Optimization of traffic operation performance in urban areas - an analytical framework methodology

Mohamed M. Shahin
Transportation Dept., Faculty of Eng., Alexandria University, Alexandria, Egypt
Email: mohamedsaz@hotmail.com

One of the main problems which face people in urban areas in developing countries is the low level of transportation system performance. Transportation infrastructure and services are becoming increasingly incompatible with the nature of urbanization and the pace of motorization. Most people have little mobility while accessibility to several essential services and facilities is generally poor. This paper presents a procedure for optimal design and evaluates different traffic operation performance strategies in urban areas. The traffic operation performance problem is formulated as an output maximization of the mobility in terms of total productive activity which can be accommodated on the facility during a given time period subject to traffic quality standards, safety standards, and noise level standards. The solution to the problem is then obtained using the Generalized Reduced Gradient (GRG2) algorithm for optimizing nonlinear problems. Furthermore, the proposed procedure is examined by being applied to Elgeish Street in Tanta city as a case study in order to indicate its capability, usefulness and practicability. The application of the proposed methodology shows that the total performance approach to traffic management is feasible and practicable. The optimum productive activity in the study segment is 104206 passenger-km/hr. Although the available roadway width is 12.0 m by which you can have 4 lanes, the optimum number of lanes is three lanes with lane width 3.6 m. This can help planners to use the other space for increasing the walkway width and/or improving the overall quality of the road environment and accordingly make the concept of sustainable development an integral part of the management of operations of existing urban transportation infrastructure.

في مدن الدول النامية، عندما بدأ الإقتصاد القومى فى الإرتفاع، زادت ملكية السيارات وإستخدامها بمعدلات كبيرة، ولم تزد مساحات الطرق بنفس المعدل. أدى ذلك إلى تدهور مستوى خدمات النقل وتأثرت تحركات المواطنين بالسلب. إن الغرض من هذا البحث هو إعداد نموذج رياضى قابل للتطبيق العملى يهدف إلى الحصول على أقصى نشاط نقلى (راكب-كم/ساعة) على الطرق فى المناطق الحضرية وفقاً لمعايير محددة. هذه المعايير تتضمن زيادة مستوى الأمان على الطرق، زيادة مستويات الخدمة، وتقليل الضوضاء إلى المستويات التى تنص عليها المواصفات الدولية. ولإختبار مدى فاعلية النموذج المقترح فقد تم تطبيقه على جزء من شارع الجيش – طنطا. وقد وجد أن القيمة المثلى لنشاط النقل فى منطقة الدراسة حوالى ١٠٤ ألف راكب-كم/الساعة، وهى القيمة التى تتوافق مع المعايير السابق ذكرها. بالرغم من أن المساحة المخصصة للمرور تكفى لإنشاء أربع حارات بعرض ٣ متر لكل حارة إلا أن عدد الحارات الأمثل قد وجد من خلال النموذج المستخدم هو ثلاث حارات فقط بعرض ٣,٦ متر. هذا يساعد المخططين على إستخدام المساحة المتبقية من عرض الطريق لزيادة عرض حارات المشاه وبالتالى تدعيم فلسفة التنمية المستدامة لتحركات المواطنين.

Keywords: Optimization problem, Traffic operation performance, Urban areas, Productive activity

1. Introduction

One of the main problems which face people in urban areas in developing countries is the low level of transportation system performance. Transportation infrastructure and services are becoming increasingly incompatible with the nature of urbanization and the pace of motorization. Most people have little mobility while accessibility to several essential services and facilities is generally poor. Furthermore, the inability, for whatever reason, of cities to plan transport systems, to manage travel demand, to relate land use and transport and to provide adequate resources for transport, leads to serious traffic congestion problems. Almost every weekday morning and evening during peak hours the capacity of many main roads is exceeded. Traffic congestions do not only cause considerable costs due to time losses; they also increase the possibility of accidents and have a negative impact on the environment (air pollution, lost fuel) and on the quality of life (health problems, noise, stress).

One solution to the ever growing traffic congestion problem could be the construction of new roads to enlarge the capacity of the traffic infrastructure. This approach is very expensive and it is often not possible due to right-of-way restrictions as well as environmental or societal constraints. In addition, it can be only executed on the longer term. So there is a need for another, short-term solution. This short-term solution exists of managing traffic in such a way that the efficiency of the existing traffic networks is increased.

Traffic management seeks to adjust, adapt, manage and improve the existing transportation system to meet specified objectives without resorting to substantial new road construction. It involves development and use of physical and policy measures to achieve the most efficient use of the traffic facilities, provide low-cost solutions to its problems, and produce a service that meets the desired objectives. The basic mission of urban traffic management is to obtain and maintain the maximum levels of people's and goods' mobility possible within the resources and environmental capacities in an area.

This paper presents a procedure for optimal design and evaluates different traffic operation performance strategies in urban areas. The traffic operation performance problem is formulated as an output maximization of the mobility in terms of total productive activity which can be accommodated on the facility during a given time period subject to traffic quality standards, safety standards, and noise level standards. The solution to the problem is then obtained using the Generalized Reduced Gradient (GRG2) Algorithm for optimizing nonlinear problems. Furthermore, the proposed procedure is examined by being applied to one of the main roads in Tanta city as a case study in order to indicate its capability, usefulness and practicability.

2. Definition of urban traffic management

Urban traffic management has a wide range of definitions according to the tasks to be carried out. These tasks could be safety, smoothness of traffic, reduction in air and noise pollution, reduction of delay, reduction of fuel consumption, or improvement of level of service.

Traffic management is defined by Goodwin P.B. [1] as a range of engineering techniques designed to carry out modest but important tasks to keep traffic flowing smoothly and safely. Some of these techniques are traffic signals, one-way systems, and parking prevention.

According to Cracknell, J.A. [2] the objective of urban traffic management is to provide for the short range traffic needs of an urban area by making most efficient use of transportation facilities and systems, by improving the movement of people and goods and not necessarily vehicles, by improving the quality and safety of the traffic, and by contributing to the improvement of the traffic related environment.

OECD scientific expert group [3] defined traffic management as a tool used for mitigating traffic congestion. Congestion management measures are usually considered as “demand side” or “supply side” types of strategies. Demand side measures are designed to reduce car demand on the system by increasing vehicle occupancy, increasing public transport systems, reducing the need to travel during a specified peak time period, and/or reducing the need to travel to a specified location. These measures include land use policies, traveler information services, economic and administrative policies, and telecommunication substitutes. Supply-side measures are intended to increase existing capacity of the system in order to improve the traffic flow for all modes. These measures include roadway operations, preferential treatment, and public transport operations.

Urban traffic management involves development and use of physical and policy measures to achieve the most efficient use of the traffic facilities, provide low-cost solutions to its problems, and produce a service that meets the desired objectives. Consequently, the main goal of traffic management is defined conventionally as to ensure an adequate traffic performance on an existing network.

Akinyemi and Zuidgeest [4] defined urban traffic management as to ensure optimum use of an existing network in an area. According to them, the objective of traffic management should be to maximize the productivity of the facilities at acceptable levels of service, emissions, noise and resource consumption levels in an area. The philosophy of the mathematical approach developed by them is that the basic mission of infrastructure operations management is to obtain and maintain the maximum levels of people and goods mobility possible within the resources and environmental capacities in an area. The procedure of this paper is based, in part, on this approach. The approach has been enhanced and modified using the principles of the highway capacity manual 2000 as well as by introducing strategy actions in the framework of the model.

The traffic operation performance is formulated in the framework of this study as an output maximization problem subject to state variables, decision variables, and traffic management strategy goals. The basic hypothesis is that the traffic operation performance is considered to be optimal when the passenger productive activity (passenger-km/h) of each traffic road is maximized (objective function). The decision variables are demand flow rates, green time proportion, total number of vehicular traffic lanes, lane width, lane use by vehicle type and lane use by vehicle movement type. The constraints include speed limit by law, desired level of service (LOS) of traffic lanes, and noise standards.

3. The mathematical model description

3.1. Definition of objective function

Productive activity is defined as the maximum passenger-kilometer of travel that can be carried in one hour from one place to another at acceptable levels of service, safety, and noise. Every road consists of some segments. The segment is the basic unit of the analysis; it is a one-directional distance from one signalized intersection to the next fig. 1.

The mathematical expression of the objective function is defined as follows:

$$\text{Maximize Productive Activity} = T \times \sum_{m} \sum_{l} \left[S_{(m,l)} \times V_{(m,l)} \times O_{(m,l)} \right]$$

where:

- T is the duration of analysis period under consideration in hours,
- $S_{(m,l)}$ is the average travel speed of vehicle mode m at lane l (Km/hr),
- $V_{(m,l)}$ is the maximum vehicle service flow rate of vehicle mode m at lane l (veh/hr), and
- $O_{(m,l)}$ is the average occupancy of each transport mode *m* at lane *l* (passenger /vehicle).

$$O_{(m,l)} = \sum_{m=1}^{n} PF_m \times OCC_m$$

where:

- n is the number of modes in the same lane,
- OCC_m is the occupancy of each mode in the same lane (passenger/vehicle mode m), and
- PF_m is the proportion of flow for each mode in the same lane.

The objective function defined above indicates that the total productive activity depends not only on the quantity being moved on the segment but also on the travel speed which used as an indicator for the quality of movement. The relationship between speed and the volume to capacity ratio is not the same as between throughput and volume to capacity ratio. The difference implies that, while a low volume to capacity ratio results in low delay or high speed, it does not necessarily result in a high productive activity on a road fig. 2.

3.1.1. Determining vehicle service flow rate

Given the total entry flow into the segment, the maximum vehicle service flow rates of vehicle mode m at lane l "$V\,(m,l)$" can be simply determined as follows [4]:

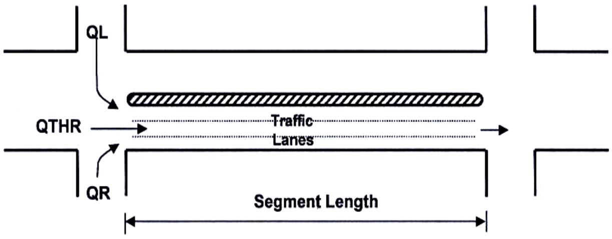


Fig. 1. Segmentation of a road.

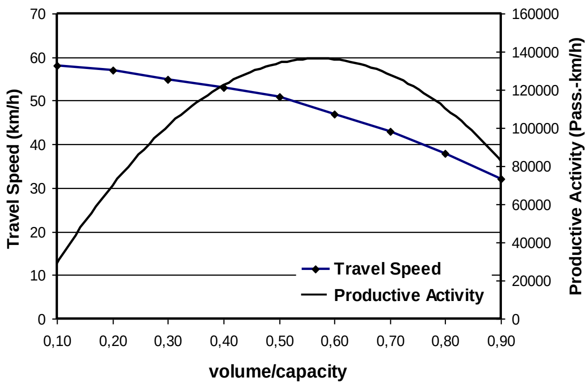


Fig. 2. Example of the relationship between productive activity and volume over capacity ratio versus the shape of a hypothetical congestion-curve [5].

$$V_{(m,l)} = \sum_m \sum_l \sum_k \left[\frac{1}{N_{(m)}} \times MIN\,[Q_{move},\ C_{move}] \times a \times \mu \right]$$

where:

$N_{(m)}$ is the number of lanes which can used for vehicle mode m,

Q_{move} is the demand by vehicle mode m for the entry = QTHR + QLT + QRT,

QTHR is the demand of through vehicles entering from the preceding segment (veh/hr),

QLT is the demand of left-turn vehicles entering from the preceding segment (veh/hr),

QRT is the demand of right-turn vehicles entering from the preceding segment (veh/hr), and

C_{move} is the maximum allowable input capacity on the entering section by vehicle mode m (Veh/hr).

Following the Highway Capacity Manual (2000) principles [6]:

$$C = 1800 \times F_W \times F_{HV}$$

where:

F_w is the adjustment factor for lane width. $= 1 + (Lane\,width - 3.6)/9$,

F_{HV} is the adjustment factor for heavy vehicles $= 1/(1 + P_T \times (E_T - 1))$,

P_T is the proportion of trucks and buses in the traffic stream, and

E_T is the passenger-car equivalents for trucks and buses.

Furthermore**:**

a is the lane use by movement type (Binary Variable) which can defined as follows:

$\alpha = 1$ if the movement can use lane l at time t

$= 0$ otherwise

δ is the lane use by vehicle type parameter (Binary Variable) which can defined as follows:

$\delta = 1$ if vehicle mode m can use lane l at time t

$= 0$ otherwise.

The possible values of Alpha and Delta for different sets for a three lane road (as an example) are presented in table 1. All realistic and possible sets for two, three and four lanes of lane use by transportation modes (private car "PC", taxi and high occupancy vehicle HOV) and movements are covered in the framework of this procedure which involves introduction of a lane use by movement parameter designated as theta as well as lane use by mode parameter designated as beta.

3.1.2. Determining average travel speed

There are two principal components of the total time that a vehicle spends on a segment of an urban street: travel time and control delay at signalized intersections. Thus, the average travel speed (*Sa*) can be determined using the following eq. [6]:

$$Sa = \frac{L}{L/U + d/3600}$$

where:

Sa is the average travel speed of through vehicles in the segment (km/h),

L is the segment length (km),

U is the average running speed on the segment (km/h), and

d is the control delay for through movements at the signalized intersection (seconds).

The average running speed on each lane is adopted from the study "modeling congestion on urban roads and assessing level of service" [7]. The relation is given as follows:

$$U = FFS \times (1 - 0.7 \times (e^{2.2 \times \ln(Q/C)}))$$

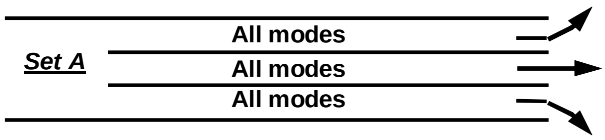
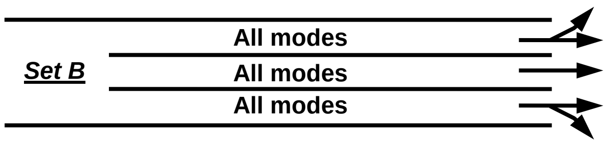
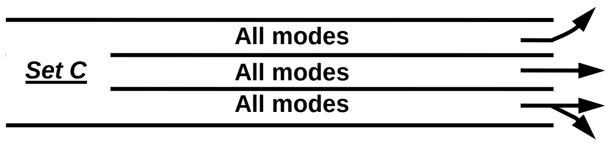
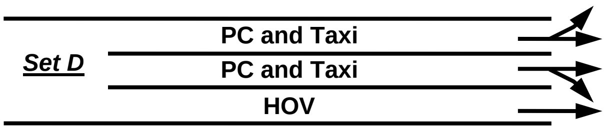
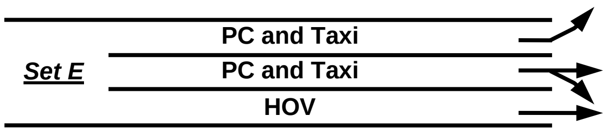
where:

U is the average running speed,
FFS is the free flow speed, and
Q/C is the Volume to capacity.

In addition, computing the segment speed requires the intersection control delays. For the signalized intersections, the delay occurring on the links depends obviously on signal parameters like cycle time, green time splits, offsets, etc. Delay also depends on the demand rate, saturation flow rate, and physical parameters of the intersection itself. The average delay on the segment delay can be mathematically expressed using the following eq. [6]:

$$d = \frac{0.5 \times c(1 - \frac{g}{c})^2}{1 - \left[\min(1,x) \times \frac{g}{c}\right]} \times F + 900T \times \left[(x-1) + \sqrt{(x-1)^2 + \frac{8 \times K \times I \times x}{Cap \times T}}\right]$$

Table 1
The possible values of Alpha and Delta for different sets for a three lane road

Alternative lane use by movement and mode	Lane	Alpha			Delta		
		LT	THR	RT	PC	Taxi	HOV
	1	1	0	0	1	1	1
	2	0	1	0	1	1	1
	3	0	0	1	1	1	1
	1	1	1	0	1	1	1
	2	0	1	0	1	1	1
	3	0	1	1	1	1	1
	1	1	0	0	1	1	1
	2	0	1	0	1	1	1
	3	0	1	1	1	1	1
	1	1	1	0	1	1	0
	2	0	1	1	1	1	0
	3	0	1	0	0	0	1
	1	1	1	0	1	1	0
	2	0	1	1	1	1	0
	3	0	1	0	0	0	1

where:

- d is the average delay incurred per vehicles on subject link (sec),
- F is the uniform delay progression adjustment factor, which accounts for effects of signal progression on delay, this is assumed to be 1 in the framework of this study for random arrival type,
- C is thelength of signal cycle facing subject link (sec),
- g is the effective green time facing subject link (sec),
- x is thedegree of saturation (volume-to-capacity ratio) of subject lane,
- T is theduration of analysis period (hours),
- Cap is the capacity of subject link (veh/hr) $= N \times S \times g / c$,
- S is the adjusted saturation flow per lane (veh./h),
- K is the incremental delay factor that is dependent on controller settings; in this study the value of 0.5 is used which is based on a queuing process with random arrivals and uniform service time equivalent to the lane capacity, and
- I is theupstream filtering/metering adjustment factor; for a signal analysis of an isolated intersection a value of 1.0 is used.

3.2. Definition of decision variables

The previous defined objective function implies that the main variables in productive activity of a segment are the number of persons carried per vehicle, average running speed, delay and service flow rate. Consequently, the major decision variables of a segment -whose appropriate values, the operation manager needs to determine and maintain- can be defined as follows:

- Demand flow rates (or metering rates) by movement and vehicle type for the entry.
- Green time proportion as a controller for the vehicular capacities at segment exit
- Total number of vehicular traffic lanes and Lane width. It must be noted that the roadway widths (pavement width) in urban areas are found to vary for roads, which have the same number of operating lanes. Similarly, the capacity also varies depending on the actual lane width.
- Lane use by vehicle type indicated by a Binary variable.
- Lane use by vehicle movement type indicated by a Binary variable.

3.3. Definition of constraints variables

The total performance approach focuses on the degree to which the segment can produce maximum activity without exceeding some environmental, safety and comfort restrictions. Because of that, the objective function should be subjected to constraints. These constraints are designed in the framework of this study and can be described as follows:

3.3.1. Noise

Excessive noise is known to cause hearing loss and may contribute to stress-related health problems including raised blood pressure and minor psychiatric illness. Noise can interfere with sleep and thus may contribute to accident proneness and reduced immunity to disease.

Transport noise, particularly road transport noise, is the major source of external acoustic energy in urban areas and is the principal cause of the perception of noise as a nuisance. Numerous research projects are carried out by the World Health Organization (WHO) to study the effects of noise and on its wider repercussions have found that an outdoor level of 70 dB(A) (L_{eq} for day time period) is unacceptable [8]. The equivalent level (L_{eq}) can be estimated using the following eq. [9]:

$$L_{eq} = 37.3 + 10 \times Log\left[Q \times (1 + 0.082 \times p)\right] \leq 70\ db(A)$$

where:

- Q is the total flow rate of all types vehicles on a segment (veh./hr), and
- P is the proportion of trucks and buses.

3.3.2. Quality of movement

The quality of movement is generally measured by using the level of service concept. Level Of Service (LOS) is described in the HCM as the overall quality measure of the speed, comfort, and safety of movement of traffic unit in facility operating condition of traffic units on the facility or route. According to HCM 2000, the operating condition of a traffic unit on a facility can be divided into six levels, A to F where A represents the best and F represents the worst quality. Table 2 shows the different level of service and related parameters, which are average travel speed for different free flow speeds for arterial roads. The level of service constraint can be described mathematically as follows:

$$U \geq U_{MIN}$$

where:
U is the average running speed on lane l, and
U_{MIN} is the minimum desirable running speed.

3.3.3. Traffic safety

Generally, the accidents on road transportation could be due to the driver (human behavior), the vehicle (poor maintenance) and/or the roadway (e.g. geometric design). The human behavior is known as the main cause of road accidents. Therefore it is important to try to improve driving behavior through a combination of enforcement actions and, simultaneously, information to the public. In this paper, the vehicle and roadway problems are assumed to be already satisfied. It is deemed that the problem can be minimized by ensuring that the maximum speed of drivers is not more than the safe speed (speed limit by law). This can be mathematically expressed as follows:

$$FFS \leq S_{LAW}$$

where:
FFS is the free flow speed, and
S_{LAW} is the speed limit by law.

Table 2
Level of service for arterial according to HCM 2000 [6]

Typical free flow speed (Km/h)	65	55	45
Level of service	Average travel speed (Km/h)		
A	≥59	≥50	≥41
B	≥46	≥39	≥32
C	≥33	≥28	≥23
D	≥26	≥22	≥18
E	≥21	≥17	≥14
F	≤21	≤17	≤14

4. Description of algorithm developed in the framework of the study

In an attempt to solve the optimization problem defined in the previous section, Microsoft Excel Solver is used. This solver uses the Generalized Reduced Gradient (GRG2) Algorithm for optimizing nonlinear problems. This algorithm was developed by Leon Lasdon, of the University of Texas at Austin, and Allan Waren, of Cleveland State University.

Microsoft Excel Solver uses iterative numerical methods that involve "plugging in" trial values for the adjustable cells (decision variables) and observing the results calculated by the constraint cells and the optimum cell. Each trial is called iteration. Because a pure "trial and error" approach would take an extremely long time (especially for problems involving many adjustable cells and constraints), Microsoft Excel Solver performs extensive analyses of the observed outputs and their rates of change as the inputs are varied, to guide the selection of new trial values.

This algorithm can be used for the optimization problem described in the framework of this study and can be summarized in terms of three main modules fig. 3. The *first module* named input data module and includes: geometric data (segment length, available width at intersection approach, available width), traffic demand data (rate of flow vehicular traffic for every transport mode), microscopic characteristics of each mode (free-flow speed, average occupancy), and traffic characteristics (cycle time, proportion green time, exit proportions of left-turn, through going and right-turn movements of each mode). The *second module* is the decision variable module which includes: demand flow rates, green time proportion, total number of vehicular traffic lanes, lane width, lane use by vehicle type and lane use by vehicle movement type. The *third module* is the constraints module and includes: speed limit by law, desired LOS of traffic lanes, and noise standards. The *last module* is the output module which gives the optimal productive activity (passenger-km/h) of the segment.

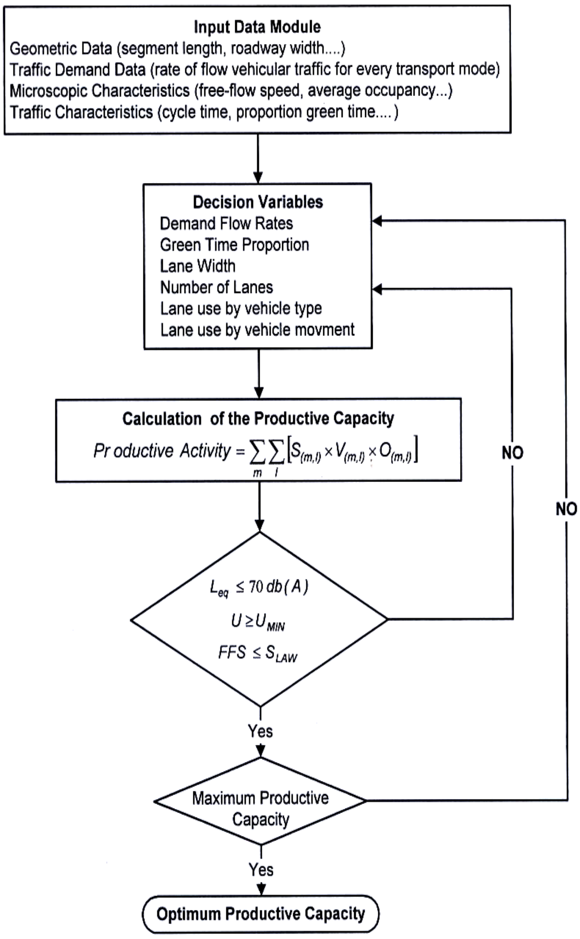


Fig. 3. Framework methodology for the optimization problem of the traffic management.

5. Case Study El-Geish Street, Tanta City

Tanta is Egypt's fifth largest city (the largest in the Delta) and is located in the center of the Nile Delta with about 94 km north of Cairo and 130 km southeast of Alexandria. Tanta city plays an important role as a commercial, trade and religious tourist center. It also plays a role as a center for many transport modes (railway, regional buses, minibuses and trucks).

In 2002, about 411000 inhabitants lived in a small area of 12.5 km^2 with a high population density of 32880 person/km^2. Between 1992 and 2002, the car-ownership has been increased from 44.4 to 77.5 veh./1000 inh. due to the increase of cars from 16200 in 1992 to 31835 in 2002, as well as the increase in the number of population from 365 to 411 thousand during the same period [10].

The study area of this work is one of the main corridors In Tanta called El-Geish Street, which connect the city center and Fast Agriculture Road. The selected segment for applying the proposed procedure connects two major streets which are Nadi-Elmoaelmeen Street and El-Nahas Street (with signalized intersection). Fig. 4 presents the main characteristics of the selected segment.

The geometric characteristics, which needed to be input to the solver, are the segment length = 550 m and the available roadway width = 12.0 m. The traffic control devices used in the selected segment are signals at El-Nahas intersection. The control characteristics are as follows: cycle time = 80 sec, green time = 40 sec, speed limit by law = 60 km/h, desired level of service (LOS) of traffic lanes = C (assumed).

The entering flow rate and exit proportion for the study segment was observed during the peak-period for 9-effective day-work in the framework of this paper. The measurement took place for the days Monday, Tuesday and Wednesday for different three weeks in November and December 2005. The traffic counts were classified into four modes, which are regularly used in El-Geish Street. These are private car, taxi, microbus and bus. Based on these measurements, the entering flow rate and exit proportion of the segment are computed out using table 3.

The decision variables are raged as follows:
- Demand flow rates (or metering rates) varies from total actual entering flow rate down to 500 veh./h, g/c proportion varied between 0.3 to 0.7, lane width varied from 3.0 m to 3.6m, lane use by vehicle type indicated

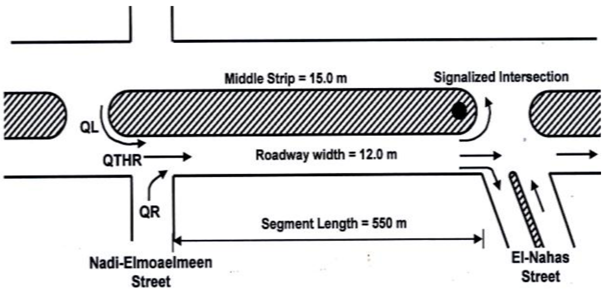


Fig. 4. The main characteristics of the study segment.

Table 3
Entering peak flow rate and exit proportion of flow rate on El-Geish Street (peak hour)

Mode	Entering flow rate (veh./h)			Exit proportion of flow rate			Average occupancy
	LT	TH	RT	LT	TH	RT	
Car	345	1545	413	0.1	0.7	0.2	1.5
Taxi	88	231	97	0.15	0.7	0.15	2
Microbus	4	47	6	0.05	0.8	0.15	15
Bus	2	17	4	0	0.9	0.1	40

by a Binary variable as described in section 3- 1, lane use by vehicle movement type indicated by a Binary variable as described in section 3-1.

By input the data described in the previous section to the excel solver, the optimum productive activity is 104206 passenger-km/h. Although the available roadway width is 12.0 m by which you can have 4 lanes, the optimum number of lanes is three lanes with lane width 3.6 m. This implies that it is seemingly inefficient to use the whole available space. This can help planners to use the other space for increasing the walkway width and/or improving the overall quality of the road environment and accordingly make the concept of sustainable development an integral part of the management of operations of existing urban transportation infrastructure. The optimum demand flow rate (or metering rate) is 1400 veh./h. The optimum g/c ration is 0.6. In addition, it is inefficient to use HOV lanes in El-Geish Street fig. 5.

The same data input in the study area are used to study the effects of changes in the roadway width as well as the proportion of green time on the values of the productive activity. Fig. 6-a studies the effects of changing the roadway width on the values of the productive activity. It shows that the lower the roadway width the lower is the productive activity. It must be noted that that the productive activity is quit similar for the roadway widths = 12.0 m and 10.0m. This may be due to the fact that the number of lanes has the primary impact on the productive activity rather than the lane width. Furthermore, the effects of proportion of green time on the productive activity is presented in fig. 6-b and shows that the lower the exit proportion of green time the lower is the productive activity.

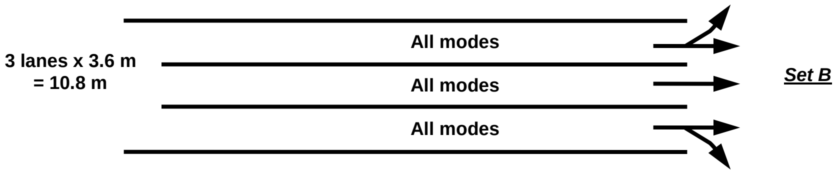


Fig. 5. The optimum set for lane use by movement and vehicle type.

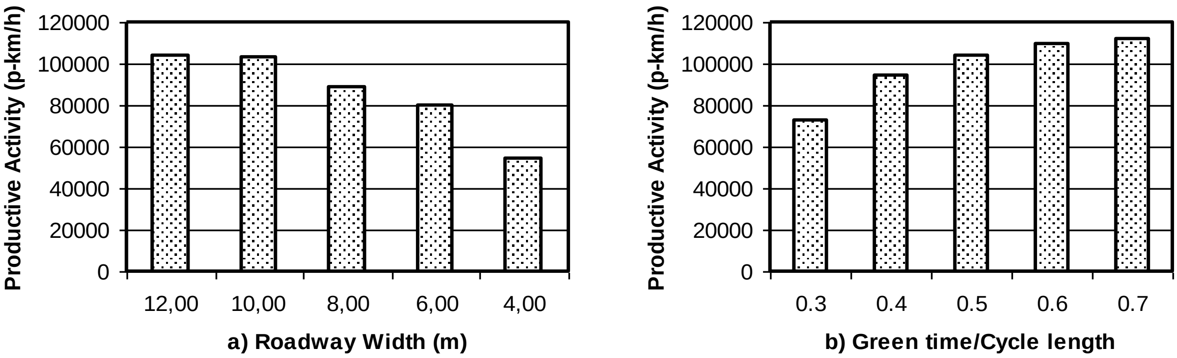


Fig. 6. Effects of changes in roadway with space and green time/cycle length on the total productive activity.

6. Conclusion and recommendation

The objective of total traffic performance approach is to maximize the productivity of the facilities at an acceptable level of service, an acceptable noise level, an acceptable safety standards, etc. The application of the proposed methodology, for the selected segment on Elgeish Street shows that the total performance approach to traffic management is feasible and practicable. The optimum productive activity in the study segment is 104206 passenger-km/hr. Although the available roadway width is 12.0 m by which you can have 4 lanes, the optimum number of lanes is three lanes with lane width 3.6 m. This implies that it is seemingly inefficient to use the whole available space. This can help planner to use the other space for increasing the walkway width and/or improving the overall quality of the road environment and accordingly increase the sustainability of the urban streets.

Undoubtedly, this study has many limitations in terms of coverage and assumptions. Consequently, in order to better approach the optimization problem, it is recommended that more studies should be carried out in order to extend the optimization problem from one segment to a corridor and to a small network. In addition, the benefit-cost analysis (total benefit of productive activity / total capital cost of improving alternatives) should be included in the process of comparing the different alternatives.

References

[1] P.B. Goodwin, "Traffic Management from Theory and Practice: Present, Past, Future", Transportation Research Record, Washington D.C. USA, No.1457, pp. 5-14 (1997).

[2] OECD Scientific Expert Group, "Congestion Control and Demand Management", OECD, Paris, France 771995021P1, ISBN 92-64-14315-7 (1994).

[3] J.A. Cracknell, "Experience in Urban Traffic Management and Demand Management in Developing Countries", World Bank Urban Transport Strategy Review, Final Report, England, Available at http://www.worldbank.org/transport (2000).

[4] E. Akinyemi and M. Zuidgeest, "Managing Transportation Infrastructure for Sustainable Development", Computer-Aided Civil and Infrastructure Engineering, Delft, The Netherlands Vol.17, pp. 148-161 (2003).

[5] Bureau of Public Roads, "Traffic Assignment Manual", Urban Planning Division, U.S. Department of Commerce, Washington DC (1964).

[6] Transportation Research Board, "Highway Capacity Manual (HCM)", National Research Council, Washington (2000).

[7] B. Maitra, P.K. Sikdar, and S.L. Dhingra, "Modeling Congestion on Urban Roads and Assessing Level of Service", Journal of Transportation Engineering, Vol. 125, Issue 6, pp. 508-514 (1999).

[8] World Health Organization WHO "Occupational and Community Noise", WHO Media Centre, Fact Sheet Number 258, Available: http://www.who.int/mediacentre/factsheets/fs258/ en/index.html (2001)

[9] Forschungsgesellschaft für Straßen- und Verkehrswesen (FGSV) - German Roads and Transport Research Association, "Guidelines for Noise Abatement Measures (protection) at Roads", Köln, Germany (1999).

[10] General Organization for Physical Planning "Tanta Master Plan – Final Report", Ministry of Housing, Utilities and Urban communities (HUUC) (2000).

Received April 23, 2006
Accepted May 6, 2006