1.1
			Indio-Cat. City-Palm Springs, CA	2.5	1.1
Large			Lancaster-Palmdale, CA	2.5	1.1
Austin, TX	1.6	1.1	Louisville, KY-IN	1.5	1.1
Baltimore, MD	1.3	1.1	Nashville-Davidson, TN	1.7	1.1
Buffalo, NY	2.1	1.1	New Haven, CT	1.4	1.1
Charlotte, NC-SC	1.2	1.1	Oklahoma City, OK	2.0	1.1
Cincinnati, OH-KY-IN	1.3	1.1	Omaha, NE-IA	2.3	1.1
Cleveland, OH	1.5	1.1	Oxnard-Ventura, CA	1.3	1.1
Columbus, OH	1.3	1.1	Poughkeepsie-Newburgh, NY	2.5	1.1
Denver-Aurora, CO	1.2	1.1	Richmond, VA	2.2	1.1
Indianapolis, IN	1.1	1.1	Rochester, NY	2.3	1.1
Jacksonville, FL	1.5	1.1	Salt Lake City, UT	1.3	1.1
Kansas City, MO-KS	2.5	1.1	Sarasota-Bradenton, FL	2.5	1.1
Las Vegas, NV	1.1	1.1	Springfield, MA-CT	1.9	1.1
Memphis, TN-MS-AR	1.6	1.1	Toledo, OH-MI	2.1	1.1
Milwaukee, WI	1.1	1.1	Tucson, AZ	1.5	1.1
Minneapolis-St. Paul, MN	1.4	1.1	Tulsa, OK	2.1	1.1
New Orleans, LA	1.4	1.1			
Orlando, FL	1.3	1.1	Small		
Pittsburgh, PA	2.5	1.1	Anchorage, AK	2.5	1.1
Portland, OR-WA	1.4	1.1	Beaumont, TX	2.5	1.1
Providence, RI-MA	2.2	1.1	Boulder, CO	2.5	1.1
Raleigh-Durham, NC	1.6	1.1	Brownsville, TX	2.5	1.1
Riverside-San Bernardino, CA	0.9	1.1	Cape Coral, FL	2.5	1.1
Sacramento, CA	1.0	1.1	Charleston-No. Charleston, SC	2.0	1.1
San Antonio, TX	1.2	1.1	Columbia, SC	1.9	1.1
San Diego, CA	0.9	1.1	Corpus Christi, TX	2.4	1.1
San Jose, CA	1.2	1.1	Eugene, OR	2.4	1.1
St. Louis, MO-IL	1.2	1.1	Knoxville, TX	2.3	1.1
Tampa-St. Petersburg, FL	1.5	1.1	Laredo, TX	2.5	1.1
Virginia Beach, VA	2.1	1.1	Little Rock, AR	1.6	1.1
			Pensacola, FL-AL	2.5	1.1
			Salem, OR	2.5	1.1
			Spokane, WA	2.4	1.1
			Wichita, KS	2.5	1.1

Based on engineering judgment most of the corridors are allocated the value of **1.1** as the incident delay ratio.

For corridor 1 with the following nonrecurring events, the value of **1.3** is considered as the incident delay ratio.

Corridor 1 Nonrecurring events:

<table>
<tr><td rowspan="3">Average Daily Frequency</td><td>Accidents</td><td>0.2</td></tr>
<tr><td>Security Checks</td><td>4.5</td></tr>
<tr><td>Vehicle Breakdowns</td><td>7.4</td></tr>
<tr><td rowspan="2">Qualitative Observation</td><td>Random Microbus Stops</td><td>High</td></tr>
<tr><td>Random Pedestrian Crossings</td><td>Medium</td></tr>
</table>

For corridor 3 with the following nonrecurring events, the value of 1.6 is considered as the incident delay ratio

Corridor 3 Nonrecurring events:

Average Daily Frequency	Accidents	2
	Security Checks	5
	Vehicle Breakdowns	17
Qualitative Observation	Random Microbus Stops	High
	Random Pedestrian Crossings	Medium

For corridor 4 with the following nonrecurring events, the value of 1.2 is considered as the incident delay ratio

Corridor 4 Nonrecurring events:

Average Daily Frequency	Accidents	0.3
	Security Checks	1.4
	Vehicle Breakdowns	1.4
Qualitative observation	Random Microbus Stops	High
	Random Pedestrian Crossings	High

Total delay estimation:

The annual recurring and nonrecurring delay costs for passenger car users, motorcyclists, taxi users ,transit users (buses and minibuses), freight transporters, and overall road users have been estimated given recurrent and nonrecurring delays that travelers face as follows:

$$DC_{pc} = N_{pc} \times O_{pc} \times (1+\alpha) \times L \times \left(\frac{1}{V_p pc} - \frac{1}{V_f pc}\right) \times VOT_{pc}$$

$$DC_m = N_m \times O_m \times (1+\alpha) \times L \times \left(\frac{1}{V_p m} - \frac{1}{V_f m}\right) \times VOT_m$$

$$DC_{tx} = N_{tx} \times O_{tx} \times (1+\alpha) \times L \times \left(\frac{1}{V_p tx} - \frac{1}{V_f tx}\right) \times VOT_{tx}$$

$$DC_{pt} = N_{pt} \times O_{pt} \times (1+\alpha) \times L \times \left(\frac{1}{V_p pt} - \frac{1}{V_f pt}\right) \times VOT_{pt}$$

$$DC_{fr} = N_{fr} \times O_{fr} \times (1+\alpha) \times L \times \left(\frac{1}{V_p fr} - \frac{1}{V_f fr}\right) \times VOT_{fr}$$

Where:

DC: The annual recurring and nonrecurring delay cost (LE per year)
N: Number of vehicle running during peak hours per year
O: Vehicle occupancy factor
α: Road incident delay factor
L: Congested corridor length (km)
V_p: Average speed during peak hours (km/hr)
V_f: Free flow speed (km/hr)
VOT: Value of time (LE/hr)

The indices *pc, m, tx, pt,* and *fr* express passenger cars, motorcycles, taxies, public transportation, and freight transportation respectively.

A wide variety of temporal indicators (e.g. STD, COV, 95th Percentile, Buffer time index) can be used to provide a range of perspectives of the reliability issue. The consultant applies *Coefficient of Variation of Travel time o*n the routes as the travel time reliability measure. The coefficient of variation of travel times is defined as standard deviation divided by mean travel time:

$$COV_i = \frac{STD_i}{\bar{T}_i}$$

Where:

i: corridor number

STD: The standard deviation of travel time

$\bar{T}$: The mean travel time

$$STD_v = standard\ deviation\ of\ speeds$$

$$STD_T = standard\ deviation\ of\ travel\ times = \frac{L}{STD_v}$$

$$T = \frac{L}{V}$$

Economic Cost of Unreliability

In general, reliability is highly valued by travelers and commercial vehicle operators reflecting the fact that a reliable transport network is a net benefit for society and that an unreliable network represents a net cost to society. A lot of work has been carried out in the Netherlands to monetize unreliability of travel time. Based on the research's outcomes (OECD 2010) and the local conditions, the consultant assumes the following rates for monetizing travel time unreliability:

Passenger cars and motorcycle:	1.0 minute travel time variation is equivalent to 0.9 minute travel time
Public Transport including taxi:	1.0 minute travel time variation is equivalent to 1.1 minute in vehicle travel time

Thus, the annual value of unreliability for passenger car users including driver are estimated as follows:

$$VOR_i^{pc} = 0.9 \times N_{pc} \times STD_i \times VOT_{pc}$$

Where:
i: Route number
VOR: Value of unreliability imposed to passenger car users (for both tails, early and late arrivals)
N_{pc}: Annual number of passenger car users who suffer from unreliability
STD_i: The average standard deviation of travel time in route *i*
VOT_{pc}: The Value of time of passenger car users

The coefficient of variation of travel time (COV) can not be monetized directly since it is unit less. The consultant monetizes the STD of travel time instead as the proxy for the COV accordingly.

Cost of Excess Fuel Consumption

In order to estimate excess fuel consumption due to traffic congestion the following steps are applied:

- Calculate average fuel efficiency
- Calculate total excess fuel (liters) used as a result of recurring and nonrecurring delay using the following formulas:

The average fuel economy calculation is used to estimate the fuel consumption of the vehicles running in the congested condition. The average fuel economy is formulated as follows:

$$\textit{Average Fuel Economy in Congestion} = 8.8 + 0.25\,(\textit{Average peak Period Congested System Speed})$$

It should be noted that a metric conversion has to be applied to the equation above since it is originally formulated based on non metric Units (Miles per Gallon).

<u>Adjusting the fuel efficiency formula for Cairo</u>

The formula above has been already developed and calibrated for USA between 1985-1995 . However, the consultant believes it is more or less useable for Cairo as well. By looking at the car composition in US between 1985-1995, and due the fact that GM cars were dominant, the Fuel Efficiency for American cars such as Chevrolet is derived as follows:

Brand/Model	MPG (City)	MPG (HWY)
Chevrolet Celebrity (6 cyl)	18	24
Buick Century (6 cyl)	16	23
Cadillac (6 cyl)	16	22
Dodge Lancer (4 cyl)	20	30
Jeep Cherokee (6 cyl)	15	17
Pontiac 6000 (6 cyl)	18	24
Lincoln Continental (6 cyl)	20	26
Chevrolet Blazer (6 cyl)	16	23

Chevrolet Camaro (8 cyl)	16	24

Source: *www.fueleconomy.gov*

Given the fleet composition in the Cairo region stated in tables A 3-9 , A3-11, it seems the following car composition and corresponding fuel economy is dominant:

Brand	Age	MPG (City)	MPG (HWY)
Isuze	< 5	18	24
Daewoo	< 5	17	25
Chevrolet	< 5	18	27
Nissan	< 10	19	25
Mercedes	< 10	19	25
Peugeot	< 20	17	22

Of course for accurate estimation, further information on Brand model, engine type, AC system availability, and so on is required.

Based on engineering judgment the consultant believes that the average fleet age at GCR would be from 10 to 12 years (Figure A10-1). Also, the average fuel consumption is estimated around 10 litres/100 km (24 MPG) in the city based on speed of 60 Km/hr which corresponds with the American estimation in 80th decade. It should be noted that the engine size of most passenger cars in the GCR is 1600 cc (Figure A10-2).

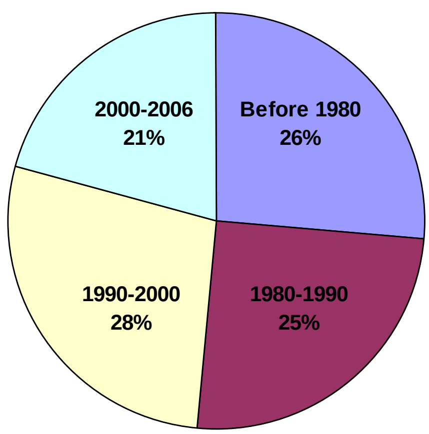

Figure A10.1Car's age distribution in Egypt

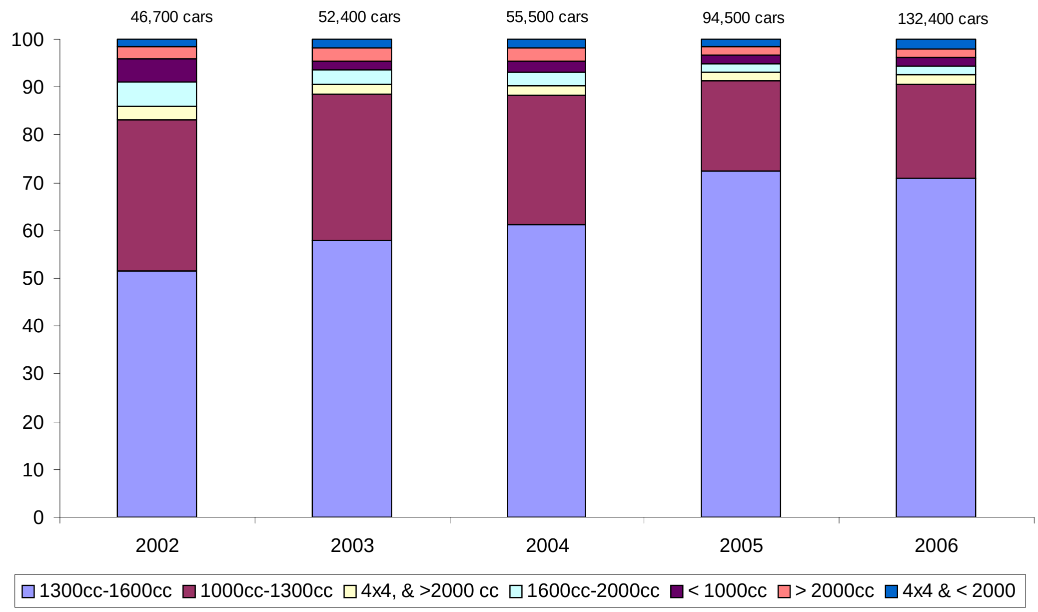

Figure A10.2Relative distribution of cars' engine size between 2002-2006 in Egypt

Source: AMIC Egypt

The fuel that is deemed "wasted due to congestion" is the difference between the amount consumed at peak speeds and free-flow speeds:

$$\begin{aligned}&Annual\ Fuel\ Wasted\ in\ Congestion = Annual\ Fuel\ Consumed\ in\ Peak\ Conditions\\&-\ Annual\ Fuel\ That\ Would\ be\ Consumed\ in\ Free\ Flow\ Condition\end{aligned}$$

$$\begin{aligned}&Daily\ Fuel\ Wasted\ (Liter) = \frac{DVKT}{Free\ Flow\ Travel\ Speed} \times\\&\left(\frac{Free\ flow\ speed}{Average\ fuel\ economy} - \frac{Peak\ period\ system\ congested\ speed}{Average\ fuel\ economy}\right)\end{aligned}$$

The formula above is applied for Gasoline cars and Diesel cars separately to derive the amount of excess gasoline consumption (EGW) and excess diesel consumption (EDW) separately.

To calculate the Excess gasoline cost, the consultant uses the following formulation:

$$EGC = EGW \times 1.8$$

Where:
EGC: Annual excess gasoline cost (LE)
EGW: Annual excess gasoline wasted (litre)

Likewise, to calculate the Excess diesel Cost, the consultant uses the following formulation:

$$EDC = EDW \times 1.0$$

Where:
EDC: Annual excess diesel cost (LE)
EDW: Annual excess diesel wasted (litre)

The total excess fuel cost is computed as follows:
EFC= EGC+EDC

Furthermore, the consultant computes the excess fuel subsidy imposed to the government due to traffic congestion:

Gasoline Subsidy:

$$EGS = EGW \times 2.2$$

Where:
EGS: Annual excess gasoline subsidy (LE)
EGW: Annual excess gasoline wasted (litre)

Diesel Subsidy:

$$EDS = EDW \times 1.1$$

Where:
EDS: Annual excess gasoline subsidy (LE)
EDW: Annual excess gasoline wasted (litre)

The total Fuel subsidy will be calculated as follows:

EFS= EGS+ EDS

Emission Cost

The consultant uses the following standard emission rates for diverse vehicular modes, to calculate the CO_2 emission due to congestion in Cairo. As shown, the standard rates below depend on only fuel type as well as the vehicle type and **not** engine type. For example, 1 liter consumed gasoline or diesel in passenger cars produces 2.40 kg CO_2.

Table A10.2: The Emission rate for diverse vehicular modes

Emission rate	CO_2
Vehicular Mode	**kg/L**
Cars (diesel and gasoline)	2,40
Motorcycle	2,42
Taxi	2,40
Bus	2,41

BRT	2,24

The annual CO_2 emission weight (Kg) is estimated as follows:

$$W_{CO_2} = GW \times 2.40 + DW \times 2.41$$

Where:
GW: Annual weight of wasted gasoline (Kg)
DW: Annual weight of wasted Diesel (Kg)

The annual CO2 emission cost (LE) is formulated as follows:

$$C_{CO_2} = W_{CO_2} \times U_{C\,CO_2}$$

Where
$U_{C\,CO_2}$: Unit cost of CO2

The consultant assumes the unit cost of CO_2 as 57 LE per ton.