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Effect of Flexible Pavement Maintenance Operations on User Cost

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Abstract : *Egyptian roads are rapidly increasing in traffic demand during the last few years. So; it becomes necessary to allocate substantial resources to construct new roadways as well as maintaining the existing infrastructure. Pavement maintenance usually requires closing some lanes of highway; this may cause disruptions to normal traffic flow. These roadway sections with reduced width may cause speed reductions, increased in travel time cost (TTC) and increased in vehicle operation cost (VOC). The aim of this study is to determine the optimal number of closed lanes to achieve: Suitable operating speed (OS) and most reduction in national income loss, TTC and VOC at work zones. This study determined work zone configuration, traffic data, vehicle data and road data for most cases work zones at eight, six and four lane-divided highway to evaluate OS, loss in national income, TTC and VOC with the aid of world bank software (HDM-4). The results obtained from this software are verifying against some actual data observed in the field. In order to achieve verifying, a framework for data collection was designed. This framework includes field investigation at Cairo ring road, field data from previous study and data collection form. The findings of this study recommended VOC decreases with increasing number of closed lane if the value of OS decreases from (free speed to 50 kph). VOC increases with increasing number of closed lane if the value of OS decreases from (50 kph to jam speed). TTC increases and OS decreases with increasing number of closed lane. VOC increases, TTC decreases and OS increases with increasing the speed limit for highway. No pronounced difference in OS value, before and at work zone, between measured speed in field and calculated speed by HDM-4 software.*

Keywords: *Vehicle operating cost, Travel time cost, Operating speed, National income.*

I. Introduction

For any country, the road system is an important part of its infrastructure which can affect economic development. An efficient road system can promote economic development because it enhances the performance of local transportation. A good level of service for a road system requires implementation of pavement management system. Therefore, various maintenance activities, such as pothole patching, crack sealing and pavement resurfacing, are regularly carried out by land transport authorities.

A work zone is referred to as a segment of road in which maintenance operations crash on one or more lanes available to traffic, or affect the operational characteristics of traffic flow through the segment. Work zone activities could cause several problems because work zones usually close one or more of the lanes available for traffic. However, lane reductions could cause a disturbance to normal traffic flow and speed reductions, further resulting in a reduction of road capacity, an increase of travel time cost and vehicle operation cost. Since vehicles in the closed lanes have to merge into the adjacent available lanes, it may increase the number of traffic conflicts and cause severe traffic safety problems.

This study aims to determine the optimal number of closed lanes in one direction for work zone on the divided rural highways to achieve reduction in travel time cost, reduction in vehicle operation cost, suitable operating speed and the most reduction in national income loss at the work zones.

Pavement Maintenance Management Systems (PMMS) should not be confused with Pavement Management Systems (PMS). PMMS is a part of the PMS program, i.e. they overlay rather than replace one to another. [1,2].

A pavement maintenance management system provides the framework for decision making in pavement maintenance based upon an objective approach. There is a logical sequence of steps in the preparation of a pavement maintenance program. In overall terms, it follows the sequence: establish objectives, define standards, assess needs, determine resources and programs, implement and monitor and review performance.

Roadway surface problems appear in many forms: holes, cracks, distortions, depressions, ruts, corrugations, edge failures, ravelling, and flushing. These problems are caused by one or more factors such as age, weather, wheel loads, design, materials, and construction and maintenance practices. [3].

Pavement maintenance activities are dividing into three broad types: 1. Routine maintenance may be described as responsive maintenance. It is required to maintain roadway in proper operational conditions. Routine maintenance may be as preventative or corrective. It does not relate to pavement condition. It includes activities that may be repeated one time over a year such as: vegetation control, drainage cleaning, culvert maintenance, cleaning road signs and traffic signals, and road sweeping and painting. 2. Annual or preventative maintenance includes only those work items related to preserving the pavement condition in acceptable manner. Temporary maintenance may be as preventative or corrective. This includes crack sealing, cleaning, patching surface holes, repairing edge failure, smoothing depressions and ruts, and other procedures that repair an undesirable surface condition. 3. Major (Structural) maintenance is the maintenance applied to the pavement for a number of years when its condition reaches unacceptable level. It may be as preventative or corrective. This includes distresses repair, resurfacing or overlaying, slurry seal, surface treatment, and rehabilitation. [4].

The Egyptian code of practice for rural and urban roads (part 2 traffic studies, chapter 8, 2008) [5], describes the use of signs, channelization devices and attenuation devices along the approach to and within the work zone.Temporary traffic control zone signs convey both general and specific messages by means of words or symbols and have the same three categories as all traffic signs: namely, regulatory signs, warning signs, and guide signs.Tapers may be used in both the transition and termination areas. Tapers are created using of channelizing devices "mainly cones", placed to move traffic out of or into its normal path.

The function of channelizing devices is to warn and alert drivers of conditions created by work activities in or near the traveled way, to protect workers in the temporary traffic control zone, and to guide drivers and pedestrians safely.The general definition of road user costs (RUC) of a work zone is the total incremental cost to the traveling public resulting from work zone activity. Road user cost usually includes several components, such as user delay costs (i.e., value of time), and vehicle operating costs (VOC).

In general, work zone traffic delay can be defined as the difference between travel time on a roadway segment without work zones and the actual longer travel time in work zones. In this study, The World Bank Highway Development and Management Model (HDM-4) used to estimating traffic delay at work zones. Hdm-4 is the most widely used macroscopic simulation tools. Work zone traffic delay defined in (HDM-4) as the difference between travel time on a roadway segment without work zones and the actual longer travel time in work zones.VOC is the cost on a vehicle during operation depending on the type of vehicle and on the roadway condition [6].Following is a highlight on the main components of vehicle operating costs considered in the (RUC): Lubricating oil, Parts, Labor, Tires, Depreciation, Vehicle time value, and Fuel Consumption.

Fuel consumption is a significant component of VOC, typically accounting for between 20 and 40 percent of the total VOC [7]. It is influenced by traffic congestion, road condition and alignment, vehicle characteristics and driving style, so it is sensitive to virtually any investment decisions on the road network. Figure (1) shows predict Method For Fuel Consumption In HDM-4 Software.

II. Study Methodology

To achieve the study objectives, the following tasks are made: Determine the work zone lane configurations, Data collection and processing: Collect all the available data which represent most Egypt rural highway, such as Traffic data, Fleet data, and Road data. Select user cost calculated Software, Analyzing results of study, verifying the study results, and finally, deducing study conclusions and recommendations. Figure (2) presents research methodology flow chart.

2.1 Work Zone Lane Configurations

In this study, work zone configurations represent most common Egyptian rural highway such as eight lane-divided highway, six lane-divided highway and four lane-divided highway. Four lane reduction to three lane (4 to 3), four lane reduction to two lane (4 to 2), four lane reduction to one lane (4 to 1), median crossover (4 to 0), three lane reduction to two lane (3 to 2), three lane reduction to one lane (3 to 1), median crossover (3 to 0), two lane reduction to one lane (2 to 1), median crossover (2 to 0) work zone configuration.

2.2 Data Collection and Processing

Input data used in this study include traffic data, fleet data, and road data.

2.2.1 Traffic Data

Required traffic data include average annual daily traffic (AADT), passenger car unit (PCU), speed limit and traffic composition for the representative vehicle fleet. Traffic data has a significant impact on the fleet speed which has a significant impact on VOC. Table (1) show the average annual daily traffic used in this study for different work zone configurations at speed limit 120, 110, 100, 90, 80 and 60 kph which represents most

Egyptian rural highways. Traffic compositions data used in this study are expected from previous study, by Egyptian group for consulting engineering (EGEC) house of expertise in favor of (GARBLT) in technical and economic study for alternative link route for Shobra-Banha highway in 2007.

2.2.2 Vehicle Fleet Data

The vehicle fleet data is needed to determine the VOC. Ten vehicles were selected to be the representative fleet in this study; presented in Figure (3).The required fleet data can be summarized by basic characteristic for vehicles; presented in Table (3) and economic unit costs such as vehicle resources cost and time value; presented in Table (4). The previous basic characteristic items and economic unit costs items were collected from several car and truck companies of public and provide sector, other was obtained from recent studies [8], [9] and [10].

2.2.3 Road Data

Road data can be utilized to determine the operation speed, travel time, VOC and other traffic parameters. The required road data can be summarized by general date such as (Traffic flow pattern: free flow, Climate condition: tropical humid, Surface class: bituminous, Pavement type: asphalt mix on granular base, Section length: 1 km, Shoulder width: 1.8 m for 384 section study in this study, and such as section name and ID, speed flow type, carriageway width and number of lanes different from section to another for 384 section), geometric data such as (rise and fall by m/km: zero, average horizontal curvature by deg./km: zero, altitude by m : zero for 384 section study in this study and speed limit different from section to another for 384 section) and work zone capacity value collected from (Hdm-4, volume seven, 2000) [11] showing in table (5).

2.3 Selection of the User Cost Analysis Tool

Several tools are commonly used for user cost analysis and economic analysis of infrastructure investments. The Highway Development and Management Model (HDM-4) are among those models and it was selected to utilization in this study. HDM-4 Package is selected because, it predict road user cost for different work zone lane configuration in road user effects model in program based on the travel speed, composition traffic, road geometry and vehicle fleet characteristics, data generated by simulation include several measures and results are obtained quickly. Figure (4) shows the structure of HDM-4 models and how they are related to each other [12].

2.4 The Main Inputs of the HDM-4

HDM-4 model needs tremendous input data such as Road section to be analysed, Vehicle fleet, Traffic characteristics, Maintenance and rehabilitation scenarios.

2.4.1 Road Section to be Anayzed

Three hundred eighty four road section models represent all cases for work zone on Egyptian rural highways selected to be studied in this study.

2.4.2 Vehicle Fleet for the Selected Sections

The required fleet data are summarized by the basic characteristic and economic unit cost of VOC items for vehicles.

2.4.3 Traffic Characteristic for the Selected Sections

Traffic Characteristic data are summarized by growth factors and traffic Composition on the selected sections.

2.4.4 Maintenance and Rehabilitation Scenarios

In this research, one alternative (Master alternative) without maintenance scenarios in traffic lane adjacent work zone in same section.

III. Results And Discussion

The results of this study were divided into two categories. The first category is the output of HDM-4 program. Such as (Road user effects, cost streams and economic evaluation). The second category is the output data of the HDM-4 program that is processed by the excel program to perform the final result of this study. Road user effects reports is considered one of the most important benefits in this study. The road user effects reports are represented by the vehicle average operating speed. Where; Cost streams and economic evaluation reports are represented by VOC and travel time costs.

3.1 Relation between AADT and VOC

Table (6) present's relation between AADT and VOC at speed limit = 120, 110, 100, 90, 80 and 60 km/hr. for work zone lane configurations for eight lane-divided highway, six lane-divided highway and four lane-divided highway. The table shows that vehicle operating costs increases with increasing average annual

daily traffic. The increasing in VOC may be traffic interactions. These interactions result in speed fluctuations and a decrease from the free speed. These interactions lead to additional fuel consumption and tyre costs. It is noted that the VOC decreases with increasing number of closed lane if the value of operating speed decreases from (free speed to 50kph.). Also, it is noted that the VOC increases with increasing number of closed lane if the value of operating speed decreases from (50 to jam speed). The decreasing and increasing in VOC may be due decreased in operating speed. Where; when operating speed decreased through range (free speed to 50kph.) the fuel consumption decreases and VOC decreases, but when operating speed decreased through range (50 to Jam speed) the fuel consumption increases and VOC increases. Where fuel consumption is a significant component of VOC, typically accounting for between 20 and 40 percent of the total VOC (HTC, 1999b). Also, it is noted that the vehicle operating costs increases with increasing Speed limit for highway.

Table (7) present's relation between AADT and increasing % in VOC at speed limit = 120, 110, 100, 90, 80 and 60 km/hr. for work zone lane configurations for eight lane-divided highway, six lane-divided highway and four lane-divided highway. The table shows that the rate of decreases between closed one lane and normal case & between closed two lane and normal case is small but it major between closed three lane and normal case for eight lane-divided highway. This may be due to reduced width and therefore capacities. This help the GARBLT to determine number of closed lane during maintenance operations on their highways network according to minimum vehicle operating cost percent.

3.2 Relation between AADT and TTC

Table (8) present's relation between AADT and TTC at speed limit = 120, 110, 100, 90, 80 and 60 km/hr. for work zone lane configurations for eight lane-divided highway, six lane-divided highway and four lane-divided highway. The table shows that travel time cost increases with increasing average annual daily traffic. The increasing in TTC may be traffic interactions. These interactions result in speed fluctuations and a decrease from the free speed. This decreases in speed leads to an increases in travel time. It is noted that the TTC increases with increasing number of closed lane. This increases in TTC may be due to reduced width and therefore capacities. Also, it is noted that the travel time cost decreases with increasing speed limit for highway. Where amount of travel time calculated from the predicted speed. Travel time is multiplied by the unit cost of time to establish the cost.

Table (9) present's relation between AADT and increasing % in TTC at speed limit = 120, 110, 100, 90, 80 and 60 km/hr. for work zone lane configurations for eight lane-divided highway, six lane-divided highway and four lane-divided highway. The table shows that the rate of increasing between closed one lane and normal case & between closed two lane and normal case is small but it major between closed three lane and normal case for eight lane-divided highway. This may be due to reduced width, therefore reduced capacity and major drop in operating speed.

Table (10) present's relation between AADT and loss in national income at speed limit = 120, 110, 100, 90, 80 and 60 km/hr. for work zone lane configurations for eight lane-divided highway, six lane-divided highway and four lane-divided highway. This help the GARBLT to determine number of closed lane during maintenance operations on their highways network according to minimum loss in national income and minimum travel time costs percent.

3.3 Relation between AADT and Operating Speed

Table (11) present's relation between AADT and operating speed at speed limit = 120, 110, 100, 90, 80 and 60 km/hr. for work zone lane configurations for eight lane-divided highway, six lane-divided highway and four lane-divided highway. It is noted that the operating speed decreases with increasing number of closed lane. This decrease in operating speed may be due to reduced width, therefore reduce capacity and traffic interactions. Also, the figure shows that operating speed decreases as average annual daily traffic increases. The decreases in operating speed may be traffic interactions. These interactions result in speed fluctuations and a decrease from the free speed. It is noted that the operating speed increases with increasing speed limit for highway.

Table (12) present's relation between AADT and decreasing % in operating speed at speed limit = 120, 110, 100, 90, 80 and 60 km/hr. for work zone lane configurations for eight lane-divided highway, six lane-divided highway and four lane-divided highway. The table shows that the rate of increases between closed one lane and normal case & between closed two lane and normal case is small but it major between closed three lane and normal case for eight lane-divided highway. This may be due to reduced width and therefore capacity. This help the GARBLT to determine number of closed lane during maintenance operations on their highways network according to minimum loss in operating speed percent.

IV. Verifying The Study Results

The results obtained from this software are verifying against some actual data observed in the field. In order to achieve verifying, a framework for data collection was designed. This framework includes three main

parts; the first part is a field investigation of work zone locations on Egyptian rural highways. The second part is field data collection from previous study. The third part is data collection form about work zone in Egyptian highway. Figure (5) shows data collection framework for verifying the study result.

4.1 Field Data Collection of Work Zone Locations on Egyptian Rural Highways

Data collected from actual work zone on Ismailia-Suez Link, Suez-90 Street Link and Passos-El warraq Link for Cairo ring road highway. Data consist of geometry characteristics of each work zone, AADT, speed limit for highway, operating speed at work zone, operating speed before work zone and no. of closed lane.

4.2 Field Data Collection from Previous Study

The second part of the designed data collection framework is field data collected from previous study on Cairo/Alexandria Agriculture Road and Cairo/Alexandria Desert Road. Its data collected by Eng. Mahmoud Youssef in favor of Benha University in your master study for Safety Measures at Working Zones on Egyptian Rural Roads in 2005. Data consist of geometry and physical characteristics of each work zone, AADT, speed limit for highway and no. of closed lane.

4.3 Data Collection Form about Work Zone in Egyptian Highway

The third part of the designed data collection framework is Data Collection Form for a sample of experts in maintenance highway. Figure (6) show data collection form. About 8 forms were to be filled by experts.

4.4 Assessment of the currently no of closed lane, verifying operating speed and Suggesting of no of closed lane to be applied at work zones

In this section, the results produced by HDM-4 program are presented for all work zone selected. The results obtained from this software are verifying against some actual data observed in the field such as operating speed before work zone and operating speed at work zone. Also, this results used to assessment of the currently no. of closed lane and suggest of no. of closed lane to be applied at work zones. Table from (13) to (15) presents a summary of HDM-4 software results for work zone selected, assessment of the currently no. of closed lane and suggest no. of closed lane to be applied at work zones for all work zone selected.

4.4.1 Work Zone on Ismailia-Suez Link for Cairo Ring Road

Ismailia-Suez Link on Cairo Ring road has a speed limit 100 kph. Field operating speed before work zone equal 95 kph while operating speed before work zone from HDM-4 software equal 96 kph. field operating speed at work zone equal 85 kph while operating speed from HDM-4 software equal 88 kph. GARBLT closed two lane in one direction during maintenance this road. This causes decreasing percent in VOC equal 1.12, increasing percent in TTC equal 6.19, loss in national income equal 75574 LE, and decreasing percent in operating speed equal 7.962%.

If GARBLT closed one lane in one direction during maintenance this road. This causes decreasing percent in VOC equal 0.41, increasing percent in TTC equal 1.06, loss in national income equal 12630 LE, and decreasing percent in operating speed equal 2.053%. If GARBLT closed one direction of this road, this cases decreasing percent in VOC for two direction equal 2.32, increasing percent in TTC for two direction equal 13.76, loss in national income for two direction equal 167860 LE, and decreasing percent in operating speed for one direction equal 8.57%. If GARBLT closed three lane in one direction during maintenance this road. This causes increasing percent in VOC equal 1.77, increasing percent in TTC equal 58.56, loss in national income equal 715124 LE, and decreasing percent in operating speed equal 38.8%.

So, the search suggest closed one direction for this highway or closed two lane in one direction or closed one lane in one direction at AADT equal 13630 vpd during maintenance this road. Assessment and suggest no. of closed lane for all work zone selected shows in figure from (13) to (14) as same method suggest no. of closed lane for Work Zone on Ismailia-Suez Link for Cairo Ring Road.

V. Conclusion

The aim of this study is to determine the optimal number of closed lanes in one direction for work zone on Egyptian divided rural highways to achieve reduction in road user costs such as (TTC and VOC) through achieving suitable operating speed at the working zones. Also, to achieve reduction in loss in national income.
Based on the results of this study, the following conclusions are presented:

- Vehicle operating cost increases, Travel time cost increases and operating speed decreases with increasing average annual daily traffic. So, GARBLT should select the maintenance operating time in the day which has less average annual daily traffic.

- ❖ Vehicle operating cost decreases with increasing number of closed lane if the value of operating speed decreases from (free speed to 50 kph.).
- ❖ Vehicle operating cost increases with increasing number of closed lane if the value of operating speed decreases from (50 kph. to jam speed).
- ❖ Travel time cost increases and operating speed decreases with increasing number of closed lane.
- ❖ Vehicle operating cost increases, travel time cost decreases and operating speed increases with increasing the speed limit for highway.
- ❖ No pronounced difference in operating speed value, before and at work zone, between measured speed in field and calculated speed by HDM-4 software.

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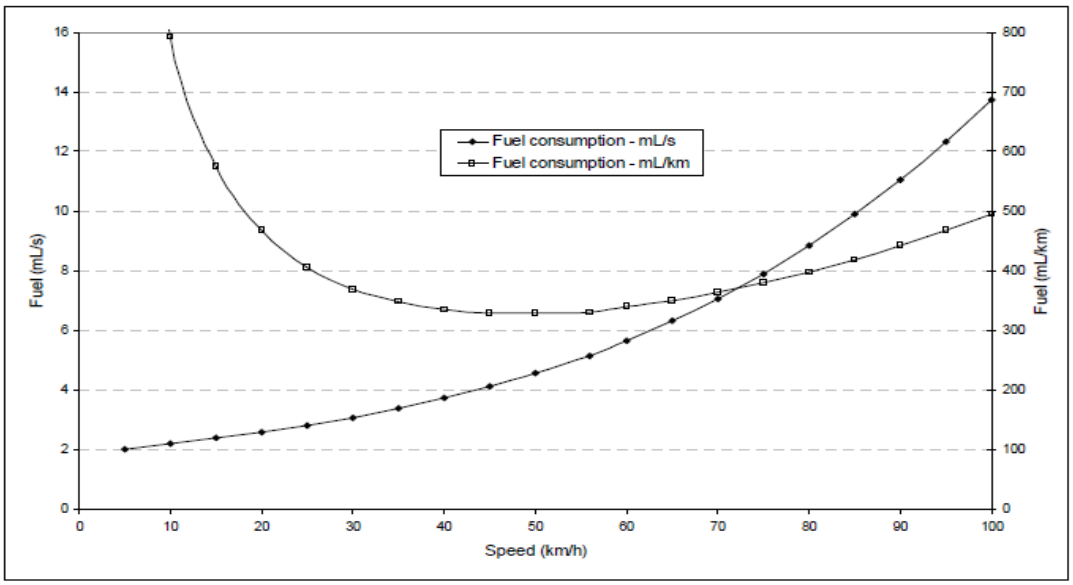


Figure (1) Predict method for fuel consumption in HDM-4 software [32].

Table (1) AADT Used for Different Work Zone Configurations at Speed Limit 120, 110, 100, 90, 80 and 60 kph.

WORK ZONE LANE CONFIGURATION					
Normal Number of Open Lanes in One Direction	Number of Open Lanes Through Work Zone in One Direction				
	1	2	3	4	Median Crossover
2	5000	5000			5000
	10000	10000			10000
	15000	15000			15000
3	5000	5000	5000		5000
	10000	10000	10000		10000
	15000	15000	15000		15000
	20000	20000	20000		20000
	25000	25000	25000		25000
4	5000	5000	5000	5000	5000
	10000	10000	10000	10000	10000
	15000	15000	15000	15000	15000
	20000	20000	20000	20000	20000
	25000	25000	25000	25000	25000
	30000	30000	30000	30000	30000
	35000	35000	35000	35000	35000

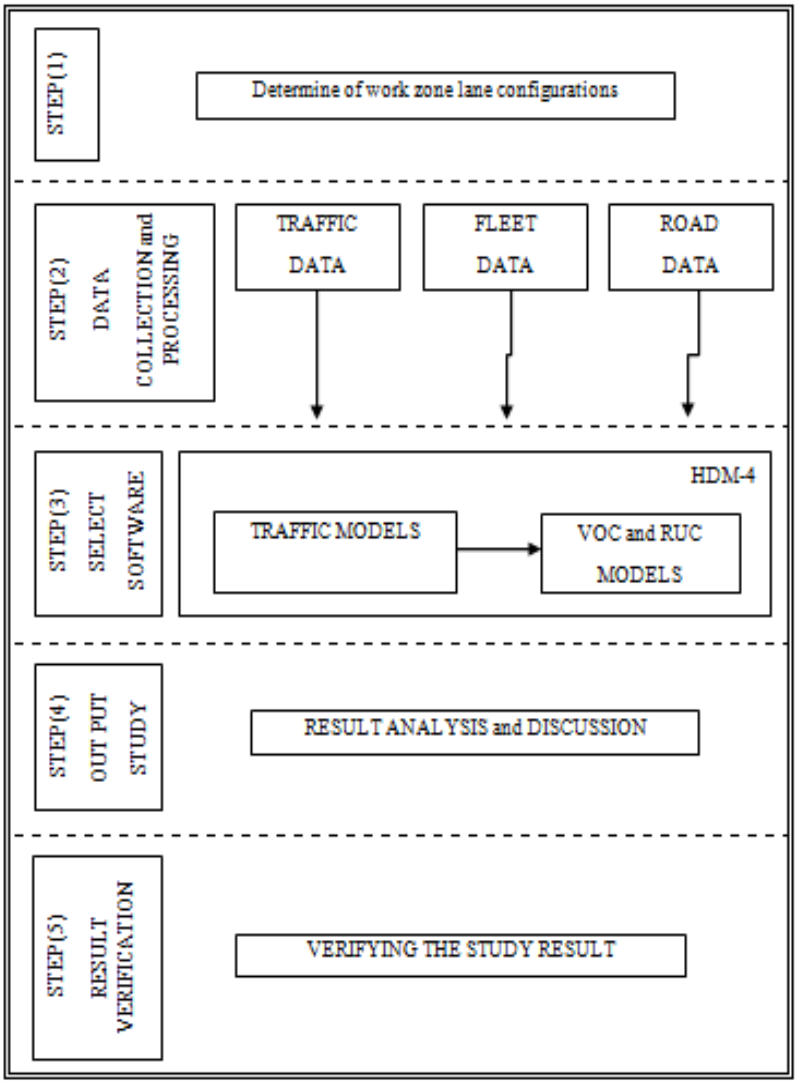


Figure (2) Research Methodology Flow Chart

Table (2) PCU and Traffic Composition are Used in this Study

Vehicle Type		PCU	Traffic Composition (%)
Bikes		0.5	8.75
Cars		1	38.25
Buses		1.6	15.35
Median Truck	2 Axle Long	1.9	25.65
	2 Axle 6 Tyres	1.9	
	3 Axle Single	2.6	
High Truck	4 Axle Single	2.6	12
	5 Axle Double	2.6	
	>5 Axle Double	2.6	
	<6 Axle Double	2.6	

Table (5) Work Zone Capacities Used in this Study

Normal Number of Open Lanes in One Direction	Number of Open Lanes Through Work Zone in One Direction PCSE/h/lane					
	0 median crossover	1	2	3	4	5
2	1100	1430				
3	1385	1320	1650			
4	1485	1320	1650	1680		
5	1550	1320	1540	1650	1705	
6	1500	1320	1430	1540	1650	1760

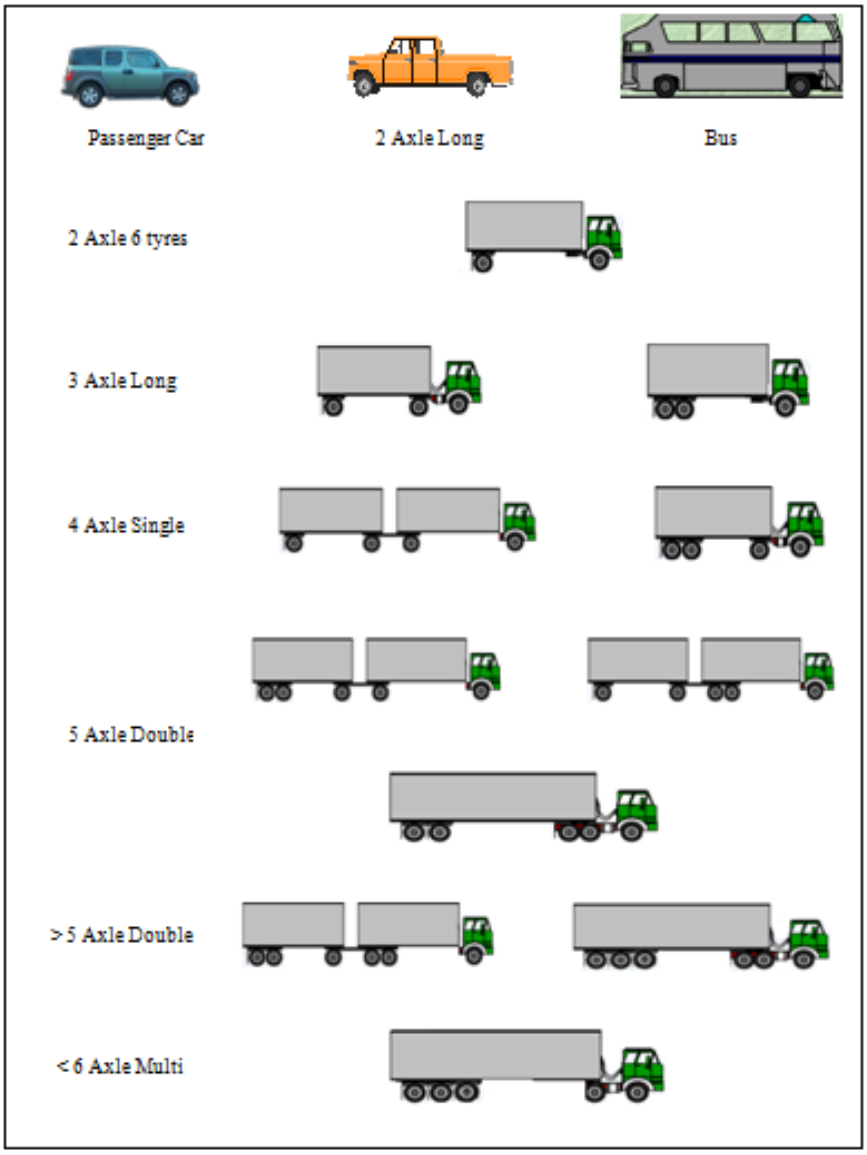


Figure (3) the Represented Vehicles

Table (3) Basic Characteristic of the Representative Fleet [3]

Definition		Basic Characteristic												
		Physical			Tyres		Utilization						Loading	
Name	Description	PCU	NO. of wheels Per Vehicle	NO. of Axle Per Vehicle	Tyre Type	Base No. oF Recaps	Average No. of KM driven per Year	Annual Working Hours	Average Life (Years)	Private Trip Use (%)	Passenger (PER)	Work Related Passenger Trip (%)	ESAL	Operating Weight (TON)
BIKES	MOTORCYCLE	0.50	2.00	2.00	PNEUMATIC	1.30	12000.00	450.00	12.00	100.00	1.10	50.00	0.00	0.10
CARS	PASSENGER CAR	1.00	4.00	2.00	RADIAL-PLY	1.30	40000.00	800.00	13.00	100.00	1.90	50.00	0.00	1.40
2 AXLE LONG	PICK UP CAR	1.90	4.00	2.00	RADIAL-PLY	1.30	60000.00	1200.00	10.00	10.00	1.30	50.00	0.01	1.50
BUSES	MEDIUM BUS	1.60	4.00	2.00	BIAS-PLY	1.30	76000.00	4800.00	10.00	10.00	38.00	50.00	0.70	6.00
2 AXLE 6 TYRES	LIGHT TRUcK	1.90	6.00	2.00	BIAS-PLY	1.30	50000.00	1300.00	10.00	0.00	1.00	100.00	0.70	2.00
3 AXLE SINGLE	MEDIUM TRUCK	1.90	10.00	3.00	BIAS-PLY	1.30	50000.00	1500.00	12.00	0.00	2.00	100.00	1.25	7.50
4 AXLE SINGLE	MEDIUM TRUCK	2.60	14.00	4.00	BIAS-PLY	1.30	75000.00	1500.00	12.00	0.00	2.00	100.00	1.25	7.50
5 AXLE DOUBLE	TRUCK TRAILER	2.60	18.00	5.00	BIAS-PLY	1.30	125000.00	2250.00	13.00	0.00	3.00	100.00	2.28	13.00
>5 AXLE DOUBLE	TRUCK TRAILER	2.60	22.00	6.00	BIAS-PLY	1.30	125000.00	2250.00	13.00	0.00	3.00	100.00	2.28	13.00
<6 AXLE Multi	SEMI TRAILER	2.60	18.00	5.00	BIAS-PLY	1.30	125000.00	2250.00	13.00	0.00	3.00	100.00	2.28	13.00

Table (4) Economic Unit Cost of the Representative Fleet [3]

DEFINITION		Ecconomic Unit cost										
		VEHICLE RESOURCSE COST								TIME VALUE		
NAME	DESCRIPTION	NEW VEHICLE	REPLACEMENT TYRE (PER ONE)	FUEL (Per Liter)	LUBRICATION OIL (per liter)	MAINTENANCE LABOUR (Per Hours)	CROW WAGES (Per Hours)	ANNUAL OVERHEAD (Per Hours)	ANNUAL INTEREST	PASSENGER WORKING TIME VALUE (Per Hours)	PASSENGER NON. WORKING TIME (Per Hours)	CARGO (Per Veh-Hrs)
BIKES	MOTORCYCLE	7000	100	1.60	8.00	6.00	-	100.00	12.00	4.32	2.16	-
CARS	PASSENGER CAR	53000	250	2.60	10.00	10.00	-	300.00	12.00	5.66	2.84	0.00
2 AXLE LONG	PICK UP CAR	60000	250	1.60	6.40	3.00	3.60	600.00	12.00	2.30	1.16	0.00
BUSES	MEDIUM BUS	275000	1030	1.80	6.40	3.76	6.00	12000.00	12.00	2.30	1.16	0.00
2 AXLE 6 TYRES	LIGHT TRUCK	110000	900	1.60	12.00	8.00	9.00	2000.00	12.00	9.00	4.50	9.00
3 AXLE SINGLE	MEDIUM TRUCK	500000	2500	1.60	12.00	8.00	10.00	4000.00	12.00	10.00	5.00	10.00
4 AXLE SINGLE	MEDIUM TRUCK	600000	2500	1.60	12.00	8.00	10.00	8000.00	12.00	10.00	5.00	10.00
5 AXLE DOUBLE	TRUCK TRAILER	800000	2500	1.60	12.00	8.00	10.00	8000.00	12.00	10.00	5.00	10.00
>5 AXLE DOUBLE	TRUCK TRAILER	800000	2500	1.60	12.00	8.00	10.00	8000.00	12.00	10.00	5.00	10.00
<6 AXLE Multi	SEMI TRAILER	700000	2500	1.60	12.00	8.00	10.00	8000.00	12.00	10.00	5.00	10.00

- **All Costs are in Egyptian Pound.**

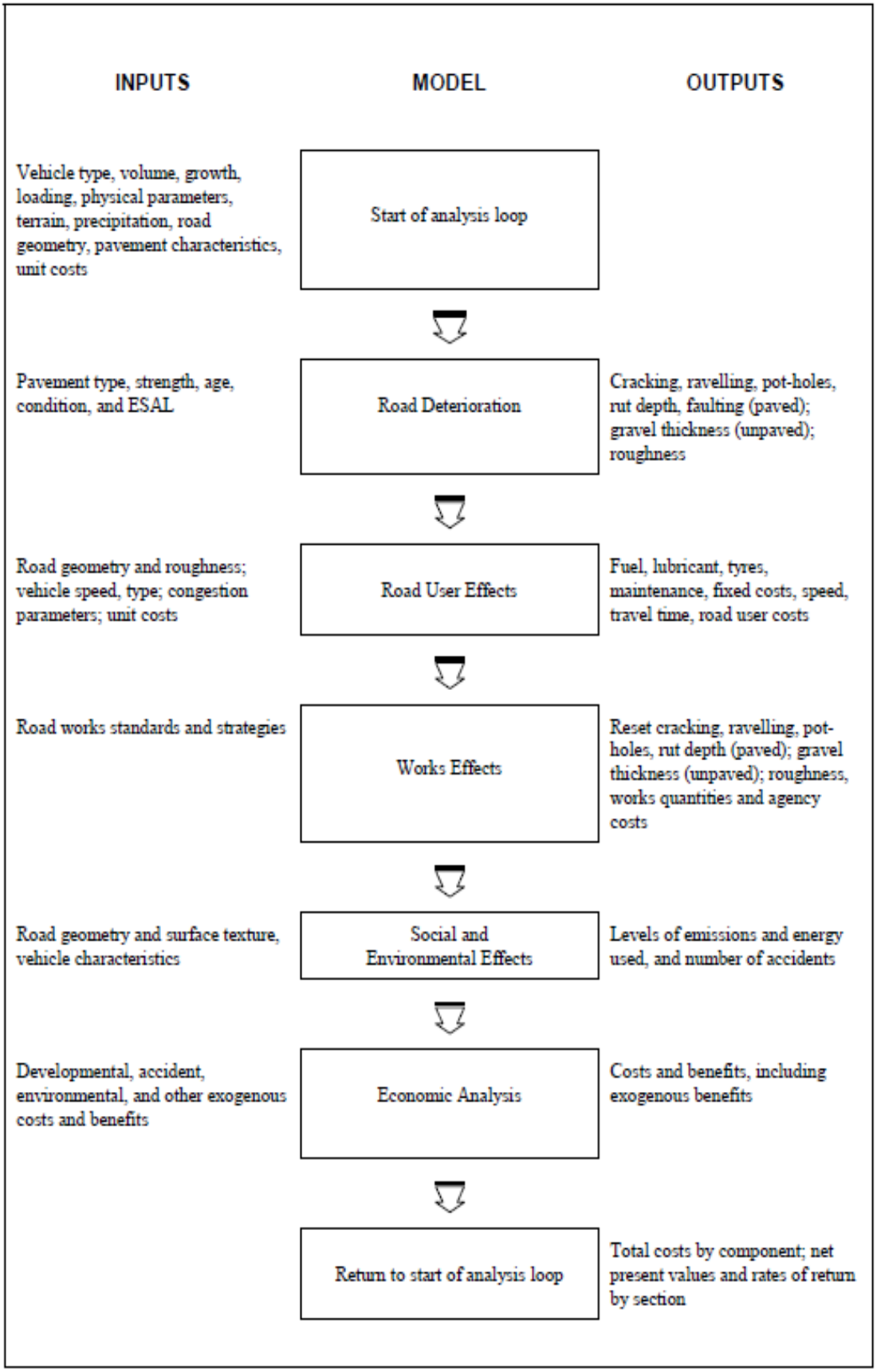


Figure (4) Overall Structure of HDM-4 Models [5]

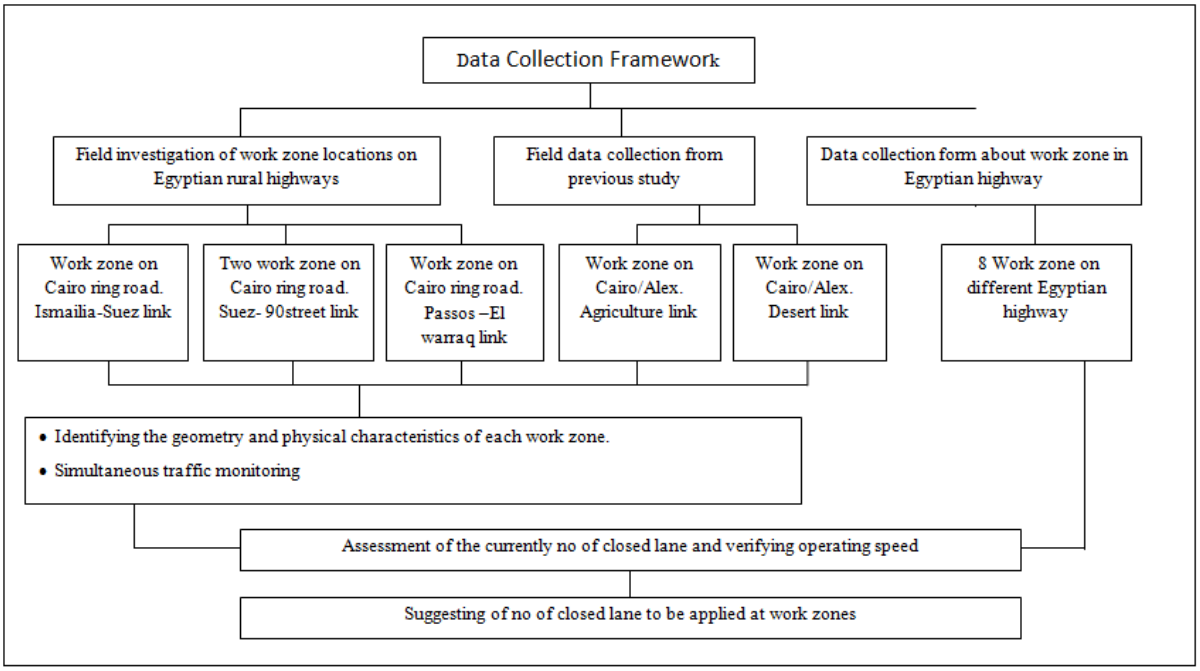
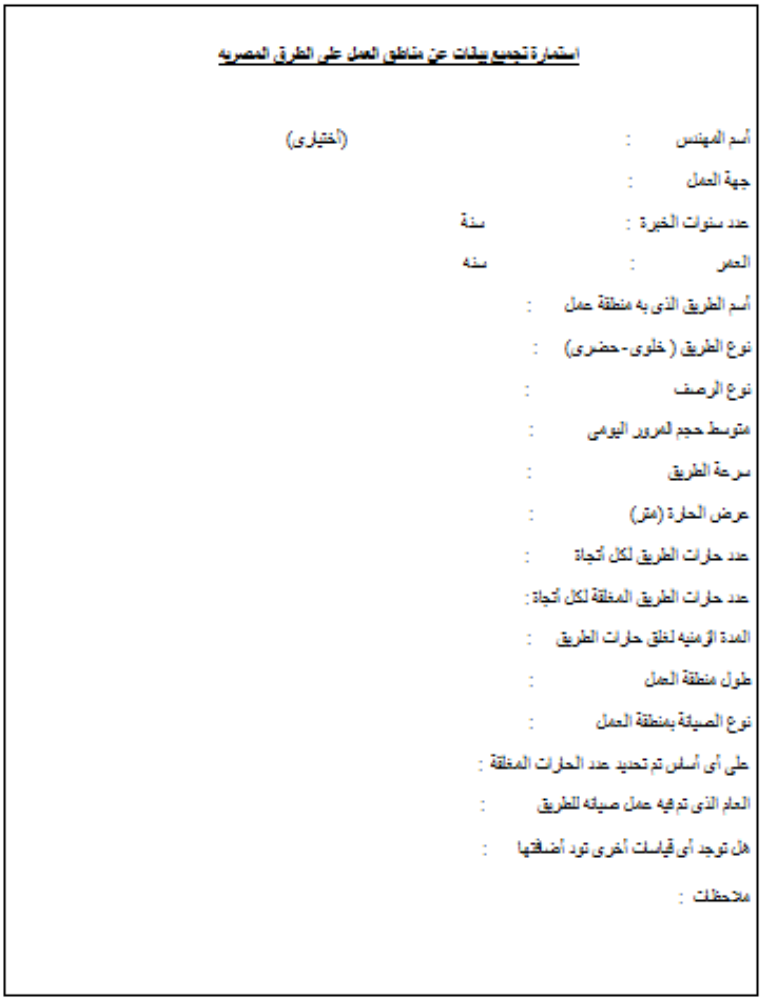


Figure (5) Data Collection Framework for Verifying the Study Result study result



استمارة تجميع بيانات عن مناطق العمل على الطرق المصريه

أسم المهندس : (أختيارى)

جهة العمل :

عدد سنوات الخبرة : سنة

العمر : سنه

أسم الطريق الذى به منطقة عمل :

نوع الطريق (خلوى - حضرى) :

نوع الرصف :

متوسط حجم المرور اليومى :

سرعة الطريق :

عرض الحارة (متر) :

عدد حارات الطريق لكل أتجاة :

عدد حارات الطريق المغلقة لكل أتجاة :

المدة الزمنيه لغلق حارات الطريق :

طول منطقة العمل :

نوع الصيانة بمنطقة العمل :

على أى أساس تم تحديد عدد الحارات المغلقة :

العام الذى تم فيه عمل صيانه للطريق :

هل توجد أى قياسات أخرى تود أضافتها :

ملاحظات :

Figure (6) Data Collection Form about Work Zone in Egyptian Highway

Table (6) Relation between AADT and VOC

AADT	Speed Limit	VOC (10^3 * LE/veh.km)											
		Eight Lane - Divided Highway					Six Lane - Divided Highway				Four Lane - Divided Highway		
		Before Work Zone (Four Lane Open)	4 to 3 One Lane Closed Section	4 to 2 Two Lane Closed Section	Median Crossover Section	4 to 1 Three Lane Closed Section	Before Work Zone (Three Lane Open)	3 to 2 One Lane Closed Section	Median Crossover Section	3 to 1 Two Lane Closed Section	Before Work Zone (Two Lane Open)	2 to 1 One Lane Closed Section	Median Crossover Section
5000	120	2599	2586	2572	2572	2504	2586	2572	2571	2504	2572	2505	2504
	110	2588	2575	2562	2562	2504	2575	2562	2561	2504	2562	2505	2504
	100	2570	2558	2546	2546	2504	2558	2546	2546	2504	2546	2504	2503
	90	2534	2535	2524	2524	2498	2535	2524	2524	2498	2524	2498	2499
	80	2493	2493	2495	2495	2489	2493	2495	2495	2489	2495	2488	2491
	60	2462	2462	2464	2464	2488	2462	2464	2464	2488	2464	2486	2493
10000	120	5204	5178	5135	5131	5047	5178	5135	5128	5047	5142	5041	5129
	110	5181	5157	5118	5114	5047	5157	5118	5112	5047	5123	5041	5129
	100	5145	5123	5091	5089	5047	5123	5091	5087	5047	5095	5041	5129
	90	5074	5077	5051	5050	5044	5077	5051	5049	5044	5054	5038	5129
	80	4991	4994	4999	4999	5041	4994	4999	5000	5041	4999	5033	5130
	60	4929	4932	4949	4952	5064	4932	4949	4955	5064	4944	5054	5153
15000	120	7814	7777	7690	7682	7969	7777	7690	7677	7969	7704	7873	8702
	110	7780	7746	7669	7663	7969	7746	7669	7659	7969	7680	7873	8702
	100	7726	7695	7637	7634	7969	7695	7637	7632	7969	7644	7873	8702
	90	7620	7626	7585	7584	7970	7626	7585	7584	7970	7589	7874	8702
	80	7496	7502	7516	7518	7971	7502	7516	7519	7971	7515	7876	8702
	60	7403	7409	7462	7471	7997	7409	7462	7478	7997	7449	7908	8749
20000	120	10430	10367	10247	10241	13169	10383	10247	10236	13169	-	-	-
	110	10384	10327	10226	10220	13169	10341	10226	10217	13169	-	-	-
	100	10312	10261	10194	10190	13169	10274	10194	10188	13169	-	-	-
	90	10172	10172	10133	10134	13169	10183	10133	10138	13169	-	-	-
	80	10006	10017	10050	10057	13169	10018	10050	10066	13169	-	-	-
	60	9882	9905	10010	10035	13262	9894	10010	10054	13262	-	-	-
25000	120	13051	12945	12813	12834	17597	12970	12813	12899	17597	-	-	-
	110	12995	12897	12791	12815	17597	12920	12791	12883	17597	-	-	-
	100	12905	12820	12758	12790	17597	12840	12758	12859	17597	-	-	-
	90	12730	12714	12699	12739	17597	12730	12699	12810	17597	-	-	-
	80	12523	12541	12611	12659	17597	12540	12611	12733	17597	-	-	-
	60	12368	12426	12606	12676	17703	12405	12606	12772	17703	-	-	-
30000	120	15678	15522	15520	15648	-	-	-	-	-	-	-	-
	110	15611	15466	15501	15636	-	-	-	-	-	-	-	-
	100	15504	15380	15473	15616	-	-	-	-	-	-	-	-
	90	15294	15259	15412	15562	-	-	-	-	-	-	-	-
	80	15047	15077	15322	15499	-	-	-	-	-	-	-	-
	60	14861	14972	15372	15573	-	-	-	-	-	-	-	-
35000	120	18311	18099	18386	18647	-	-	-	-	-	-	-	-
	110	18234	18040	18371	18639	-	-	-	-	-	-	-	-
	100	18109	17948	18348	18626	-	-	-	-	-	-	-	-
	90	17865	17815	18297	18587	-	-	-	-	-	-	-	-
	80	17577	17626	18227	18525	-	-	-	-	-	-	-	-
	60	17361	17547	18341	18666	-	-	-	-	-	-	-	-

Table (7) Relation between AADT and Increasing % in VOC

AADT	Speed Limit	Decreasing % in Vehicle Operation Cost Between Work Zone Sections and Before Work Zone Section								
		Eight Lane - Divided Highway				Six Lane - Divided Highway			Four Lane - Divided Highway	
		4 to 3 One Lane Closed Section	4 to 2 Two Lane Closed Section	Median Crossover Section	4 to 1 Three Lane Closed Section	3 to 2 One Lane Closed Section	Median Crossover Section	3 to 1 Two Lane Closed Section	2 to 1 One Lane Closed Section	Median Crossover Section
5000	120	-0.50	-1.04	-1.04	-3.66	-0.54	-0.58	-3.17	-2.60	-2.64
	110	-0.50	-1.00	-1.00	-3.25	-0.50	-0.54	-2.76	-2.22	-2.26
	100	-0.47	-0.93	-0.93	-2.57	-0.47	-0.47	-2.11	-1.65	-1.69
	90	0.04	-0.39	-0.39	-1.42	-0.43	-0.43	-1.46	-1.03	-0.99
	80	0.00	0.08	0.08	-0.16	0.08	0.08	-0.16	-0.28	-0.16
	60	0.00	0.08	0.08	1.06	0.08	0.08	1.06	0.89	1.18
10000	120	-0.50	-1.33	-1.40	-3.02	-0.83	-0.97	-2.53	-1.96	-0.25
	110	-0.46	-1.22	-1.29	-2.59	-0.76	-0.87	-2.13	-1.60	0.12
	100	-0.43	-1.05	-1.09	-1.90	-0.62	-0.70	-1.48	-1.06	0.67
	90	0.06	-0.45	-0.47	-0.59	-0.51	-0.55	-0.65	-0.32	1.48
	80	0.06	0.16	0.16	1.00	0.10	0.12	0.94	0.68	2.62
	60	0.06	0.41	0.47	2.74	0.34	0.47	2.68	2.22	4.23
15000	120	-0.47	-1.59	-1.69	1.98	-1.12	-1.29	2.47	2.19	12.95
	110	-0.44	-1.43	-1.50	2.43	-0.99	-1.12	2.88	2.51	13.31
	100	-0.40	-1.15	-1.19	3.15	-0.75	-0.82	3.56	3.00	13.84
	90	0.08	-0.46	-0.47	4.59	-0.54	-0.55	4.51	3.76	14.67
	80	0.08	0.27	0.29	6.34	0.19	0.23	6.25	4.80	15.80
	60	0.08	0.80	0.92	8.02	0.72	0.93	7.94	6.16	17.45
20000	120	-0.60	-1.75	-1.81	26.26	-1.31	-1.42	26.83	-	-
	110	-0.55	-1.52	-1.58	26.82	-1.11	-1.20	27.35	-	-
	100	-0.49	-1.14	-1.18	27.71	-0.78	-0.84	28.18	-	-
	90	0.00	-0.38	-0.37	29.46	-0.49	-0.44	29.32	-	-
	80	0.11	0.44	0.51	31.61	0.32	0.48	31.45	-	-
	60	0.23	1.30	1.55	34.20	1.17	1.62	34.04	-	-
25000	120	-0.81	-1.82	-1.66	34.83	-1.21	-0.55	35.67	-	-
	110	-0.75	-1.57	-1.39	35.41	-1.00	-0.29	36.20	-	-
	100	-0.66	-1.14	-0.89	36.36	-0.64	0.15	37.05	-	-
	90	-0.13	-0.24	0.07	38.23	-0.24	0.63	38.23	-	-
	80	0.14	0.70	1.09	40.52	0.57	1.54	40.33	-	-
	60	0.47	1.92	2.49	43.14	1.62	2.96	42.71	-	-
30000	120	-1.00	-1.01	-0.19	-	-	-	-	-	-
	110	-0.93	-0.70	0.16	-	-	-	-	-	-
	100	-0.80	-0.20	0.72	-	-	-	-	-	-
	90	-0.23	0.77	1.75	-	-	-	-	-	-
	80	0.20	1.83	3.00	-	-	-	-	-	-
	60	0.75	3.44	4.79	-	-	-	-	-	-
35000	120	-1.16	0.41	1.83	-	-	-	-	-	-
	110	-1.06	0.75	2.22	-	-	-	-	-	-
	100	-0.89	1.32	2.85	-	-	-	-	-	-
	90	-0.28	2.42	4.04	-	-	-	-	-	-
	80	0.28	3.70	5.39	-	-	-	-	-	-
	60	1.07	5.64	7.52	-	-	-	-	-	-

Table (8) Relation between AADT and TTC

AADT	Speed Limit	Travel Time Costs (10^3 * LE/veh.km)											
		Eight Lane - Divided Highway					Six Lane - Divided Highway				Four Lane - Divided Highway		
		Before Work Zone (Four Lane Open)	4 to 3 One Lane Closed Section	4 to 2 Two Lane Closed Section	Median Crossover Section	4 to 1 Three Lane Closed Section	Before Work Zone (Three Lane Open)	3 to 2 One Lane Closed Section	Median Crossover Section	3 to 1 Two Lane Closed Section	Before Work Zone (Two Lane Open)	2 to 1 One Lane Closed Section	Median Crossover Section
5000	120	417	423	432	432	549	423	432	432	549	432	544	562
	110	424	429	438	438	549	429	438	438	549	438	544	562
	100	436	440	447	447	549	440	447	448	549	447	545	562
	90	460	460	466	466	559	460	466	466	559	466	554	571
	80	497	497	497	497	579	497	497	498	579	497	575	591
	60	636	636	636	636	669	636	636	636	669	636	666	676
10000	120	835	847	882	887	1243	847	882	890	1243	875	1218	1312
	110	848	859	893	898	1243	859	893	901	1243	886	1218	1312
	100	872	881	912	916	1243	881	912	919	1243	905	1218	1312
	90	919	920	947	951	1256	920	947	954	1256	941	1233	1323
	80	995	995	1012	1016	1284	995	1012	1019	1284	1005	1263	1343
	60	1271	1271	1291	1296	1412	1271	1291	1300	1412	1283	1400	1444
15000	120	1252	1270	1356	1367	2153	1270	1356	1376	2153	1339	2078	3063
	110	1272	1289	1372	1382	2153	1289	1372	1390	2153	1355	2078	3063
	100	1308	1322	1397	1407	2153	1322	1397	1414	2153	1382	2078	3063
	90	1379	1380	1449	1459	2157	1380	1449	1465	2157	1435	2087	3063
	80	1492	1493	1548	1558	2164	1493	1548	1566	2164	1532	2104	3063
	60	1907	1907	1972	1984	2243	1907	1972	1993	2243	1954	2213	3139
20000	120	1671	1709	1855	1876	6189	1695	1855	1891	6189	-	-	-
	110	1697	1733	1874	1894	6189	1719	1874	1908	6189	-	-	-
	100	1745	1778	1904	1922	6189	1764	1904	1936	6189	-	-	-
	90	1840	1856	1971	1989	6189	1840	1971	2001	6189	-	-	-
	80	1990	2007	2106	2125	6189	1991	2106	2139	6189	-	-	-
	60	2543	2562	2678	2700	6317	2543	2678	2716	6317	-	-	-
25000	120	2090	2168	2380	2415	11018	2143	2380	2440	11018	-	-	-
	110	2123	2199	2400	2433	11018	2174	2400	2458	11018	-	-	-
	100	2182	2257	2434	2464	11018	2231	2434	2486	11018	-	-	-
	90	2300	2356	2515	2543	11018	2328	2515	2564	11018	-	-	-
	80	2488	2546	2687	2718	11018	2516	2687	2741	11018	-	-	-
	60	3179	3246	3410	3446	11155	3212	3410	3472	11155	-	-	-
30000	120	2509	2641	2933	2986	-	-	-	-	-	-	-	-
	110	2549	2680	2954	3004	-	-	-	-	-	-	-	-
	100	2620	2751	2987	3033	-	-	-	-	-	-	-	-
	90	2761	2872	3081	3124	-	-	-	-	-	-	-	-
	80	2987	3100	3293	3340	-	-	-	-	-	-	-	-
	60	3815	3948	4171	4224	-	-	-	-	-	-	-	-
35000	120	2929	3128	3517	3593	-	-	-	-	-	-	-	-
	110	2975	3175	3536	3608	-	-	-	-	-	-	-	-
	100	3058	3260	3567	3632	-	-	-	-	-	-	-	-
	90	3223	3404	3672	3733	-	-	-	-	-	-	-	-
	80	3485	3672	3926	3992	-	-	-	-	-	-	-	-
	60	4451	4669	4961	5037	-	-	-	-	-	-	-	-

Table (9) Relation between AADT and Increasing % in TTC

AADT	Speed Limit	Increasing % in Travel Time Cost Between Work Zone Sections and Before Work Zone Section								
		Eight Lane - Divided Highway				Six Lane - Divided Highway			Four Lane - Divided Highway	
		4 to 3 One Lane Closed Section	4 to 2 Two Lane Closed Section	Median Crossover Section	4 to 1 Three Lane Closed Section	3 to 2 One Lane Closed Section	Median Crossover Section	3 to 1 Two Lane Closed Section	2 to 1 One Lane Closed Section	Median Crossover Section
5000	120	1.44	3.60	3.60	31.65	2.13	2.13	29.79	25.93	30.09
	110	1.18	3.30	3.30	29.48	2.10	2.10	27.97	24.20	28.31
	100	0.92	2.52	2.52	25.92	1.59	1.82	24.77	21.92	25.73
	90	0.00	1.30	1.30	21.52	1.30	1.30	21.52	18.88	22.53
	80	0.00	0.00	0.00	16.50	0.00	0.20	16.50	15.69	18.91
	60	0.00	0.00	0.00	5.19	0.00	0.00	5.19	4.72	6.29
10000	120	1.44	5.63	6.23	48.86	4.13	5.08	46.75	39.20	49.94
	110	1.30	5.31	5.90	46.58	3.96	4.89	44.70	37.47	48.08
	100	1.03	4.59	5.05	42.55	3.52	4.31	41.09	34.59	44.97
	90	0.11	3.05	3.48	36.67	2.93	3.70	36.52	31.03	40.60
	80	0.00	1.71	2.11	29.05	1.71	2.41	29.05	25.67	33.63
	60	0.00	1.57	1.97	11.09	1.57	2.28	11.09	9.12	12.55
15000	120	1.44	8.31	9.19	71.96	6.77	8.35	69.53	55.19	128.75
	110	1.34	7.86	8.65	69.26	6.44	7.84	67.03	53.36	126.05
	100	1.07	6.80	7.57	64.60	5.67	6.96	62.86	50.36	121.64
	90	0.07	5.08	5.80	56.42	5.00	6.16	56.30	45.44	113.45
	80	0.07	3.75	4.42	45.04	3.68	4.89	44.94	37.34	99.93
	60	0.00	3.41	4.04	17.62	3.41	4.51	17.62	13.25	60.64
20000	120	2.27	11.01	12.27	270.38	9.44	11.56	265.13	-	-
	110	2.12	10.43	11.61	264.70	9.02	10.99	260.03	-	-
	100	1.89	9.11	10.14	254.67	7.94	9.75	250.85	-	-
	90	0.87	7.12	8.10	236.36	7.12	8.75	236.36	-	-
	80	0.85	5.83	6.78	211.01	5.78	7.43	210.85	-	-
	60	0.75	5.31	6.17	148.41	5.31	6.80	148.41	-	-
25000	120	3.73	13.88	15.55	427.18	11.06	13.86	414.14	-	-
	110	3.58	13.05	14.60	418.98	10.40	13.06	406.81	-	-
	100	3.44	11.55	12.92	404.95	9.10	11.43	393.86	-	-
	90	2.43	9.35	10.57	379.04	8.03	10.14	373.28	-	-
	80	2.33	8.00	9.24	342.85	6.80	8.94	337.92	-	-
	60	2.11	7.27	8.40	250.90	6.16	8.09	247.29	-	-
30000	120	5.26	16.90	19.01	-	-	-	-	-	-
	110	5.14	15.89	17.85	-	-	-	-	-	-
	100	5.00	14.01	15.76	-	-	-	-	-	-
	90	4.02	11.59	13.15	-	-	-	-	-	-
	80	3.78	10.24	11.82	-	-	-	-	-	-
	60	3.49	9.33	10.72	-	-	-	-	-	-
35000	120	6.79	20.08	22.67	-	-	-	-	-	-
	110	6.72	18.86	21.28	-	-	-	-	-	-
	100	6.61	16.64	18.77	-	-	-	-	-	-
	90	5.62	13.93	15.82	-	-	-	-	-	-
	80	5.37	12.65	14.55	-	-	-	-	-	-
	60	4.90	11.46	13.17	-	-	-	-	-	-

Table (10) Relation between AADT and Loss in National Income

AADT	Speed Limit	Loss in National Income Between Work Zone Sections and Before Work Zone Section								
		Eight Lane - Divided Highway				Six Lane - Divided Highway			Four Lane - Divided Highway	
		4 to 3 One Lane Closed Section	4 to 2 Two Lane Closed Section	Median Crossover Section	4 to 1 Three Lane Closed Section	3 to 2 One Lane Closed Section	Median Crossover Section	3 to 1 Two Lane Closed Section	2 to 1 One Lane Closed Section	Median Crossover Section
5000	120	6000	15000	15000	132000	9000	9000	126000	112000	130000
	110	5000	14000	14000	125000	9000	9000	120000	106000	124000
	100	4000	11000	11000	113000	7000	8000	109000	98000	115000
	90	0	6000	6000	99000	6000	6000	99000	88000	105000
	80	0	0	0	82000	0	1000	82000	78000	94000
	60	0	0	0	33000	0	0	33000	30000	40000
10000	120	12000	47000	52000	408000	35000	43000	396000	343000	437000
	110	11000	45000	50000	395000	34000	42000	384000	332000	426000
	100	9000	40000	44000	371000	31000	38000	362000	313000	407000
	90	1000	28000	32000	337000	27000	34000	336000	292000	382000
	80	0	17000	21000	289000	17000	24000	289000	258000	338000
	60	0	20000	25000	141000	20000	29000	141000	117000	161000
15000	120	18000	104000	115000	901000	86000	106000	883000	739000	1724000
	110	17000	100000	110000	881000	83000	101000	864000	723000	1708000
	100	14000	89000	99000	845000	75000	92000	831000	696000	1681000
	90	1000	70000	80000	778000	69000	85000	777000	652000	1628000
	80	1000	56000	66000	672000	55000	73000	671000	572000	1531000
	60	0	65000	77000	336000	65000	86000	336000	259000	1185000
20000	120	38000	184000	205000	4518000	160000	196000	4494000	-	-
	110	36000	177000	197000	4492000	155000	189000	4470000	-	-
	100	33000	159000	177000	4444000	140000	172000	4425000	-	-
	90	16000	131000	149000	4349000	131000	161000	4349000	-	-
	80	17000	116000	135000	4199000	115000	148000	4198000	-	-
	60	19000	135000	157000	3774000	135000	173000	3774000	-	-
25000	120	78000	290000	325000	8928000	237000	297000	8875000	-	-
	110	76000	277000	310000	8895000	226000	284000	8844000	-	-
	100	75000	252000	282000	8836000	203000	255000	8787000	-	-
	90	56000	215000	243000	8718000	187000	236000	8690000	-	-
	80	58000	199000	230000	8530000	171000	225000	8502000	-	-
	60	67000	231000	267000	7976000	198000	260000	7943000	-	-
30000	120	132000	424000	477000	-	-	-	-	-	-
	110	131000	405000	455000	-	-	-	-	-	-
	100	131000	367000	413000	-	-	-	-	-	-
	90	111000	320000	363000	-	-	-	-	-	-
	80	113000	306000	353000	-	-	-	-	-	-
	60	133000	356000	409000	-	-	-	-	-	-
35000	120	199000	588000	664000	-	-	-	-	-	-
	110	200000	561000	633000	-	-	-	-	-	-
	100	202000	509000	574000	-	-	-	-	-	-
	90	181000	449000	510000	-	-	-	-	-	-
	80	187000	441000	507000	-	-	-	-	-	-
	60	218000	510000	586000	-	-	-	-	-	-

Table (11) Relation between AADT and Operating Speed

AADT	Speed Limit	Operating Speed (Km/hr)											
		Eight Lane - Divided Highway					Six Lane - Divided Highway				Four Lane - Divided Highway		
		Before Work Zone (Four Lane Open)	4 to 3 One Lane Closed Section	4 to 2 Two Lane Closed Section	Median Crossover Section	4 to 1 Three Lane Closed Section	Before Work Zone (Three Lane Open)	3 to 2 One Lane Closed Section	Median Crossover Section	3 to 1 Two Lane Closed Section	Before Work Zone (Two Lane Open)	2 to 1 One Lane Closed Section	Median Crossover Section
5000	120	99.72	97.33	94.35	94.35	72.8	97.33	94.35	94.2	72.8	94.35	73.43	71.18
	110	98.41	96.19	93.24	93.24	72.8	96.19	93.24	93.1	72.8	93.24	73.43	71.18
	100	96.05	94.08	91.5	91.5	72.68	94.08	91.5	91.37	72.68	91.5	73.3	71.06
	90	90.64	90.63	88.3	88.3	71.42	90.63	88.3	88.18	71.42	88.3	71.99	69.92
	80	83.13	83.13	83.12	83.12	69.2	83.13	83.12	83.01	69.2	83.12	69.7	67.91
	60	64.3	64.3	64.3	64.3	61.01	64.3	64.3	64.22	61.01	64.3	61.26	60.35
10000	120	99.68	97.29	92.33	91.83	64.66	97.29	92.33	91.48	64.66	93.12	65.91	61.41
	110	98.37	96.15	91.34	90.87	64.66	96.15	91.34	90.53	64.66	92.08	65.91	61.41
	100	96.02	94.04	89.77	89.34	64.59	94.04	89.77	89.04	64.59	90.44	65.83	61.37
	90	90.62	90.61	86.74	86.36	63.92	90.61	86.74	86.08	63.92	87.35	65.07	60.94
	80	83.12	83.12	81.61	81.23	62.75	83.12	81.61	80.96	62.75	82.21	63.74	60.17
	60	64.3	64.3	63.29	63.03	57.71	64.3	63.29	62.85	57.71	63.69	58.22	56.4
15000	120	99.63	97.24	90.04	89.3	56.54	97.24	90.04	88.76	56.54	91.22	58.41	39.84
	110	98.33	96.1	89.18	88.47	56.54	96.1	89.18	87.97	56.54	90.29	58.41	39.84
	100	95.98	94.01	87.81	87.17	56.54	94.01	87.81	86.71	56.54	88.82	58.39	39.84
	90	90.59	90.58	84.98	84.4	56.45	90.58	84.98	83.98	56.45	85.89	58.17	39.84
	80	83.11	83.1	79.89	79.32	56.31	83.1	79.89	78.92	56.31	80.78	57.79	39.84
	60	64.3	64.3	62.13	61.75	54.41	64.3	62.13	61.47	54.41	62.74	55.17	38.88
20000	120	99.59	96.36	87.76	86.77	26.29	97.19	87.76	86.06	26.29	-	-	-
	110	98.28	95.22	87.02	86.09	26.29	96.06	87.02	85.41	26.29	-	-	-
	100	95.95	93.12	85.86	85	26.29	93.97	85.86	84.39	26.29	-	-	-
	90	90.57	89.69	83.21	82.43	26.29	90.55	83.21	81.88	26.29	-	-	-
	80	83.1	82.36	78.17	77.41	26.29	83.09	78.17	76.87	26.29	-	-	-
	60	64.3	63.8	60.98	60.46	25.76	64.29	60.98	60.09	25.76	-	-	-
25000	120	99.54	94.85	85.49	84.26	15.9	96.02	85.49	83.36	15.9	-	-	-
	110	98.24	93.7	84.88	83.71	15.9	94.88	84.88	82.86	15.9	-	-	-
	100	95.91	91.59	83.91	82.84	15.9	92.78	83.91	82.08	15.9	-	-	-
	90	90.55	88.17	81.43	80.47	15.9	89.37	81.43	79.77	15.9	-	-	-
	80	83.09	81.07	76.44	75.5	15.9	82.09	76.44	74.82	15.9	-	-	-
	60	64.29	62.94	59.82	59.18	15.7	63.62	59.82	58.72	15.7	-	-	-
30000	120	99.48	93.35	83.23	81.75	-	-	-	-	-	-	-	-
	110	98.19	92.19	82.74	81.34	-	-	-	-	-	-	-	-
	100	95.87	90.06	81.96	80.69	-	-	-	-	-	-	-	-
	90	90.52	86.65	79.65	78.5	-	-	-	-	-	-	-	-
	80	83.07	79.78	74.72	73.58	-	-	-	-	-	-	-	-
	60	64.29	62.07	58.66	57.89	-	-	-	-	-	-	-	-
35000	120	99.43	91.85	80.97	79.25	-	-	-	-	-	-	-	-
	110	98.14	90.67	80.6	78.97	-	-	-	-	-	-	-	-
	100	95.83	88.53	80.02	78.54	-	-	-	-	-	-	-	-
	90	90.5	85.13	77.87	76.52	-	-	-	-	-	-	-	-
	80	83.06	78.49	72.98	71.66	-	-	-	-	-	-	-	-
	60	64.29	61.21	57.5	56.61	-	-	-	-	-	-	-	-

Table (12) Relation between AADT and Decreasing % in Operating Speed

AADT	Speed Limit	Decreasing % in Operating Speed Between Work Zone Sections and Before Work Zone Section								
		Eight Lane - Divided Highway				Six Lane - Divided Highway			Four Lane - Divided Highway	
		4 to 3 One Lane Closed Section	4 to 2 Two Lane Closed Section	Median Crossover Section	4 to 1 Three Lane Closed Section	3 to 2 One Lane Closed Section	Median Crossover Section	3 to 1 Two Lane Closed Section	2 to 1 One Lane Closed Section	Median Crossover Section
5000	120	-2.40	-5.39	-5.39	-27.00	-3.06	-3.22	-25.20	-22.17	-24.56
	110	-2.26	-5.25	-5.25	-26.02	-3.07	-3.21	-24.32	-21.25	-23.66
	100	-2.05	-4.74	-4.74	-24.33	-2.74	-2.88	-22.75	-19.89	-22.34
	90	-0.01	-2.58	-2.58	-21.20	-2.57	-2.70	-21.20	-18.47	-20.82
	80	0.00	-0.01	-0.01	-16.76	-0.01	-0.14	-16.76	-16.15	-18.30
	60	0.00	0.00	0.00	-5.12	0.00	-0.12	-5.12	-4.73	-6.14
10000	120	-2.40	-7.37	-7.88	-35.13	-5.10	-5.97	-33.54	-29.22	-34.05
	110	-2.26	-7.15	-7.62	-34.27	-5.00	-5.85	-32.75	-28.42	-33.31
	100	-2.06	-6.51	-6.96	-32.73	-4.54	-5.32	-31.32	-27.21	-32.14
	90	-0.01	-4.28	-4.70	-29.46	-4.27	-5.00	-29.46	-25.51	-30.23
	80	0.00	-1.82	-2.27	-24.51	-1.82	-2.60	-24.51	-22.47	-26.81
	60	0.00	-1.57	-1.98	-10.25	-1.57	-2.26	-10.25	-8.59	-11.45
15000	120	-2.40	-9.63	-10.37	-43.25	-7.40	-8.72	-41.86	-35.97	-56.33
	110	-2.27	-9.31	-10.03	-42.50	-7.20	-8.46	-41.17	-35.31	-55.88
	100	-2.05	-8.51	-9.18	-41.09	-6.60	-7.77	-39.86	-34.26	-55.15
	90	-0.01	-6.19	-6.83	-37.69	-6.18	-7.29	-37.68	-32.27	-53.62
	80	-0.01	-3.87	-4.56	-32.25	-3.86	-5.03	-32.24	-28.46	-50.68
	60	0.00	-3.37	-3.97	-15.38	-3.37	-4.40	-15.38	-12.07	-38.03
20000	120	-3.24	-11.88	-12.87	-73.60	-9.70	-11.45	-72.95	-	-
	110	-3.11	-11.46	-12.40	-73.25	-9.41	-11.09	-72.63	-	-
	100	-2.95	-10.52	-11.41	-72.60	-8.63	-10.19	-72.02	-	-
	90	-0.97	-8.13	-8.99	-70.97	-8.11	-9.57	-70.97	-	-
	80	-0.89	-5.93	-6.85	-68.36	-5.92	-7.49	-68.36	-	-
	60	-0.78	-5.16	-5.97	-59.94	-5.15	-6.53	-59.93	-	-
25000	120	-4.71	-14.11	-15.35	-84.03	-10.97	-13.18	-83.44	-	-
	110	-4.62	-13.60	-14.79	-83.82	-10.54	-12.67	-83.24	-	-
	100	-4.50	-12.51	-13.63	-83.42	-9.56	-11.53	-82.86	-	-
	90	-2.63	-10.07	-11.13	-82.44	-8.88	-10.74	-82.21	-	-
	80	-2.43	-8.00	-9.13	-80.86	-6.88	-8.86	-80.63	-	-
	60	-2.10	-6.95	-7.95	-75.58	-5.97	-7.70	-75.32	-	-
30000	120	-6.16	-16.33	-17.82	-	-	-	-	-	-
	110	-6.11	-15.73	-17.16	-	-	-	-	-	-
	100	-6.06	-14.51	-15.83	-	-	-	-	-	-
	90	-4.28	-12.01	-13.28	-	-	-	-	-	-
	80	-3.96	-10.05	-11.42	-	-	-	-	-	-
	60	-3.45	-8.76	-9.95	-	-	-	-	-	-
35000	120	-7.62	-18.57	-20.30	-	-	-	-	-	-
	110	-7.61	-17.87	-19.53	-	-	-	-	-	-
	100	-7.62	-16.50	-18.04	-	-	-	-	-	-
	90	-5.93	-13.96	-15.45	-	-	-	-	-	-
	80	-5.50	-12.14	-13.73	-	-	-	-	-	-
	60	-4.79	-10.56	-11.95	-	-	-	-	-	-

Table (13) Summary of HDM-4 software results for work zone selected in four lane-divided highway

Location		Cairo/Alex. agric. road between Kafr El zayat and Damanhour	Badr-Sherben highway
No. of Lane/1dir.		2	2
No. of closed Lane/1dir.		1	2
Speed Limit		90	80
field operating speed before work zone		No Measure	No Measure
field operating speed at Work zone speed		No Measure	No Measure
AADT (vpd/1dir.)		15000	8250
Maintenance Date		2005	2011
Data Collection Type		previous study	from forms
Before Work Zone (Two Lane Open)	VOC	7589	4122.6
	TTC	1435	827.2
	Operating Speed	85.89	82.528
2 to 1 One Lane Closed Section	VOC	7874	4142.25
	%VOC	3.76	0.344
	TTC	2087	1022.2
	%TTC	45.44	22.177
	Loss in National Income	652000	195000
	Operating Speed	58.17	65.826
	% Operating Speed	-32	-19.9
Median Crossover Section	VOC	8702	4206.35
	%VOC	14.67	1.647
	TTC	3063	1079.8
	%TTC	113.45	28.478
	Loss in National Income	1628000	252600
	Operating Speed	39.84	62.879
	% Operating Speed	-54	-23.85
Suggesting no. of closed lane/ 1dir.		closed one lane	closed one lane

Table (14) Summary of HDM-4 software results for work zone selected in six lane-divided highway

Location		Cairo-El Fayoum highway	Rashed-El brols highway	Dominate canal highway	Asyout-souhage-Red sea highway	Cairo/Alex. agric. road between Kafr El dware and Kafr El zayat	Quntra-Mit abou koum
No. of Lane/1dir.		3	3	3	3	3	3
No. of closed Lane/1dir.		3	3	1	1	2	2
Speed Limit		100	120	60	80	90	80
field operating speed before work zone		No Measure	No Measure	No Measure	No Measure	No Measure	No Measure
field operating speed at Work zone speed		No Measure	No Measure	No Measure	No Measure	No Measure	No Measure
AADT (vpd/1dir.)		10000	9000	5000	6000	25000	5000
Maintenance Date		2010	2009	2012	2015	2011	2012
Data Collection Type		from forms	from forms	from forms	from forms	from forms	from forms
Before Work Zone (Three Lane Open)	VOC	5123	4659.6	2462	2993.2	12730	2493
	TTC	881	762.2	636	596.6	2328	497
	Operating Speed	94.04	97.298	64.3	83.128	89.37	83.13
3 to 2 One Lane Closed Section	VOC	5091	4622.4	2464	2995.8	12699	2495
	%VOC	-0.62	-0.772	0.08	0.084	-0.24	0.08
	TTC	912	792	636	600	2515	497
	%TTC	3.52	3.73	0	0.342	8.03	0
	Loss in National Income	31000	29800	0	3400	187000	0
	Operating Speed	89.77	92.734	64.3	82.818	81.43	83.12
	% Operating Speed	-5	-4.6	0	-0.4	-9	0
Median Crossover Section	VOC	5087	4616.6	2464	2996	12810	2495
	%VOC	-0.7	-0.892	0.08	0.088	0.63	0.08
	TTC	919	798.4	636	602.2	2564	498
	%TTC	4.31	4.49	0	0.642	10.14	0.2
	Loss in National Income	38000	36200	0	5600	236000	1000
	Operating Speed	89.04	92.024	64.22	82.6	79.77	83.01
	% Operating Speed	-5.32	-5.42	-0.12	-0.632	-10.74	-0.14
3 to 1 Two Lane Closed Section	VOC	5047	4538.4	2488	2999.4	17597	2489
	%VOC	-1.48	-2.658	1.06	0.06	38.23	-0.16
	TTC	1243	1104.2	669	720	11018	579
	%TTC	41.09	43.358	5.19	19.01	373.28	16.5
	Loss in National Income	362000	342000	33000	123400	8690000	82000
	Operating Speed	64.59	66.288	61.01	67.91	15.9	69.2
	% Operating Speed	-31	32.2	-5	-18.6	-82	-17
Suggesting no. of closed lane/ 1dir.		closed one lane or one direction	closed one lane or one direction	closed one lane or one direction	closed one lane or one direction	closed one lane or one direction	closed one lane or one direction

Table (15) Summary of HDM-4 software results for work zone selected in eight lane-divided highway

Location		Cairo ring road. Ismailia-Suez link	Cairo ring road. Suez-90street link	Cairo ring road. Suez-90street link	Cairo ring road. Passos –El warraq link	Cairo/Alex. Desert. At km 110	Cairo/Alex. Desert. at sec 6
No. of Lane/1dir.		4	4	4	4	4	4
No. of closed Lane/1dir.		2	2	1	1	2	4
Speed Limit		100	100	100	100	120	120
field operating speed before work zone		95	95	95	95	No Measure	No Measure
field operating speed at Work zone speed		85	80	85	90	No Measure	No Measure
AADT (vpd/1dir.)		13630	27800	27800	20250	25237	30000
Maintenance Date		2015	2015	2015	2015	2005	2009
Data Collection Type		Field Data	Field Data	Field Data	Field Data	previous study	from forms
Before Work Zone (Four Lane Open)	VOC	7018	14360	14360	10442	13051	15678
	TTC	1189	2427	2427	1767	2090	2509
	Operating Speed	96	95.89	95.89	95.95	99.54	99.48
4 to 3 One Lane Closed Section	VOC	6990	14254	14254	10389	12945	15522
	%VOC	-0.41	-0.74	-0.74	-0.5	-0.81	-1
	TTC	1201	2534	2534	1802	2168	2641
	%TTC	1.06	4.31	4.31	1.97	3.73	5.26
	Loss in National Income	12630	106360	106360	35100	78000	132000
	Operating Speed	94.02	90.73	90.73	93.04	94.85	93.35
	% Operating Speed	-2.053	-5.34	-5.34	-3.03	-4.71	-6.16
4 to 2 Two Lane Closed Section	VOC	6939	14278	14278	10322	12813	15520
	%VOC	-1.12	-1.67	-1.67	-1.14	-1.82	-1.01
	TTC	1264	2744	2744	1931	2380	2933
	%TTC	6.19	12.93	12.93	9.23	13.88	16.9
	Loss in National Income	75574	314100	314100	163650	290000	424000
	Operating Speed	88.35	82.82	82.82	85.76	85.49	83.23
	% Operating Speed	-7.962	-13.59	-13.59	-10.62	-14.11	-16.33
Median Crossover Section	VOC	6937	14373	14373	10320	12834	15648
	%VOC	-1.16	0.01	0.01	-1.17	-1.66	-0.19
	TTC	1272	2783	2783	1949	2415	2986
	%TTC	6.88	14.51	14.51	10.28	15.55	19.01
	Loss in National Income	83930	352740	352740	182250	325000	477000
	Operating Speed	87.76	81.64	81.64	84.89	84.26	81.75
	% Operating Speed	-8.57	-14.82	-14.82	-11.52	-15.35	-17.82
4 to 1 Three Lane Closed Section	VOC	7168	17597	17597	13390	17.597	-
	%VOC	1.77	36.36	36.36	28.14	34.83	-
	TTC	1904	11018	11018	6430	11018	-
	%TTC	58.56	404.95	404.95	262.18	427.18	-
	Loss in National Income	715124	8836000	8836000	4663600	8928000	-
	Operating Speed	58.76	15.9	15.9	25.77	15.9	-
	% Operating Speed	-38.8	-83.42	-83.42	-73.14	-84.03	-
Suggesting no. of closed lane/ 1dir.		closed one lane or two lane or one direction	closed one lane or two lane or 1dir.	closed one lane or two lane or 1dir.	closed one lane or two lane or one direction	closed one lane or two lane or 1dir.	closed one lane