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THE SIGNIFICANCE OF TRAVEL TIME COST ASSOCIATED WITH PAVEMENT OVERLAYING

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تأثر تكلفة زمن الرحلة المرتبطة بتغطية الرصف

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خلاصـــــــة

فى هـــذا الـــبحث تم عمـــل تقييم اقتصادي لتكلفة زمن الرحلة المرتبطة بصيانة الرصف حيث أن ملايين من الجـنيهات تفقـــد بطريقة غير مباشرة خلال أعمال صيانة الرصف. وتشتمل تكلفة زمن الرحلة على جزأين : الأول هو تكلفة التشغيل الإضافية نتيجة التأخير والازدحام للمركبات عند مناطق تنفيذ الصيانة والجزء الثانى هو : تكلفة التشغيل الـــزائدة نتيجة حالة الرصف قبل تنفيذ الصيانة مباشرة مقارنة بحالته عند الإنشاء . وعادة يتم عمل الصيانة خلال عمر الرصـــف حيث يتأثر مستوى الأداء بنوع الصيانة وتوقيتها ومستوى جودتها . وتتدرج أنواع الصيانة من صيانة جسيمة مـــثل الـــتغطية وإعادة البناء إلى صيانة بسيطة مثل دهان الشروخ وملئ الحفر والدهان السطحي وقد أزداد الاهتمام فى الفترة الأخيرة لدى هيئات الطرق بأعمال تغطية الرصف البسيطة والسميكة مما يتطلب الاهتمام بالإدارة والتخطيط لتلك الإعمال .

ويشـــتمل هـــذا البحث على وسيلة لتحديد تكلفة زمن الرحلة (تكلفة التشغيل الإضافية والزائدة) والمرتبطة بأعمال تغطية الرصف وكذلك نتائج التحليلات العملية لأحد مشروعات تغطية الرصف ويشتمل التحليل على: ١-ربط بدائل الصيانة بحالة الرصف ، ٢- معدل الأداء لتنفيذ أعمال الصيانة ، ٣- طرق تحويلات المرور عند مناطق الصيانة ،٤ - تأثير الازدحام ،٥- تأثر أنواع المركبات المختلفة بأعمال التغطية .

وتوضح النتائج أن تكلفة زمن الرحلة (الفائدة المفقودة) تمثل استثمار ضخم يصل إلى حوالي ٤٠,١٢% ، ٢٤,١% بالنسبة لتكلفة التغطية البسيطة والجسيمة على الترتيب والتي يجب أخذها في الاعتبار عند جدولة أعمال الصيانة .وتمثل تكلفة زمن الرحلة للمركبات الخاصة ٣٩,٦٧% بالنسبة لأنواع مركبات النقل والتي تمثل حوالي ٦٠,٣٣% .

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ABSTRACT

This paper evaluates travel time cost adjoined by maintenance of highways. Millions of travel time bounds are indirectly lost within the application of pavement maintenance works. ***Travel Time Cost*** (TTC) includes two main parts; first, *Added Running Cost* (ARC) as a result of delaying and congestion during the construction of maintenance works and second, *Extra Running Cost* (ERC) due to the current pavement condition before maintenance with respect to the condition of pavement after construction. Pavement maintenance is usually done within the pavement life such that the performance of any pavement is greatly affected by the type, time element and quality of maintenance it receives. Pavement maintenance activities are descendingly ranked from; major maintenance such as overlaying and rehabilitation, to minor maintenance such as crack sealing, potholes filling, surface dressing, etc. Authorities of highways recognizing the importance of overlaying (thin and thick) and are looking for the right approaches to overcome the problems with which they are confronted. There is indeed, a great need for proper planning and management of maintenance works.

This paper describes a procedure for determining travel time cost (ARC&ERC) and the analysis of results of practical pavement overlaying project. The analysis involves an evaluation of; 1) the pavement condition-based maintenance alternative, 2) productivity rates of maintenance construction process, 3) traffic handling methods, 4) the effects of traffic congestion, and finally 5) The significance of different vehicle types with pavement overlaying works. The results indicate that travel time cost (or lost benefits) represents a huge investment on the average; 40.12% and 24.1% of thin and thick overlay cost respectively that must be involved in the scheduling process of maintenance works. Travel time cost of passenger cars represents 39.67% with respect to different truck types that represent about 60.33 %. Also, a summary of travel time sensitive variables are presented.

1. INTRODUCTION

Life cycle cost analysis (LCCA) is a process for evaluating the total economic worth of a useable project segment by analyzing initial costs and discounted future costs, such as maintenance, reconstruction, restoration, rehabilitation, and resurfacing costs over the life of the project segment. Life cycle cost analysis is an important step in a pavement management process. One of the basic tenets of LCCA is that it may be advantageous to spend more money up-front on durable construction in order to reduce total costs over the life of the project. Some of the concerns included: difficulty in choosing discount rates, questions on how to determine user costs, and impact of changing technology on making accurate estimates of labour and material costs. LCCA, whether performed at a network level to select projects or at a project level choose between design or maintenance options is a multi-step process requiring information from many sources. The basic difference between the network level evaluation and the project level evaluation is the amount and detail of information required. The first step in conducting an LCCA of alternative pavement projects or pavement designs is to identify the long-term implications in terms of future maintenance and rehabilitation activities required to support each of the alternatives. The time period for evaluation of these alternatives is usually referred to as the analysis period (Govindarajan, Shelley, Karen, 2000).

The costs considered by most agencies in the LCCA include agency costs, namely capital cost of undertaking the work, and future maintenance costs. User delay costs are used as input during project selection strategy. When assessing the cost of an alternative, whether selecting between projects or selecting within projects, it is imperative that the cost of the work and the related user cost due to increase in travel time during construction is considered.

In the past, at least three methods have been used to determine value of time for trucks. They are:1) the **cost savings method**, which is based on the cost savings to operators per unit of time, 2) the **revenue (net profit) method**, which estimates the net increase in profit resulting from the reduction in travel time, and 3) the **willingness to pay method**, which measures the "perceived" value of time from observed or stated choices under trade-off situations involving time and money. Cost savings method can produce overly conservative estimates since it does not account for the potential increase in revenue associated with time saving. The benefit/loss calculations based on the revenue method will be inaccurate except in the cases in which operators possess a perfect knowledge of the marginal profit (Adkins, Allen, and William, 1967).

Following is a procedure to assess the travel time cost, as a component of user cost, associated with pavement maintenance. Thereafter, the results of a practical example to define the impact of relative variables are discussed.

2. DELAY AT OVERLAYING ZONES APPLICATION

2-1 Effects of Overlaying Erection

The cost of overlaying (or any maintenance activity) package depends on the unit price of the package and the size of the area on which the package is performed. The duration of the maintenance activities depends on the work-speed of the activity and the number of effective work-hours per day that depends on the number of shifts and the kind of road barrier construction used. Different work-speeds on maintenance packages were taken into account. To calculate the duration of a maintenance-activity one can apply the following formula:

$$\text{Duration} = \frac{\text{Length of the section (in meter)}}{\text{Work speed (in m/hr)} * \text{Effective work hour per day}} + \text{Set up time}$$

Where the setup time (and duration are expressed in days) is generally the time that is needed to set up and break down a permanent road barrier; this time depends on the applied road barrier system.

2.2 Traffic Handling Systems and Traffic Flow

There are three traffic handling systems are used; first system Figure (1-a), one lane of overlaying compartment way is closed and the traffic of this way used one lane alone. Second system Figure (1-b) one lane of overlaying compartment way is closed and the traffic of this way is diverted to the adjacent emergency lane for this way. Shortly after the traffic has passed the work compartment it is redirected to its initial lanes. Third system Figure (1-c) two lanes on a way are closed where the traffic is sent to the other two emergency lanes. So that it requires some concentration by motorists to stay between the temporarily marked lines. Shortly after the traffic has passed the work compartment, it is redirected to the initial lanes.

3. ROAD USER COSTS AT OVERLAYING ZONES

Road user costs are an aggregation of three separate cost components; vehicle operating costs, crash-related costs, and user delay costs. Vehicle Operating Costs (VOC) vary directly with level of serviceability (i.e. condition of the road). The difference in VOC occurring between a rehabilitation action and no rehabilitation can be considered as a measure of the relative difference in benefits. Significant research has been performed on relating user cost data for various highway type and design characteristics (Claffey, 1971, Thomas, 1970, SRI,1976, Zaniewski, 1982). User costs are borne by highway users traveling on the facility. From the LCCA perspective, user costs are the differential costs incurred by the motoring public between alternative strategies and associated maintenance and rehabilitation strategies over the analysis period. There is further restricted to differences in user costs resulting from differences in long-term pavement design decisions. Non-user costs and accident costs are very difficult to capture in numerical terms. These costs can be real, but they are usually omitted in the LCCA. Figure (2) shows the components of user cost including travel time cost elements.

Models for user delay costs during rehabilitation were first developed in Texas (McFarland, 1972). A user delay cost model based on queuing theory and capable of incorporating a variety of traffic handling methods, in addition to factors such as type of facility, traffic volume, length of rehabilitation zone, and the time of day, was developed by Karan, 1975.

4. DERIVATION OF TRAVEL TIME COST (TTC) VALUES

Every roadway section that is traveled has TTC associated with it and represents the expenses to operate the vehicle over that section. The absolute difference between the total motorist costs in the "before" condition and total motorist costs in the "after" condition is the total extra (excess) cost (ERC). The delay costs (ARC) within the construction of maintenance activities are the most significant cost component. Delays are experienced as the travel speed goes down due to capacity, geometric, and operational constraints. The delay from the "before" condition is compared to that of the "after" or improved condition and difference represents delay savings. (Ginger, Stockton, Robert , 2000).

4-1 Traffic Handling Cost

Traffic handling cost (THC), or maintenance of traffic, is defined as the cost required to maintain the traffic flow in a continuous and safe fashion during the time required for maintenance. It includes the following items: arrow brades, temporary traffic signs, temporary painted and pavement stripping tape, removable of temporary signs, marks and construction materials. THC component is an additional cost in each contract, normally a function of the facility, total cost of contract, type of work, etc..

There are three commonly used methods of handling traffic. First, when applying an overlay on two lane roads with shoulders, traffic in overlay direction is diverted into the shoulder or traffic in the "non overlay direction" is diverted into the shoulder, and traffic in the "overlay direction" is diverted into the "non-overlay lane". Second; when applying an overlay on a two- lane roads without shoulders, all traffic travels on the "non-overlay lane" (alternating). Finally, when applying an overlay on a four- lane divided or undivided roads with shoulders, traffic travels through the overlay direction only in one direction at a reduced speed and that at least one lane in the overlay direction remained opened to traffic.

4-2 Estimating Added Running Cost (ERC)

Added user costs are those incurred by a user on a facility due to delays experienced during maintenance/rehabilitation (overlay) activities. Added user cost includes the excess cost of stopping and slowing down, the cost of delay while stopped, and the excess cost of travelling at a reduced speed through the restricted area. These costs can be defined as a function of traffic volume with respect to the methods of traffic handling during a maintenance operation (Rada, 1985).

Flow of different types of vehicles at different times of day ranging from peak time to off-peak night time should be taken into account to estimate the total cost of delays to users caused by maintenance works. Added user costs are resulting from shutdown due to maintenance. No studies, concerning Egypt, have been done to determine the added user costs as a result of maintenance construction. So, An update of the modified models (Azmy, 1988) was used in this study. Because of the absence of any related studies on this information in Egypt, and in order to include the component of added user cost in this study, it was decided to use the models of vehicle operating cost VOC developed and adjusted for different types of vehicles as follow (Azmy, 1988):

$$(VOC)_{PC} = C^{(10.8064-0.0166*PCI)} * f \tag{1}$$

$$(VOC)_{ST} = C^{(11.894-0.0145*PCI)} * f \tag{2}$$

$$(VOC)_{MT} = C^{(12.161-0.0164*PCI)} * f \tag{3}$$

$$(VOC)_{AT} = C^{(12.467-0.0125*PCI)} * f \tag{4}$$

Where:

VOC = vehicle operating cost, L.E per 1000 veh.km.

$(VOC)_{PC}$ = estimated vehicle operating cost for a passenger car.

$(VOC)_{ST}$ = estimated vehicle operating cost for a small truck

$(VOC)_{MT}$ = estimated vehicle operating cost for a Medium truck

$(VOC)_{AT}$ = estimated vehicle operating cost for a articulated truck

PCI = Pavement condition index (from 0, failed, to 100, excellent)

f = adjustment conversion factor, = 2.69

C = constant, =1.85

4-3 Estimating Extra Running Cost (RUC)

Running user costs were subdivided into: i) vehicle running costs (i.e., fuel, lubricant oil, tyres, spare parts and maintenance labor), and ii) annual costs (i.e., vehicle depreciation, interest costs, crew wages, insurance and licensing fees and overhead costs). Extra running user costs are caused by the deterioration of pavements and are affected by the existing surface conditions and characteristics of the vehicles using the road. Existing pavement surface condition reflects the interaction between pavement design standards, maintenance policy, environment and traffic volume and composition.

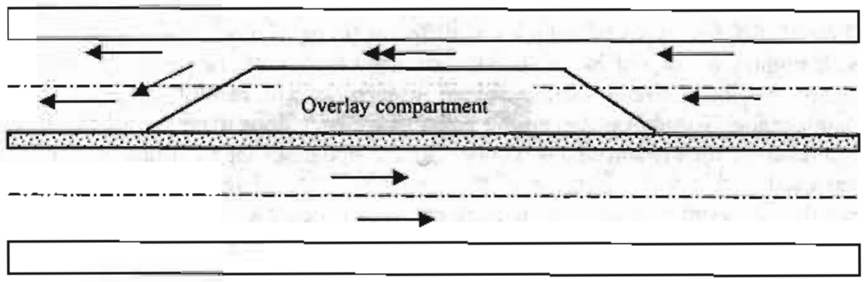


Figure (1-a) one of lanes is closed, so that only three of the four lanes are opened

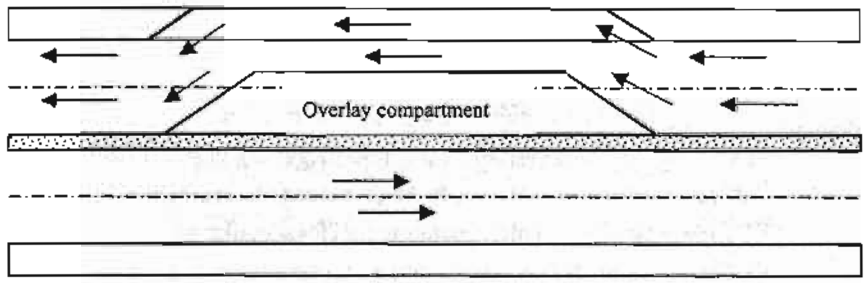


Figure (1-b) one of lanes is closed and emergency lane is used beside three lanes are opened

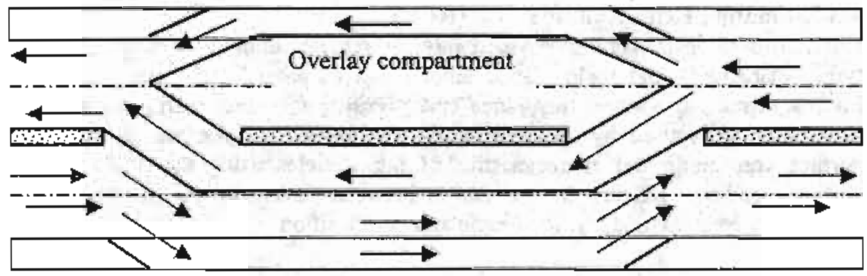


Figure (1-c) two lanes on a way of compartment are closed, so two emergency lanes beside two of the four lanes are opened

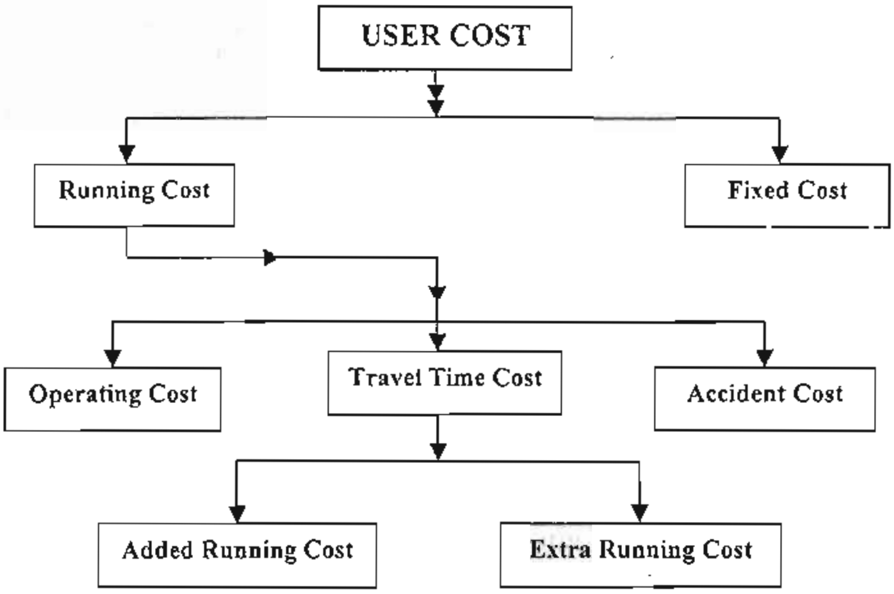


Figure (2) User cost components (Azmy, 1988)

5. ANALYSIS AND RESULTS

Within our pilot study we consider Cairo-Ismailia (4-lane divided) road of 10 kilometers overlaying length; for each 1km the road is divided in compartment segments and the constraints of overlaying (thin) are as follow:

- Compartment segment 100m with 50m after and before.
- Number of segments = 10
- Productivity rates = 6 segments (100m each) /day for one lane and 3 segments for two lanes overlaying or thick overlay for one lane.
- Equations (5) & (6) are used to calculate added and extra (ARC&ERC) running cost values, respectively.

Table (1) shows the field collected data and Table (2) includes travel time cost values for different traffic handling methods.

$$ARC = ? \frac{HV*24}{1000} ? ? (VOC_2 - VOC_1) \quad (5)$$

$$ERC = \{RC_1 - RC_2\} ? \frac{HV*24}{1000} \quad (6)$$

$$TTTC = ARC + ERC + THC \quad (7)$$

Where:

ARC	= added running cost, L.E/ km
VOC_1	= Vehicle operating costs just before overlaying
VOC_2	= Vehicle operating costs as a result of delaying within overlaying erection

RC_1 = running cost as a result of current condition, L.E/ km
RC_2 = running cost, as a result of excellent pavement condition L.E/ km
ERC = extra running cost, L.E/ km
THC = traffic handling cost, l.E/km
TTTC = total travel time cost, L.E/km

Table (1) Data of travel time cost elements for different traffic handling systems

Vehicle Type	Traffic Handling Method I, *Direction A*					
	HV* Veh/hr	**PHF****	**F*****	**S****** Km/hr	**ARC***	**ERC****
PC	374	0.567	65.96	48	188.71	267.83
ST	407	0.593	68.64	46	398.33	509.32
MT	60	0.397	15.11	40	691.13	615.2
AT	42	0.365	11.5	41	694.18	692.97
	Traffic Handling Method II, *Direction A*					
	HV Veh/hr	**PHF**	**F**	**S** Km/hr	**ARC**	**ERC**
PC	618	0.551	112.16	46	216.11	267.83
ST	275	0.362	75.97	44	449.23	509.32
MT	70	0.463	15.19	44	558.83	615.2
AT	59	0.319	18.5	45	559.18	692.97
	Traffic Handling Method III- *Direction A&B*					
	HV Veh/hr	**PHF**	**F**	**S** Km/hr	**ARC**	**ERC**
PC	436	0.52	83.85	42	272.71	267.83
ST	188	0.39	48.21	41	527.43	509.32
MT	54	0.41	13.7	40	691.13	615.2
AT	42	0.33	12.73	38	801.68	692.97

Where:
PC = passenger cars
ST = small Truck
MT = medium truck
AT = articulated truck
HV* = hourly volume, veh./hr
PHF** = peak hour factor, = HV/4*V15(peak 15 minute count within the hour)
F*** = peak rate of flow within hour.
S**** = average travel speed, km/hr.
ARC* = added running cost, L.E/1000 veh/km
ERC** = extra running cost, L.E/1000 veh/km
THC* = traffic handling cost, l.E/km

Table (2) include Added Running Cost (ARC). Extra Running Cost (ERC) and the total cost (T = ARC + ERC). Added and extra running costs are calculated using equations 5 & 6 with different variables discussed hereinafter.

Table (2) Travel time cost with different traffic handling methods

Vehicle Type	Travel time cost for T.H.M. L.E/km								
	Method I			*Method II*			*Method III*		
	ARC	**ERC**	**T**	**ARC**	**ERC**	**T**	**ARC**	**ERC**	**T**
PC	1693.9	2404.1	4098	3205.4	3972.5	7178	2853.6	2802.6	5656
ST	3890.9	4975.1	8866	2964.9	3361.5	6327	2379.8	2298.1	4678
MT	995.2	885.9	1881	938.8	1033.5	1962	895.7	797.3	1693
AT	699.73	698.5	1398	791.8	981.3	1773	808.1	698.5	1507
THC	60			170			380		
Total* TTTC*	16,303			17,410			13,914		

Where:

ARC	= added running cost, L.E/ km
ERC	= extra running cost, L.E/ km
THC	= traffic handling cost, I.E/km
T	= total travel time cost / vehicle type, L.E/km
TTTC	= total travel time cost, L.E/km

6- CONCLUSION AND RECOMMENDATIONS

We considered three traffic handling systems through overlay erection of 4 lane divided roads. First system figure (1-a), one lane of overlaying compartment way is closed and the traffic of this way used one lane alone. Second system figure (1-b), one lane of overlaying compartment way is closed and the traffic of this way is diverted to the adjacent emergency lane for this way. Shortly after the traffic has passed the work compartment it is redirected to its initial lanes. Finally; the third system figure (1-c), two lanes on a way are closed where the traffic is sent to the other two emergency lanes. So that it requires some concentration by motorists to stay between the temporarily marked lines. Shortly after the traffic has passed the work compartment, it is redirected to the initial lanes.

Based on the economic analysis of travel time cost elements defined in Tables (1&2) and are shown in Figures (3 to 7), the conclusions can be summarized as follow:

1- There are a considerable reduction of vehicles speed within the compartment of overlaying erection varying with the traffic handling system
2- The benefits (saving of travel time cost) from using the third system are about 25.13% and 17.17% with respect to the second and first system respectively. So, the third system should be preferred than two other systems from an economic viewpoint. For safety reasons, one may deviate from this economic rule of thumb.
3- The travel time cost (or excess cost) represents a huge investment on the average; 40.12% and 24.1% of thin and thick overlay cost respectively that must be involved in the scheduling process of maintenance works.
4- Travel time cost for different truck types represent about 60.33 % with respect to 39.67% of passenger cars.
5- Small trucks represent the highest percentage of travel time cost 39.84%. On the otherwise, medium and articulated trucks represent 11.12% and 9.38% of travel time cost respectively.

Figure (3) Speed distribution for traffic handling method (I)

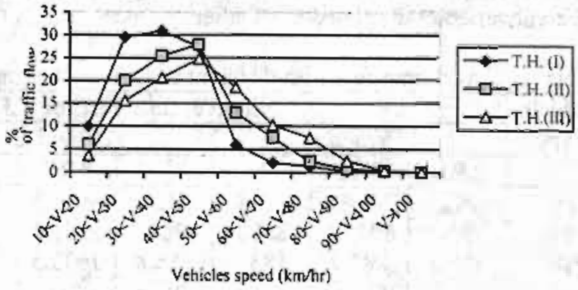


Figure (4) Travel time cost elements for traffic handling method (I)

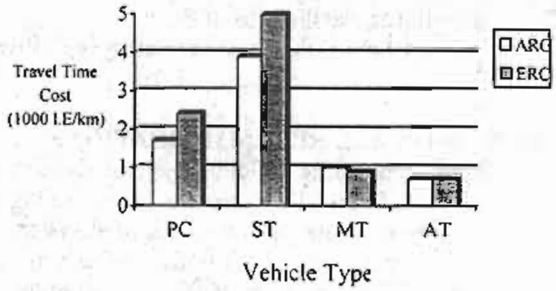


Figure (5) Travel time cost elements for traffic handling method (II)

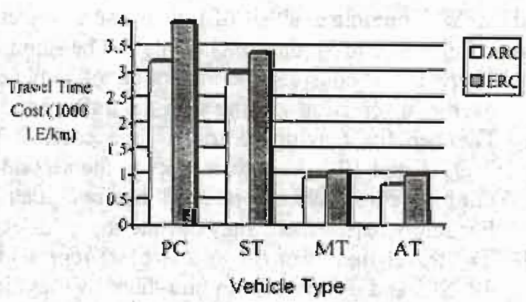


Figure (6) Travel time cost elements for traffic handling method (III)

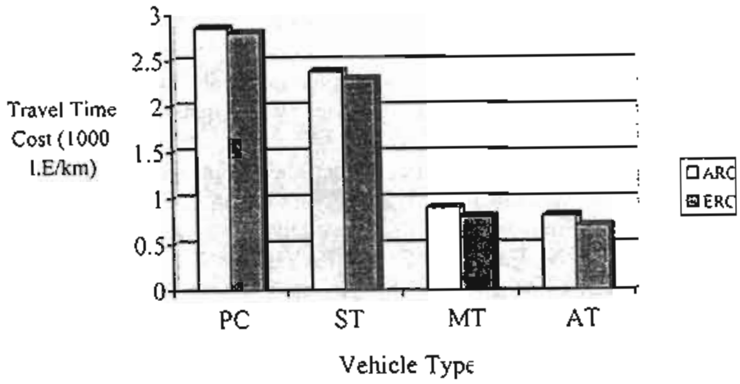
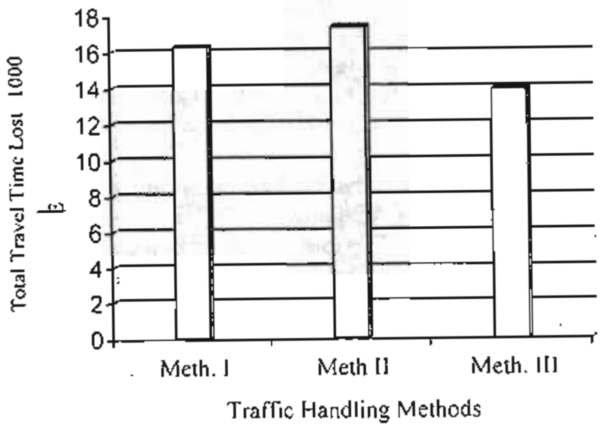


Figure (7) Travel time cost for different traffic handling methods



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