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ROAD TRANSPORT ANALYSIS IN EGYPT

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PREFACE

This report is one of a series of publications which describe various studies undertaken under the sponsorship of the Technology Adaptation Program at the Massachusetts Institute of Technology.

In 1971 the United States Department of State, through the Agency for International Development, awarded the Massachusetts Institute of Technology a grant, the purpose of which was to provide support for the development at M.I.T., in conjunction with institutions in selected developing countries, of capabilities useful in the adaptation of technologies and problem solving techniques to the needs of those countries. At M.I.T., the Technology Adaptation Program provides the means by which the long-term objective, for which the A.I.D. grant was made, may be achieved.

This report describes the application of a highway transportation planning framework developed at M.I.T., the Road Investment Analysis Model, to the analysis and evaluation of highway investment decisions in Egypt. A zone comprising roughly one-fourth of the road network of the Delta was selected for analysis, and two specific links were investigated in detail. The net benefits of alternate construction and maintenance policies were assessed and the most cost effective policy recommended to the Transport Planning Authority. In a separate activity, a study of the present stocks and requirements for road evaluation equipment was performed and a list of recommended new equipment is being reviewed by the Ministry of Transport.

During the summer of 1977, the Transport Planning Authority undertook an intercity taxi operating cost survey to update the preliminary data used in the earlier analysis. A portion of the zone under study was selected for the network analysis, and traffic count data were collected and an O-D survey of the study zone was performed. The input data for the link and network analysis were prepared in Cairo, and seminars were given at Cairo University and the Transport Planning Authority on the capabilities and data requirements of the network model. Additional user cost surveys for intercity lorries, intercity buses, and private cars were conducted by the Transport Planning Authority. Cairo University participants visited M.I.T. to perform the link analyses and contribute to the preparation of the final report.

The link analyses disclosed several key data items which must be developed before the network analysis could proceed and emphasized the need for road evaluation equipment. Further operating cost surveys were made by the Transport Planning Authority; the Road and Waterway Authority conducted traffic classification and axle load surveys; and Cairo University and Road and Waterway Authority participants analyzed the climatic and sub-surface drainage effects on road deterioration for representative Egyptian conditions.

The network analysis was performed on the M.I.T. computer facilities in August, 1978. Ten alternative maintenance policies were analyzed over the network study zone, reflecting three types of investment concerns important to the Egyptian Transport Planning Authority. First was the question of the relative frequency of the maintenance activities, in this case asphalt concrete overlays, which will affect the mean road surface condition of each road class. Second, was the relative magnitude of the investments as reflected in the overlay thickness, which would affect the rate of future deterioration of the riding surface in each road class. And third, was the question of the relative levels of investment among the three road classes - primary, secondary, and tertiary - to achieve the most effective overall investment strategy in the network.

The implications of the link and network analyses were then extrapolated to the entire Egyptian paved road network. The investment levels and returns were determined, and physical and financial requirements estimated for the short and long term. Comparisons between the predictions of the link results and network results were also made.

In the process of making this TAP-sponsored study, some insight has been gained into how appropriate technologies can be identified and adapted to the needs of developing countries per se, and it is expected that the recommendations developed will serve as a guide to other developing countries for the solution of similar problems which may be encountered there.

Fred Moavenzadeh
Program Director

ABSTRACT

A highway transportation planning framework developed at M.I.T., the Road Investment Analysis Model (RIAM), has been applied to the analysis and planning of highway investment decisions in Egypt at both the link and network levels. During the link evaluation phase, five reconstruction and subsequent maintenance policy alternatives were analyzed on each of twenty-five links independently, in a zone comprising roughly one-fourth of the paved road network of the Nile Delta. The five alternatives included do-nothing; a premix overlay followed by either scheduled or demand-responsive maintenance; and a double (asphalt over premix) overlay followed by either scheduled or demand-responsive maintenance. For each alternative and on each link, economic analyses of net present value, first year benefits, and internal rate of return were performed against the do-nothing alternative. Where data were lacking or unreliable, surveys were undertaken or engineering judgments were used.

The results of the twenty-five link-evaluation applications of the Road Investment Analysis Model indicated that there were four classes of link performance in the study zone under the proposed structural overlays and subsequent maintenance standards. These classes were:

(i) links which are in excellent present condition and for which the proposed investments may be postponed;

(ii) links which are in poor present condition and for which the proposed investments produce acceptable results. This means that the heavier structural overlay performs satisfactorily for the entire analysis period thus requiring no major subsequent maintenance investments;

(iii) links which are in poor present condition and which performed marginally under the proposed investments, in that the heavier structural overlay failed in from 5-14 years requiring major subsequent maintenance investments, and for which heavier initial investments should be considered; and

(iv) links which are of weak structural strength and poor present condition and which would have performed poorly under the proposed investments, in that both of the proposed structural overlays failed in less than 5 years and where all of the net benefits accrued from major subsequent maintenance investments, and for which heavier initial investments or reconstruction must be considered.

A tentative general finding which held true on all links analyzed was that, of the four post-construction maintenance policies studied, the one with the heaviest overlay dominated the economic analysis, independent of the effectiveness of the original double (asphalt over premix) overlay, which was the more extensive of the two construction options analyzed.

During the network evaluation phase the links in the study zone were analyzed simultaneously and as interdependent, being coupled through a stochastic traffic assignment procedure. Ten alternative maintenance policies were analyzed over the network study zone, reflecting three types of investment concerns important to the Egyptian Transport Planning Authority. Among the questions addressed were: (1) the relative frequency of the maintenance activities; (2) the relative magnitude of the investments as reflected in the overlay thickness; and (3) the relative levels of investment among the three road classes primary, secondary, and tertiary - to achieve the most effective overall investment strategy in the network. The analysis indicated that the more uniform the investment levels among the road classes, the higher the economic performance of the network. Additionally, the heavier the level of investment, the greater was the economic return from that investment, given that the investment was distributed fairly evenly among the various road classes. The optimum alternative identified was found to consist of frequent, light overlays on the primary system (where additional structural strength is not required) and initial heavy overlays followed by frequent, light overlays on the secondary and tertiary systems (where additional structural strength is needed to meet future

traffic demands). These results held true whether the performance was judged on economic efficiency or user satisfaction (consumer surplus).

The implications of the link and network analyses were then determined for the entire Egyptian paved road network. Returns on investment were found to range between 7 and 14 times the level of investment, while in turn these levels of investment were from 3 to 5 times greater than present levels of expenditure. The range of returns was consistent between the link and network extrapolations, although the network predictions were for investments and returns typically smaller than those of the link predictions by 30-40%. The returns on the proposed investments ranged from 3 to 7 billion (thousand million) Egyptian pounds.

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CHAPTER 1. INTRODUCTION

The road network in Egypt comprises over 26,000 kilometers of roads with approximately 12,000 km paved and 14,000 km unpaved, and highway inter-city transportation accounts for approximately three-fourths of present annual ton-kilometers and passenger kilometers (a situation which is expected to be maintained over the next decade). Although recent partial appraisal reports of the road network by independent consultants (1) have concluded that on average the highway system is in relatively good condition, with the poorer conditions being concentrated in the less heavily trafficked paved roads, the capabilities of the Egyptian Ministry of Transport to maintain the present system or expand the paved network during the coming decades have not been sufficiently addressed. The relative importance of the various links comprising the primary, secondary, and tertiary road networks to the overall performance of the road transport network are not well understood, nor is there agreement on the appropriate design and maintenance standards for the various classifications of links and upon criteria for upgradings.

Given the limited resources available for road transportation investments, either in construction of new facilities or maintenance and upgrading of existing facilities, there is a growing need within the Egyptian Ministry of Transport for a hierarchy of analytic techniques capable of evaluating the capital budgeting and programming of alternative scenarios for major investments in expanding or upgrading the network; of analyzing the various interdependencies between the alternative projects and maintenance policies of a road system, including both the appropriate timing and scaling of these projects; and of evaluating the economic consequences of alternative design, construction, and maintenance standards. The present Egyptian techniques for evaluation of road transport investments and corresponding data inventories are rather inadequate for the application of analytic models for road investment evaluation.

The purpose of this research is to demonstrate the application of an existing analytic framework, the Road Investment Analysis Model (2), to road transport investment decisions in Egypt, and to develop the necessary procedures for its modification and adaptation to the local Egyptian conditions.

1.1 Background

Highway transportation is clearly the predominant mode of both freight and passenger movements in Egypt, although this current predominance is partly a result of capacity limitations on the railways and inland waterways and should diminish in the future. Nevertheless, highways will remain the major means of transport, requiring substantial future maintenance and upgrading investments to retain present levels of service.

The organization responsible for highways is the Roads and Waterways Authority (RWA) of the Ministry of Transport, which has jurisdiction over the main roads of Egypt. Regional roads (typically unpaved) come under local jurisdiction. The existing organization for road maintenance includes the following elements:

- the central maintenance division in Cairo;
- eight maintenance divisions, one for each maintenance district
- twenty-five maintenance sections, plus two more within the occupied territory;
- fifty-seven maintenance subsections; and
- roughly 3000 road workers individually responsible for short lengths of road.

This organizational scheme is based on the direct assignment of specific road sections to each worker, typically three kilometers in agricultural areas and seven kilometers in desert areas, with each road worker living close-by. Approximately 100 km of agricultural roads or 200 km of desert roads are usually included within one maintenance subsection which has a separate base with the necessary equipment. Five to ten subsections are then grouped into a maintenance section. Each RWA maintenance district, which comprises two to five sections, has a maintenance division which is supervised by the central maintenance division in Cairo.

The individual road workers observe the road and indicate any damage to the assistant engineer of the maintenance subsection. They also maintain the shoulders by filling with nearby soil, only very seldom using select material. Groups of seven to ten workers are assembled if there are larger maintenance operations to be done, such as the removal of sand dunes with bulldozers provided by the district. Patching is also done by these larger groups using cold-mix prepared and delivered by the maintenance section, which also supplies workers specialized in asphalt repairs and equipment if the operations are on a large scale. Filling cracks with bitumen is done by units of three to four men.

The maintenance sections perform a periodic pavement sealing operation, which is done depending on the actual condition of the asphalt concrete, on the average of every five years. The maintenance sections and subsections perform only routine maintenance. Periodic maintenance and upgradings are done by independent companies on the basis of tenders, but are administered and supervised by the maintenance divisons of the districts.

Because of these relatively decentralized and field-oriented aspects of maintenance management, investment decisions are not now based on a systematic, nationwide evaluation of transport needs and priorities. There are virtually no project feasibility studies with supporting estimates of costs and benefits, and, in general, there is no rational analytic basis for the allocation of resources to and within the transport sector. Although reasonable results are being achieved with the present maintenance procedures, it may become more difficult to cope with growing traffic volumes, increased vehicle speeds and loads and other demands on the level of road serviceability in the future.

1.2 Purpose and Scope

The primary purpose of this cooperative research effort is the strengthening of Egyptian institutional capabilities for the analysis and evaluation of highway investments. This has been accomplished by establishing a data collection and inventory methodology reflecting the parameters appropriate for upgrading and maintenance decisions in Egypt, by applying and calibrating an existing evaluation framework -

the Road Investment Analysis Model - for use in these decisions, and by the training of Transport Planning Authority and Cairo University personnel in the use of these data collection and analysis techniques. Emphasis has been placed on the identification and resolution of the major issues confronting the establishment of appropriate maintenance and upgrading standards and schedulings for Egypt.

Specifically, the work built upon the recent MIT effort in Ethiopia (2) by applying the developed framework and methodology to the following issues:

1. Economic evaluation of proposed projects (both new construction and upgrading of existing links);
2. Economic evaluation of design and maintenance standards in the context of the larger road network;
3. Development of projections of future maintenance requirements and traffic patterns; and
4. Recommendation of equipment required to develop and maintain the data inventory of the network condition and maintenance activities.

To demonstrate the methodology, the team concentrated on data collection and analyses for a single maintenance district, through the involvement of Cairo University graduate and undergraduate students, and collaboration with Transport Planning Authority officials and Cairo University faculty on the development and use of this evaluation framework on Egyptian maintenance and upgrading situations of immediate interest. The calibration aspect of the project involved adapting to Egyptian conditions empirical relationships of pavement deterioration and maintenance effects which have been developed by MIT and applied in Ethiopia, and is proceeding over the longer term.

The scope of the research effort involved the evaluation of road transport in a zone comprising roughly one-fourth of the paved road network of the Nile Delta at both the link and the network level. During the link-evaluation phase, five reconstruction and subsequent maintenance policy alternatives were analyzed on each of twnety-five

links independently. The five alternatives included do-nothing; a premix overlay followed by either scheduled or demand-responsive maintenance; and a double (asphalt over premix) overlay followed by either scheduled or demand-responsive maintenance.

In the network-evaluation phase, ten alternative maintenance policies were analyzed over the study zone, reflecting three types of investment concerns of importance to the Egyptian Transport Planning Authority. First was the question of the relative frequency of the maintenance activities, in this case asphalt concrete overlays, which will affect the mean road surface conditions for each road class. Second, was the relative magnitude of the investments as reflected in the overlay thickness, which would affect the rate of future deterioration of the riding surface in each road class. Third, was the question of the relative levels of investment among the three road classes - primary, secondary, and tertiary - to achieve the most effective overall investment strategy in the network. For each alternative, economic analyses of net present value, first year benefits, and internal rate of return were performed against the do-nothing alternative. Where data were lacking or unreliable, surveys were undertaken or engineering judgments were used.

Chapter 2 presents the modeling approach in sufficient detail to allow this report to be self-contained. The link evaluation methodology, including the construction, road deterioration and maintenance, road user cost, link traffic, exogenous costs/benefits, and economic evaluation submodels, is discussed. Also presented is the stochastic traffic assignment algorithm for network analysis.

Chapter 3 presents the data collection and analysis efforts conducted in the course of this research, and indicates where assumptions and engineering judgments were made. Also presented are the results of surveys on operating costs, axle loads, and origin-destination flows.

Chapter 4 presents the analysis and results of the link evaluation phase, showing construction, maintenance, vehicle operation, and tota economic costs for each of the 125 link-alternatives analyzed. Net present values, first year benefits, and internal rates of return are

also given. The implications of data reliabilities and additional construction or maintenance policies is also discussed.

Chapter 5 presents the analysis and results of ten maintenance policies being applied to the study network as a whole. The primary focus was on the relative thickness and frequency of overlays among the various road classes. The effects of each of the alternatives is discussed both from a strict economic efficiency viewpoint and a consumer surplus (user satisfaction) viewpoint, and various economic indicators are presented.

Chapter 6 extrapolates the results obtained from the link and network analyses to the Egyptian paved road network as a whole. Total investment levels and returns on investment are presented, as is a discussion of the magnitude of the proposed investments in terms of current expenditure levels.

Chapter 7 concludes the report with a summary and some recommendations.

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2. Moavenzadeh, F., et al., The Road Investment Analysis Model: Summary Report, TAP Report 77-4, Massachusetts Institute of Technology, Cambridge, Massachusetts, Winter 1977 (Technology Adaptation Program).

CHAPTER 2. OVERVIEW OF THE MODELLING APPROACH

This chapter summarizes the modelling approach incorporated within an analytic model - the Road Investment Analysis Model - for use in evaluating alternative design, construction, and maintenance strategies on low-volume roads at either the link or the network level. The focus of the model is on project-level engineering decisions and their implications for total transport costs. The types of decisions which are within the scope of the model include the choice of alignment, geometric standard, surface type, maintenance policy, and construction and maintenance methods. The costs considered include total construction costs; labor, equipment, materials, overhead, and total maintenance costs; normal and generated traffic vehicle operating and travel time costs; and exogenous costs; all described in financial, economic and foreign exchange terms. The model may be used at both the prefeasibility and feasibility stages of project evaluation, and has been structured so that it provides information useful in both budgetary and economic planning of low-volume roads, as well as the impacts of foreign exchange requirements and network configurations.

Only the paved road relationships will be described here, as this was the only class of roads analyzed in Egypt under this study. However, complete and detailed documentation of all analytic techniques may be found in Volumes Two and Three of this report series, General Framework for Link Evaluation (1) and General Framework for Network Evaluation (2), respectively, to which the reader is referred.

2.1 ANALYTIC FRAMEWORK

The basic function of the Model is to estimate construction, maintenance, exogenous, and user costs for a system of roads which are to be designed, constructed and maintained to specific standards, and subject to known traffic demands and ancillary investments. This is done by simulating the life of each road from initial construction, through periodic upgrading, and through the annual cycle of use,

deterioration, and maintenance. The basic structure of the Model is shown in Figure 2-1.

The simulation is accomplished by determining construction and maintenance activities to be performed, and by estimating road conditions, traffic volumes, ancillary investments, and all associated costs on a year-by-year basis throughout the analysis period. The specific operations undertaken in each year are as follows.

A construction submodel schedules projects, allocates a percentage of construction costs to the current year, and updates the status of the link and activates generated traffic and/or exogenous cost/benefits (if any) as projects are completed. The various types of construction projects which may be undertaken include new construction, overlaying, pavement reconstruction, widening, widening and reconstruction, realignment, and removal from service.

Updating of the road includes the opening of sections to traffic and the abandonment of older sections. All costs are input by the User, in financial, economic, and foreign exchange terms.

A road deterioration and maintenance submodel estimates the average and final surface conditions for the year as a function of the initial design standard, last year's surface conditions, the volume and composition of the traffic during the current year, the local environment, and the specified maintenance policy. Surface deterioration may be estimated for both paved and unpaved roads. A range of typical maintenance activities may be specified for each surface type on either a scheduled or demand responsive basis; these are priced in financial, economic, and foreign exchange terms according to the amount of maintenance which is actually performed. The condition of the road is expressed in terms of roughness and rut depth (all roads), cracking, and patching (paved roads), and looseness and moisture content (unpaved roads).

Figure 2-1

DATA REQUIREMENTS

National or Regional Parameters

Design Standards
- Geometric standards
- Pavement sections
- Material characteristics

Maintenance Standards
- Routine Maintenance Criteria for Earth Gravel and Paved Roads
- Resurfacing Criteria

Highway Program Parameters

Construction Unit Costs
Maintenance Unit Costs
Basic Vehicle Ownership and Operating Costs

Project Parameters

Traffic
Exogenous Costs/Benefits
Physical Characteristics of the Alignment
Specific Design and Maintenance Standards to be Studied
Schedule for Implementation

SIMULATION OF A LINK-ALTERNATIVE

For each year in analysis period:

↓

Estimate costs for road construction or upgrading based on design standards and construction unit costs

↓

Update the status of the road based on project completions

↓

Assign this year's traffic

↓

Assign this year's exogenous costs/benefits

↓

Estimate road deterioration, effects of maintenance, costs, and average surface conditions

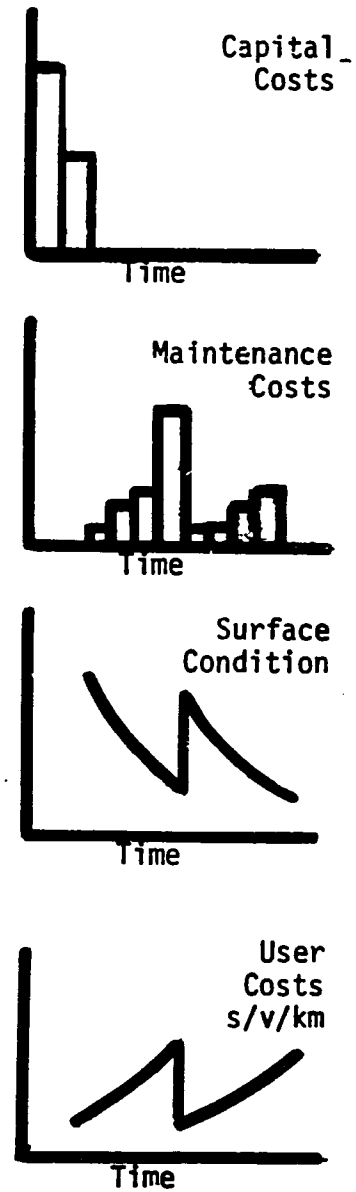
↓

Estimate user costs based on geometric standards, surface type and surface condition

↓

Store results for evaluation phase

RESULTS



A User cost submodel estimates the costs of operating vehicles over each road as a function of surface type and condition, environment, design geometrics (grade, curvature, and width), and vehicle characteristics. The components of vehicle operating costs include running costs (fuel, oil, tires, maintenance parts, and maintenance labor), annual fixed costs (depreciation, interest, crew costs, and overhead costs), and travel time costs (passenger time and cargo holding costs). Cost estimates are prepared for a fleet of vehicles representative of those which will actually be using the road, by vehicle type, in financial, economic, and foreign exchange terms.

A traffic submodel estimates the current year's traffic volumes based on the previous year's traffic and the anticipated growth, by vehicle type, for both normal and generated traffic. If the network option is used, the origin-destination demands are assigned to the system using a stochastic user-equilibrium approach. Both the actual and perceived costs of travel are then recorded in financial terms, to measure the consumer surplus of the system.

An exogenous costs/benefits submodel estimates the current year's exogenous net costs based on the previous year's costs and benefits and anticipated growth, in financial, economic, and foreign exchange terms.

The results of the simulation include a record of the expenditures incurred by the Highway Authority for capital improvements and maintenance; a record of the costs incurred by road users, both normal and generated; a detailed history of the status and deterioration of each road; and a history of the traffic volumes and ancillary investments. All estimates, other than construction and ancillary investments, are made in terms of physical quantities, from which total costs are obtained by applying the appropriate unit rates. The Model is therefore not dependent on the use of a particular monetary system, nor is it affected by changes in relative prices. All costs are estimated in financial, economic, and foreign exchange terms.

2.2 ROAD CONSTRUCTION

The key functions of the construction submodel are to allocate construction costs by cost component (financial, economic, and foreign exchange) on a year-by-year basis over the duration of the project, to modify the physical characteristics of the link as projects are completed, and to activate generated traffic and generated exogenous costs/benefits sets to the link (if any) as projects are completed. Key features of the model are as follows.

Projects may be scheduled for any year in the analysis period, and may consist of new construction, pavement reconstruction, widening, and so on. Projects may also be scheduled sequentially, as in staging; that is, a link may be constructed to a low standard initially, followed at a future date by pavement reconstruction, widening, realignment, or some other form of upgrading. Each project may affect any or all sections of the link, each having its own physical characteristics and design standards.

Construction costs are input by the User in financial, economic, and foreign exchange terms, along with salvage values, and the time distribution of these costs over the project duration.

Generated traffic sets and/or generated exogenous costs/benefits sets are activated and assigned to the link upon completion of the project, if any have been defined by the User as generated by this project.

2.2.1 Data Requirements

The data requirements of the road construction submodel consist of the cost of the project, in financial, economic, and foreign exchange terms; the distribution of costs over the project duration; its salvage values; and the type of improvement and physical characteristics of the alignment, on a section by section basis. The projects considered range from new construction to various forms of road improvement, with data requirements summarized in Table 2-1.

TABLE 2-1

DATA REQUIREMENTS FOR VARIOUS TYPES OF IMPROVEMENTS

Data Item	New Construction	Overlay	Pavement Reconstruction	Widen	Widen and Reconstruct	Realignment	Remove From Service
Location							
Length	X					X	
Start Station	X					X	
End station	X					X	
Subgrade CBR	X					X	
Geometry							
Rise	X					X	
Fall	X					X	
Curvature	X					X	
Width	X			X	X	X	
Surfacing							
Surface type	X	X	X		X	X	
Surface thickness	X	X	X		X	X	
Shoulder type	X	X	X		X	X	
Shoulder thickness	X	X	X		X	X	
Structural number	X	X	X		X	X	
Deterioration type	X	X	X		X	X	
Condition							
Serviceability	X	X	X	X	X	X	
Roughness	X	X	X	X	X	X	

2.2.2 Description of the Submodel

The construction submodel operates on all projects in one of three ways, depending upon the project status in the current year. The three status conditions which any project may experience in any year are: (a) not active (either not yet scheduled or already completed); (b) on-going, or (c) opening to traffic.

Inactive projects are ignored by the model in the current year. On-going projects, but projects not opening to traffic in this year, are processed to determine the costs incurred during the current year, by cost component (financial, economic, and foreign exchange). Salvage values are also computed, by cost component, for use in the last year of the economic analysis period. The costs for this project are added to the totals for the link being analyzed, by cost type. Projects opening to traffic in the current year cause the physical characteristics of the affected link to be modified to reflect the completed construction activities. The modifications made to the link are dependent upon the type of construction which has occurred.

For sections where the pavement structure is being modified (those experiencing new construction, overlay, reconstruction, widening and reconstruction, or realignment) the following data items are modified: pavement name, carriageway type, carriageway thickness, shoulder type, shoulder thickness, structural number, serviceability, roughness, and deterioration model type. In addition, the pavement age, axle history, cracking, and patching are set to zero.

For sections where the pavement cross-section is being modified (all types except overlay and reconstruction) the carriageway and shoulder widths are modified.

For sections where the alignment is being modified (new construction or realignment) the following data items are modified: start chainage, end chainage, geometric standard, length, rise, fall, curvature, and subgrade CBR.

For sections which are being removed from service, the section status is modified to "inactive."

In addition, if the project is to generate any traffic and/or exogenous cost/benefit sets, then the status of these sets is modified to active in the current year.

2.3 ROAD DETERIORATION AND MAINTENANCE

The maintenance-deterioration model computes two types of information essential to the successful operation of the the total cost model: maintenance resources and costs and the condition of road surface. These are computed for each link under each alternative for each year of the planning horizon. The maintenance cost is added directly to the total highway cost, while the condition of the road surface is used as an input to the user cost submodel for estimating road user costs. Thus, the surface condition predicted by the maintenance model affects the total highway cost indirectly, but very importantly, through its effect on road user costs.

The four basic types of variables that affect the maintenance cost and surface condition are: the environment, the traffic demand, the characteristics of the constructed highway, and the proposed maintenance standards and unit costs. The exact nature of a set of inputs needed to adequately describe each situation will depend upon the type of design under consideration.

Output from the maintenance submodel is of the same form regardless of the design. Maintenance costs are originally computed as the quantities of labor, equipment, and materials required. These are converted to monetary costs based on the applicable factor prices. The costs predicted by this submodel are for actual maintenance activities, plus supervision and overhead, in financial, economic, and foreign exchange terms. The results may be expressed either as a discounted economic summary of the analysis period on a link-alternative basis, providing the total discounted expenditure and resources consumed by each maintenance activity, along with the percentage breakdown in terms of

labor, equipment, materials, and overhead; or as an annual undiscounted economic summary of a requested link for a requested year on a section-by-section basis, providing physical quantities performed and total economic and foreign exchange costs.

Roadway surface condition is computed by the maintenance submodel, and described for paved roads in terms of roughness, rut depth, and patching and cracking. Also provided are the modified structural number of the section and the years since major maintenance was last performed. The surface condition parameters are used within the user cost submodel, along with curvature, grade, etc., to compute road user costs for each year.

2.3.1 Description of the Submodel

Maintenance-deterioration estimates are made for the following categories of maintenance activities: surface maintenance and other maintenance, which includes shoulder maintenance, drainage maintenance, and vegetation control. The emphasis in this discussion is placed on the problem of surface maintenance. This emphasis coincides with the distribution of costs for maintaining low-volume roads, as surface maintenance is usually responsible for over half of the maintenance cost and in some extreme cases can account for practically all of the expenditures. A second reason for concentrating on surface maintenance is the obvious trade-off potential with construction and user costs. Other types of maintenance also provide the opportunity for tradeoff, but usually involve smaller amounts of resources.

2.3.1.1 Road Surface Deterioration

The deterioration of paved roads is handled in one of two ways, depending upon whether the base is flexible or stabilized. For flexible pavements with granular bases, the general AASHO Road Test (6) results are used, with some modifications. For flexible pavements with stabilized bases, the TRRL Kenya (7) results are used. In either case, the traffic composition is converted into standard equivalent single axle loads of 18,000 lbs. (8,200 kg). The equations used in the RIAM are those suggested by the TRRL Kenya work (5,7).

Modified Structural Number

In the analysis of pavement performance a convenient index of pavement strength is needed. This index must satisfy the condition that two pavements of the same type having the same index will perform identically. The concept of structural number developed during the AASHO Road Test satisfies this requirement, provided that the strength of the subgrade, the impact of the environment, and the drainage characteristics of the base and sub-base are incorporated, establishing a modified structural number. The structural number of a pavement is defined by an empirical linear relationship in which the thickness and strength of each pavement layer are combined together as follows:

$$SN = \sum_{i=1}^{n} a_i D_i \qquad (2\text{-}1)$$

where a_i is the strength co-efficient of the ith layer

D_i is the thickness of the ith layer, in inches.

The most satisfactory way of taking into account the strength of the subgrade, the environmental impact, and the drainage characteristics of the base and the sub-base is to modify the structural number of the pavement so that it is equal to the structural number of a road of the same type which behaves in the same way, but which was built in a standard environment on a standard subgrade with standard drainage characteristics. This has been done in one of two ways, depending upon whether the base is flexible or stabilized.

The TRRL Kenya study of road deterioration (5) assumed Kenya to be the standard environment and standard subgrade, including only the effect of subgrade strength in the modification of structural number, producing the following relation:

$$\overline{SN} = SN + 3.51 \, Log_{10}CBR - 0.85(Log_{10}CBR)^2 - 1.43 \qquad (2\text{-}2)$$

where $\overline{SN}$ is the modified structural number,

SN is the structural number of the pavement and

CBR is the California Bearing Ratio of the subgrade

To allow direct comparisons with the AASHO Road Test, the most convient standards to use are the AASHO conditions themselves, (4) producing the following equation for the modified structural number of granular base pavements:

$$(1 + \overline{SN}) = (1 + SN) * (REGFAC)^{-0.10684} \left(\frac{CBR}{CBR_o}\right)^{0.14744} \qquad (2\text{-}3)$$

where REGFAC is the regional-and-drainage factor

CBR_o is the CBR of the AASHO subgrade (=2.69)

and the other parameters are as in Equation (2-2).

A higher regional-and-drainage factor indicates a weaker effective pavement. The values of REGFAC range from 0.1 in a frozen subgrade condition to 5.0 in a saturated subgrade condition.

Deterioration of Flexible Pavements with Granular Base

Paved surface performance for roads with granular bases is analyzed in the submodel by a routine which simulates the cycle of deterioration and repair. Deterioration is predicted as a function of equivalent axle loads and modified structural number. The equations used to predict this deterioration are of the form of the general AASHO equation as presented in the "Interim Guide." (4) Deterioration is initially predicted in terms of AASHO concept of serviceability - PSI. This serviceability measure is related to three measurable characteristics of the surface: slope variance (SV), rut depth (RD), and the amount of cracking and patching (CP) by the equation (8):

$$PSI = 5.03 - 1.91 \, Log_{10}(1 + SV) - 0.01 \sqrt{10CP} - 1.38 \, RD^2 \qquad (2\text{-}4)$$

Deterioration is predicted as a drop in AASHO serviceability, PSI, for each year of the analysis period. The equation for estimating deterioration is the general AASHO equation: (illustrated in Figure 2-2).

$$PSI(V,\overline{SN}) = 4.2 - 2.7(1.58V(1 + \overline{SN})^{-9.36})^{\text{exponent}}$$

where exponent $= 0.40 + 1094(1 + \overline{SN})^{-5.19}$ (2-5)

V is the cumulative volume of equivalent standard axles

$\overline{SN}$ is the modified structural number

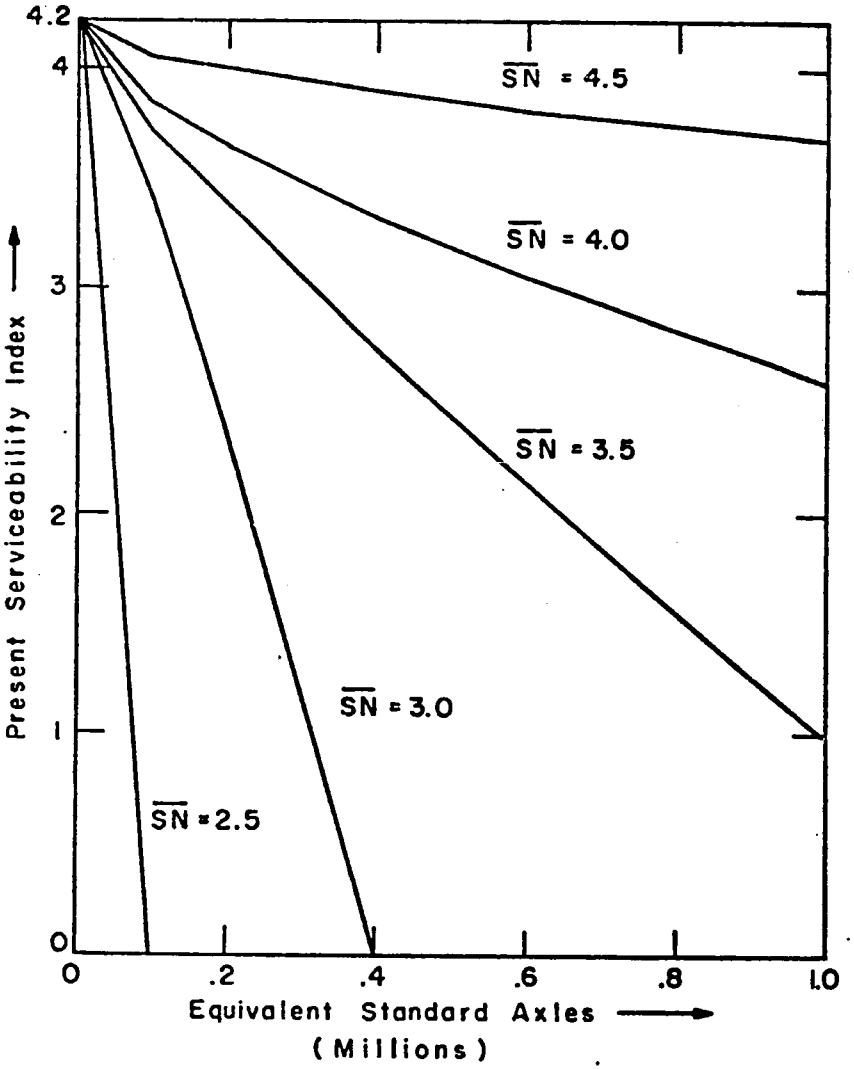


Figure 2-2 AASHO Serviceability Equation

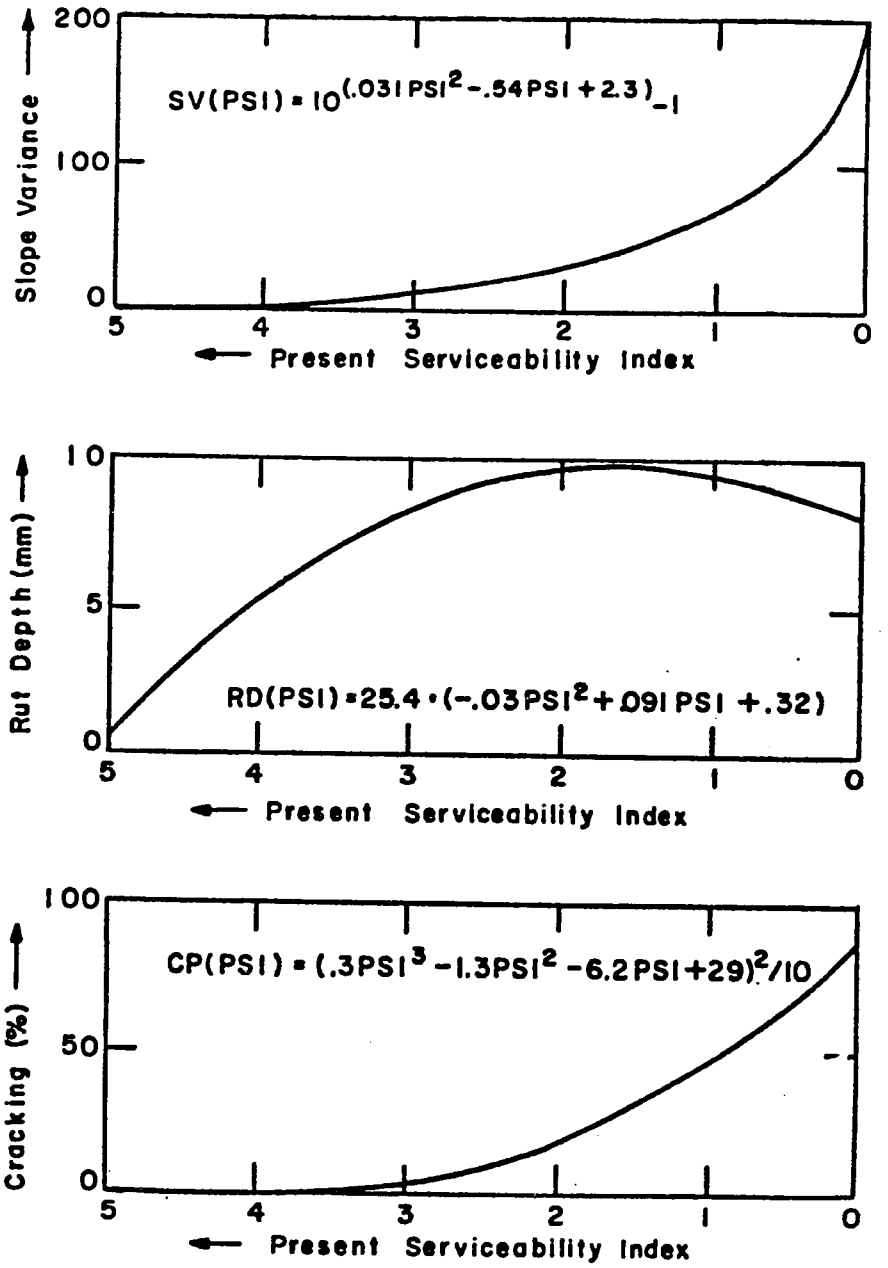


Figure 2-3. Damage Indicators vs. Serviceability

From this, the deterioration caused by an equivalent traffic volume of ΔV ensuing after a previous total equivalent volume of V would be

$$\Delta PSI(V, \Delta V, \overline{SN}) = PSI(V, \overline{SN}) - PSI(V + \Delta V, \overline{SN}) \qquad (2\text{-}6)$$

in which ΔPSI is the deterioration due solely to the equivalent traffic volume ΔV.

Using this new level of serviceability, the degree of deterioration measured in terms of slope variance (SV), rut depth (RD), and the amount of cracking and patching (CP) is found using the relationships (9) which are illustrated in Figure 2-3. The roughness of the road is calculated from the slope variance, assuming a normal distribution of the slopes to yield (10):

$$ROUGH(mm/km) = 636.62\sqrt{SV} \qquad (2\text{-}7)$$

Deterioration of Flexible Pavements with Stabilized Bases

The deterioration of pavements with stabilized bases is based on the TRRL Kenya research on road deterioration (5), with little additional information being available. All the deterioration relationships included in this model are in the form of polynomial equations relating a surface condition variable to traffic loading for a range of modified structural numbers, which were further regressed in terms of the modified structural number.

Roughness

The relationships used are derived from the Kenya data in conjunction with Road Note 31 (11). They are illustrated in Figure 2-4 and given below:

$\overline{SN} \leq 2.5$	$R = R_0 + 3200N$
$\overline{SN} = 3.0$	$R = R_0 + 483N$
$\overline{SN} = 3.5$	$R = R_0 + 159N$
$\overline{SN} \geq 4.0$	$R = R_0 + 119N$

In these equations

R is the roughness measured in mm/km by a fifth-wheel bump integrator towed at 30km/hr;

R_0 is the roughness when the road was new;

N is the total cumulative traffic loading in millions of equivalent (8200kg) standard axles per lane

The above equations were further regressed over structural number to yield:

$$R = R_0 + 1250N/[10^{a^{1/3}-b^{1/3}-1.3841}] \qquad (2\text{-}9)$$

where $a = \sqrt{0.20209 + 23.1318C^2} - 4.8096C$,

$b = \sqrt{0.20209 + 23.1318C^2} + 4.8096C$, and

$c = 2.1989 - \overline{SN}$

which is valid for $\overline{SN} > 2.2$

Rut Depth

The maximum mean rut depth measured on any of the test sections in Kenya was about 8mm, and the majority of measurements were between 3mm and 5mm regardless of traffic (5). The maximum mean rut depth which is tolerable before reconstruction becomes necessary is usually about 20mm for this type of pavement; therefore, it is unlikely that failure will occur through excessive rutting. Rut depth was also shown to have no measurable effect on vehicle operating costs, and therefore rut depth relationships have not been included in the model for this type of pavement.

Cracking

The estimation of pavement cracking is necessary to determine the maintenance requirement of a road. Two aspects of cracking must be predicted, namely the mean level of cracking in the wheeltracks and the total pavement area where severe local cracking occurs. The traffic loadings which were necessary to produce mean levels of cracking of $1m/m^2$

and $3m/m^2$ on the test sections in Kenya have been regressed (7) to yield:

$$\overline{SN} < 4.0 \quad CP = 300\,\overline{SN} - 1200 + \frac{21600N}{(\overline{SN})^{\overline{SN}}} \qquad (2\text{-}10)$$

$$\overline{SN} \geq 4.0 \quad CP = \frac{21600N}{(\overline{SN})^{\overline{SN}}}$$

where CP is the total area of cracking plus patching per km in one traffic lane. These results are illustrated in Figure 2-5.

Deterioration of Other Types of Paved Roads

Relationships for other types of pavements may be included in the model when further research has been carried out; but, in the meantime, it is assumed that either paved deterioration option used will predict similar types of deterioration, especially when compared with earth and gravel roads. However, care must be used in determining a realistic regional-and-drainage factor for the AASHO-based relationships when applying them to tropical and sub-tropical situations.

2.3.1.2 Paved Surface Maintenance

Maintenance activities are the same for flexible pavements, regardless of base type, although the component costs may vary depending on surface type. The maintenance activities included in the model for paved surface are: patching, surface dressing, overlaying, rehabilitation, and miscellaneous.

Sealing cracks and filling ruts have not been included in the model as maintenance options because, although used occasionally to rectify premature pavement failures, the techniques are not in general use for routine maintenance. Excessive cracking is best dealt with by the application of a surface dressing, and excessive rut depth, being indicative of pavement fatigue, by an overlay.

The amount of maintenance work to be done during the year is determined by the deterioration parameters and the specified maintenance policy. Table 2-2 gives a review of the paved road maintenance activities and their units which are included in the model.

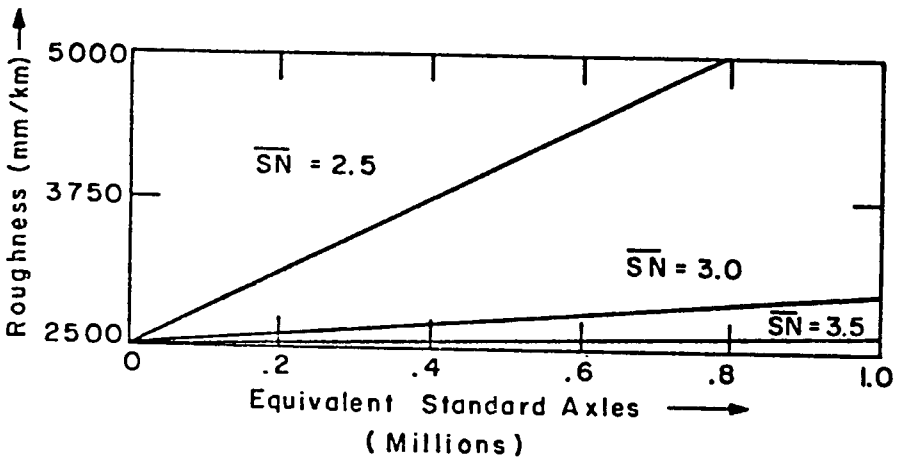


Figure 2-4 TRRL Roughness Relation

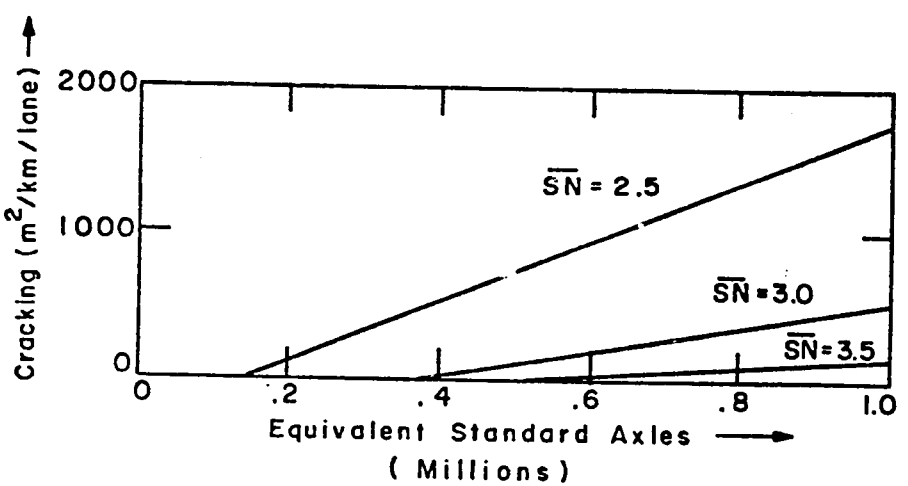


Figure 2-5 TRRL Cracking Relation

TABLE 2-2

Maintenance activities and units

Unpaved Road Sections	
Dry Season Grading	kilometers
Wet Season Grading	kilometers
Spot Regravelling	cubic meters
Gravel Resurfacing	cubic meters
Miscellaneous routine maintenance	kilometers
Paved Road Sections	
Patching	square meters
Surface Dressing	square meters
Overlaying	cubic meters
Rehabilitation	kilometers
Miscellaneous routine maintenance	kilometers

2.3.2 Maintenance Activities

The Model has incorporated four maintenance activities for both paved and unpaved roads into its structure, each of which may be scheduled or responsive in any given maintenance standard; and miscellaneous routine maintenance which is strictly scheduled at once per year. Scheduled maintenance activities are done at specific times, regardless of the state of roadway deterioration, while responsive maintenance activities are done when the roadway has deteriorated to a specific condition, regardless of the time at which that condition is reached.

Maintenance activities on paved roads include patching, surface dressing (seal coating), overlaying, rehabilitation, and miscellaneous routine maintenance. Patching may be scheduled as square meters per kilometer per year to be patched, but not to exceed the area requiring patching; or responsive as the percentage of cracked area to be patched, subject to a maximum square meters per kilometer constraint. Surface dressing may be scheduled as the number of years between surface dressings; or responsive as the maximum tolerable percentage cracking, subject to minimum and maximum years between surface dressings constraints. Overlaying may be scheduled as the number of years between overlays; or responsive as the maximum tolerable roughness before overlay, subject to minimum and maximum years between overlay constraints. Rehabilitation may be scheduled as the number of years between rehabilitations; or responsive as the maximum tolerable roughness before rehabilitation, subject to minimum and maximum years between rehabilitations constraints. In addition, surface dressing, overlaying, and/or rehabilitation, whether scheduled or responsive, may be subjected to a last analysis year to consider surface dressing, overlaying, and/or rehabilitation constraint, respectively. Miscellaneous routine maintenance is strictly scheduled at one time per year. Table 2-3 gives an explanation of the activities and their scheduling options.

TABLE 2-3: MAINTENANCE ACTIVITIES AND SCHEDULING OPTIONS

Maintenance activities and scheduling options

(S = Scheduled Maintenance R = Responsive Maintenance)

Unpaved Road Sections**

1. Surface grading--dry season

   S = days/grading R = 1000 vehicles/grading

   subject to min-max days/grading constraints

2. Surface grading--wet season

   S = days/grading R = 1000 vehicles/grading

   subject to min-max days/grading constraints

3. Spot regravelling of gravel road section

   S = cubic meters/km/year R = percent annual loss to be replaced

   subject to max m^3/km/yr constraint

4. Gravel resurfacing of gravel road sections

   S = years/resurfacing R = minimum tolerable gravel thickness (mm)

   subject to min-max years/resurfacing constraints

   Subject to last applicable analysis year constraint*

   Desired gravel thickness after resurfacing*

   Type of gravel being placed*

5. Miscellaneous routine maintenance

   S = one km/km/yr

Paved Road Sections**

1. Patching--weighted average of skin and deep patches

   S = square meters/km R = maximum tolerable % cracking & patching

   subject to max unpatched cracks constraint subject to max square meters/km constraint

2. Surface dressing (seal coating)

   S = years/surface dressing R = maximum tolerable % cracking & patching

   subject to min-max yrs/surface dressing constraints

   Subject to last applicable analysis year constraint*

3. Overlaying

   S = years/overlaying R = maximum tolerable roughness

   subject to min-max yrs/overlaying constraints

   Subject to last applicable analysis year constraint*

   Thickness and material type of overlay*

4. Rehabilitation

   S = years/rehabilitation R = maximum tolerable roughness subject

   subject to min-max yrs/rehabilitation constraints

   Subject to last applicable analysis year constraint*

   Resultant modified structural number*

   Resultant deterioration model type*

*Applies to both scheduled and responsive options

**In addition, a separate cost adjustment factor may be applied to each activity

2.3.3 Maintenance Costs

The costs of maintenance operations in each year are estimated based on the quantities of maintenance performed and appropriate unit costs. These unit costs provide the breakdown of activity costs into labor, equipment, materials, and overhead components. Each of these components is further broken down into financial, economic, and foreign exchange costs. These costs are intended to represent national averages for the various activities. However, since actual costs per unit of activity may vary depending on region, terrain, activity frequency, level of activity, and/or other factors, each activity of each standard may be weighted by a cost adjustment factor which modifies the national unit costs for that activity.

2.4 VEHICLE OPERATING COSTS

This section describes the methods used to estimate vehicle operating costs, which reflect the geometric standards to which the road was constructed, the type of surface, and the current surface condition as determined through the interactions of pavement design, environment, maintenance policy, and the volume and composition of traffic. Operating costs are estimated by first determining the amount of resources consumed in vehicle operation, and then by applying appropriate factor prices. The output from the submodel consists of vehicle operating and travel time costs for the year, broken down by type of vehicle and cost category.

The four basic types of variables that effect vehicle costs are: road geometrics, environment, surface type and condition, and vehicle characteristics and costs. The exact nature of required inputs for any given situation will depend upon the type of surface under consideration, as some environmental and condition data elements are required for unpaved but not for paved roads.

Vehicle operating costs are a function of road geometry, environment, surface type and condition, and the characteristics of the vehicles using the road. Because road gradients differ in each direction, the costs of vehicle operation per kilometer are computed for both directions of

travel and then averaged. The surface conditions used in the vehicle operating cost paved road relationships represent the average conditions for each year.

Costs are calculated in two categories: operating costs and travel time costs. Operating costs are those costs incurred through owning and operating the vehicle, and include fuel, oil, tires, maintenance parts and labor, depreciation, interest, overhead, and crew costs. Travel time costs are related to the time value of persons and cargo holding costs. Costs are computed in financial, economic, and (in some cases) foreign exchange terms.

Financial costs represent the actual costs incurred by owning and operating vehicles over the road. Economic costs represent the real costs to the economy of that ownership and operation. Foreign exchange costs represent the real costs to the economy which must be provided for in foreign currencies. The outputs of the submodel are vehicle operating and travel time costs, total costs, and speeds, by road section and vehicle type.

2.4.1 Description of the Submodel

Cost and quantity estimates are made for the following elements of total vehicular costs: fuel consumption, oil consumption, tire consumption, spare parts, maintenance labor, depreciation, interest charges, overhead, crew costs, passenger time costs, and cargo holding costs.

Data Requirements

The data requirements of the submodel consist of road geometry, environment, surface type and condition, and vehicle characteristics and costs. The specific variables required are as follows (see Table 2-4).

Road Geometry is specified in terms of the rise and fall of the road (m/km), horizontal curvature (^{o}/km), and road width (m). These variables reflect the geometric standards of the road as it exists in the current year.

Environmental input to this submodel is the mean elevation of the road section, in meters above sea level.

TABLE 2-4

DATA REQUIREMENTS

	Coding or Units
Road Geometry	
1. Road Rise	meters per kilometer
2. Road Fall	meters per kilometer
3. Curvature	degrees per kilometer
4. Road Width	meters
Environment	
5. Elevation	meters
Surface Type and Condition	
6. Surface Type	paved or unpaved
7. Roughness	millimeters per kilometer
8. Rut depth	millimeters
9. Looseness	millimeters
10. Moisture Content	percent
Vehicle Characteristics and Costs	
11. Vehicle Classification	TRRL category
12. Fuel Type	petrol or diesel
13. Brake Horsepower	BHP
14. Gross weight	metric tons
15. Equivalent Axle Factor	*
16. Cost of New Vehicle (F,E,X)	per vehicle
17. Tire Cost (F,E,X)	per tire
18. Fuel Cost (F,E,X)	per litre
19. Oil Cost (F,E,X)	per litre
20. Maintenance Labor Wage (F,E,X)	per hour
21. Crew Cost (F,E,X)	per hour
22. Value of Time (F,E)	per passenger hour
23. Overhead Costs (F,E,X)	annual or percent of operating costs
24. Interest Rate (F,E)	percent
25. Cargo Holding Costs (F,E,X)	per truck hour
26. Spare Parts Price Ratio (E/F, X/E)	percent
27. Average Number of Passengers	integer
28. Annual Crew Hours	hours per year
29. Annual Operating Hours	hours per year
30. Annual Kilometers Driven	kilometers per year
31. Average Vehicle Life	years
32. Age Distribution	percent
33. Annual Fleet Growth Rates	percent

*See Section 3.3.1.1

TABLE 2-5

COMPONENTS OF OPERATING COSTS

	Financial	Economic	Foreign Exchange
A. Running Costs			
1. Fuel	yes	yes	yes
2. Oil	yes	yes	yes
3. Tires	yes	yes	yes
4. Maintenance Parts	yes	yes	yes
5. Maintenance Labor	yes	yes	yes
B. Annual Fixed Costs			
6. Depreciation	yes	yes	yes
7. Financing Charges	yes	yes	no
8. Crew Costs	yes	yes	yes
9. Overhead Costs	yes	yes	yes
C. Travel Time Costs			
10. Passenger Time Costs	yes	yes	no
11. Cargo Holding Costs	yes	yes	yes

Surface Type is either unpaved (earth or gravel) or paved (bituminous treated or asphalt concrete). Surface conditions are described in terms of surface roughness (mm/km) and rut depth (mm) for all roads, and also surface looseness (mm) and moisture content (%) for unpaved roads.

Vehicle Characteristics and Costs are defined for the traffic using the road which may be represented by up to seven different vehicle types. The required characteristics of each of these representative vehicles are summarized in Table 2-4.

2.4.2 Cost of Operation

The various components of vehicle operating and travel time costs are summarized in Table 2-5. The specific relations used to estimate these costs are described below, following a discussion of vehicle speed and age.

Vehicle Speed

The average operating speeds of vehicles using the road are needed in order to estimate fuel consumption and travel time, which is used to apportion the annual fixed costs and determine the value of time savings. The speed prediction relations used in the model are based on the work of TRRL in Kenya, and were developed from 130,000 observations of speeds for different vehicle types, road geometrics, and surface conditions over a two year period (3). These relations are of the following general form:

$$\text{SPEED} = F\ (\text{RISE, FALL, CURVATURE, ELEVATION, WIDTH, ROUGHNESS, MOISTURE CONTENT, RUT DEPTH}) \qquad (2\text{-}11)$$

The actual co-efficients for TRRL's multiple linear regression analysis are shown in Table 2-6. The relationships do not account for vehicle interaction from congestion or speed cycle changes, but do reflect the small effects of reduced road width (below 5 meters). The TRRL equations were developed for passenger cars, light goods vehicles, medium and heavy goods vehicles (in one category), and buses, for both paved and unpaved roads.

TABLE 2-6 COEFFICIENTS FOR SPEED EQUATIONS

	α_0 (Constant)	α_1 Rise	α_2 Fall	α_3 Curvature	α_4 Altitude	α_5 Roughness	α_6 Moisture	α_7 Rut Depth	α_8 Width
1. Passenger Cars									
Paved	105.27	-0.37243	-0.07589	-0.11056	-0.00491	-0.00089	N/A	N/A	7.31
Unpaved	84.19	-0.20947	-0.06977	-0.11812	N/A	-0.00089	-0.13481	-0.18584	4.32
2. Light Load Commercial									
Paved	89.75	-0.41810	-0.04962	-0.07376	-0.00278	-0.00095	N/A	N/A	7.31
Unpaved	81.23	-0.31708	-0.05925	-0.09664	N/A	-0.00095	-0.29296	-0.19657	4.32
3. Buses									
Paved	72.40	-0.52558	0.06663	-0.06611	-0.00417	-0.00036	N/A	N/A	3.29
Unpaved	62.58	-0.49172	-0.01022	-0.04628	N/A	-0.00036	-0.16327	-0.09054	6.36
4. Medium & Heavy Load Commercial									
Paved	49.80	-0.51892	0.02989	-0.05807	-0.00042	-0.00060	N/A	N/A	3.29
Unpaved	49.20	-0.43342	0.00445	-0.06098	N/A	-0.00060	-0.22111	-0.26535	6.36
Variable Units	------	meters/km	meters/km	°/km	meters	mm/km	%	mm	meters
Safe Range of Variable Validity									
Paved	-----	0-85	0-85	0-200	0-2500	2000-5000	-----	-----	-----
Unpaved	-----	0-80	0-80	0-250	------	2000-14000	0-30	0-75	-----

GENERAL FORM OF EQUATIONS

SPEED = $\alpha_0 + \alpha_1$RISE + α_2FALL + α_3CURVATURE + α_4ALTITUDE + α_5ROUGHNESS + α_6MOISTURE + α_7RUT DEPTH

If road width is less than 5.0 meters, SPEED = SPEED - α_8(5.0 - ROAD WIDTH)

TABLE 2-7 COEFFICIENTS FOR FUEL CONSUMPTION EQUATIONS

	α_0 (Constant)	α_1 Speed	α_2 Speed	α_3 Rise	α_4 Fall	α_5 Roughness	α_6 Looseness	α_7 GVW	α_8 BHP/GVW
1. Passenger Cars									
Paved	53.56	498.3716	0.0058	1.5936	-0.8539	N/A	N/A	N/A	N/A
Unpaved	46.90	614.0499	0.0079	1.7235	-1.0657	0.0011	0.8218	N/A	N/A
2. Light Load Commercial									
Paved	74.70	1150.5088	0.0131	2.9058	-1.2774	N/A	N/A	N/A	N/A
Unpaved	72.78	844.2944	0.0137	2.8283	-1.3062	0.0011	1.7565	N/A	N/A
3. Medium Load Commercial									
Paved	105.43	902.5266	0.0143	4.3616	-1.8335	N/A	N/A	N/A	-2.3955
Unpaved	121.99	795.8916	0.0150	4.1760	-2.2200	0.0014	1.9688	N/A	-2.6192
4. Buses & Heavy Load Commercial									
Paved	-48.60	902.5266	0.0143	4.3616	-1.8335	N/A	N/A	69.2	-2.3955
Unpaved	-32.00	795.8916	0.0150	4.1760	-2.2200	0.0014	1.9688	69.2	-2.6192
Variable Units	-----	km/hr	km/hr	m/km	m/km	mm/km	mm	MT	HP/MT
Safe Range of Variables									
Paved	-----	see limits as defined in Table 4-3		0-85	0-85	2000-5000	-----	8.5-40	5-40
Unpaved	-----	"		0-80	0-80	2000-14000	0-20	8.5-40	5-40

Fuel Consumption = $\alpha_0 + \alpha_1$/SPEED + α_2SPEED^2 + α_3RISE + α_4FALL + α_5ROUGHNESS + α_6LOOSENESS + α_7/GVW + $\alpha_8 \frac{\text{POWER}}{\text{GVW}}$

Vehicle Age Spectrum

The age distribution of the vehicle fleet using a road affects maintenance, depreciation, and financing costs. One aspect of TRRL's work was therefore to develop a vehicle age distribution function for the Kenya vehicle fleet.

While the form of this function is generally applicable, the data base on which the function is based is strictly Kenyan, and as such can be said to model only the Kenyan situation. Since no generally valid function is available at present, the Model allows the User the option of choosing one of four age spectrum relations, with differing implications for depreciation, annual kilometrage, and cumulative kilometrage. These are the TRRL (12), DeWeille (13), constant age spectrum, and MIT (10) relations.

2.4.2.1 Resource Consumption

Running costs consist of those costs which are incurred as a direct result of vehicle usage, and include the costs of fuel, oil, tires, and maintenance parts and labor. Generally speaking, they vary with vehicle class and age, surface type (paved and unpaved) and condition, design geometry, vehicle speed, and driver habits. The major source of new primary data on resource consumption relationships for the various components of running costs is the TRRL Kenya Study (3). Although the study was not complete in every respect, it serves as the primary source for the relationships used in the Model. The specific components of running costs are computed as follows.

Fuel Consumption

The general form of the fuel consumption relations used in the Model is:

$$\text{FUEL} = (\text{FUEL TYPE FACTOR})\text{FL} \qquad (2\text{-}12)$$

where FUEL is f(SPEED, RISE, FALL, ROUGHNESS, LOOSENESS GVW, PWR)

FL is fuel consumption at constant speed in liters/1000 km

GVW is Gross vehicle weight, in metric tons

PWR is Power to weight ratio (horsepower/GVW)

FUEL TYPE FACTOR is Increased fuel consumption ratio due to speed cycle changes (1.08 for petrol engines, 1.13 for diesel engines)

The equations were developed by TRRL using multiple linear regression techniques on the results of experiments conducted with (i) passenger cars using a Ford Cortina estate wagon, (ii) light goods vehicles using a Land Rover, and (iii) buses and medium and heavy goods vehicles using a 7-ton Bedford diesel truck and a varying payload.

Since the fuel consumption data for buses and medium and heavy goods vehicles were obtained using the Bedford Lorry, the experimental results were compared by TRRL with survey data. The incorporation of a gross vehicle weight factor into the relationship gave good correlation, as follows:

$$\Delta FUEL = FUEL - FUEL_E = 69.2 \sqrt{GVW} - 154 \qquad (2\text{-}13)$$

In this equation:

FUEL = the actual fuel consumption in liters/1000 kms

$FUEL_E$ = the estimated fuel consumption calculated from the equation for medium good vehicles

GVW = the gross vehicle weight in metric tons

Using this result, the equation for medium goods vehicles was extrapolated to include heavier vehicles. The resulting equations together with the equations for cars and light goods vehicles are summarized in Table 2-7.

On unpaved roads, TRRL was able to relate two surface condition variables roughness and looseness - to fuel consumption. However, for paved roads, surface condition did not affect fuel consumption within the range of conditions studied. In order to extend the paved road relation to include roughness, the Model allows the User the option of utilizing the relationships developed by Claffey(14).

These relationships are in the form of a matrix of fuel consumption multipliers for speeds between 16 and 80 km/hr and roughness between 1800 and 5000 mm/km for all vehicle classes, save heavy goods commercial vehicles. The multiplier outside these ranges is unity. The matrix is shown in Table 2-8.

Oil Consumption

The consumption of oil represents about 1% of the total cost of vehicle usage and, as such, there has been very little research in relating oil consumption rates to either geometry, surface condition, or vehicle age. The oil consumption rates are shown in Table 2-9.

Tire Consumption

From their survey of operators, TRRL was able to develop two equations for estimating tire consumption:

(a) Passenger cars and light goods vehicles

$$TC = (-83 + 0.058R)10^{-3} \qquad R \geq 2000$$
$$= .03 \qquad R < 2000 \qquad (2\text{-}14)$$

(b) Medium and heavy goods vehicles and buses

$$TC = (83 + .0112R)GVW\ 10^{-4} \qquad R \geq 1500$$
$$= GVW\ .10^{-2} \qquad R < 1500 \qquad (2\text{-}15)$$

where: TC = the number of tires consumed per 1000 kilometers

GVW = the gross vehicle weight in metric tons

R = the roughness in millimeters per kilometer, which ranged from 1500-7500 in the condiitions analyzed.

Maintenance Spare Parts Consumption

The TRRL survey of operators showed maintenance spare parts consumption to be a function of road roughness and the vehicle age in kilometers. This consumption rate is expressed as a percentage of the new financial cost of the vehicles per 1000 kilometers. The relations are as given in Table 2-10.

Maintenance Labor Hours

The general functional form specified by TRRL for predicting hours of maintenance labor required per 1000 kilometers of vehicle operation is:

$$\text{LABOR HOURS} = f(\text{PC, ROUGHNESS}) \qquad (2\text{-}16)$$

where PC is the maintenance parts consumption rate as determined in the previous section. The relations are as given in Table 2-11.

TABLE 2-8

CLAFFEY'S MULTIPLIERS FOR FUEL CONSUMPTION ON ROUGH PAVED ROADS

	Roughness = 1800 mm/km			Roughness = 5000 mm/km		
Speed (km/hr)	Pass Car	Light Goods	Bus & Medium Goods	Pass Car	Light Goods	Bus & Medium Goods
16	1.0	1.0	1.0	1.01	1.00	1.03
32	1.0	1.0	1.0	1.05	1.00	1.06
48	1.0	1.0	1.0	1.20	1.01	1.07
64	1.0	1.0	1.0	1.34	1.06	1.08
80	1.0	1.0	1.0	1.50	1.16	1.20

Notes: (1) If velocity is less than 16 km/hr, roughness less than 1800/mm/km, or vehicle is heavy goods, then the multiplier is unity.
(2) Speeds over 80 km/hr are treated as 80 km/hr, and roughness over 5000 mm/km is treated as 5000 mm/km
(3) Interpolate linearly between ranges as necessary

TABLE 2-9

OIL COMSUMPTION RATES (LITRES PER 1000 KM)

	PAVED ROADS	UNPAVED ROADS
Passenger Car	1.2	2.4
Light Goods	1.8	3.6
Buses & Medium & Heavy Goods	4.0	8.0

TABLE 2-10

MAINTENANCE SPARE PARTS CONSUMPTION (PER 1000 KM)

	α_0	α_1	α_2
Passenger Cars and Light Goods Vehicles	-2.03	0.00180	1.0
Medium and Heavy Goods	0.48	0.00037	1.0
Buses	-67.00	0.06000	0.5

Spare Parts = $(\alpha_0 + \alpha_1 \text{ROUGHNESS})(\text{CUMULATIVE KM})^{\alpha 2} \cdot 10^{-8}$

TABLE 2-11

MAINTENANCE LABOR HOURS (PER 1000 KM)

	α_0	α_1
Passenger Cars and Light Goods Vehicles	851	-0.078
Medium and Heavy Goods	2975	-0.078
Buses	2640	-0.078

Maintenance Labor Hours = ($_0$ + $_1$ROUGHNESS) · (Spare Parts Rate)

Note: if Roughness >6000, Roughness = 6000

2.4.2.2 Costing of Resources Consumption

Consumed resources are costed in financial economic, and foreign exchange terms, as described below.

Fuel

The fuel consumption costs are computed per kilometer as the fuel resources consumed (liters per thousand kilometers) times the appropriate unit cost component (cost per liter in financial, economic, and foreign exchange terms) divided by one thousand.

Oil

The oil consumption costs are computed per kilometer as the oil resources consumed (liters per thousand kilometers) times the appropriate unit cost component (cost per liter in financial, economic, and foreign exchange terms) divided by one thousand.

Tires

The tire consumption costs are computed per kilometer as the tires consumed (tires per thousand kilometers) times the appropriate unit cost component (cost per tire in financial, economic, and foreign exchange terms) divided by one thousand.

Spare Parts

The spare parts consumption costs in financial terms are computed per kilometer as the parts consumed (fraction of new vehicle financial price per thousand kilometers) times the financial price of the new vehicle divided by one thousand. In economic terms, it is computed as the financial spare parts cost times the economic to financial spare parts cost ratio. The reason for this difference in methodology is that in many countries the vehicle is dutied at a different rate than are spare parts. In foreign exchange terms, it is computed as the economic spare parts cost times the foreign exchange to economic spare parts cost ratio.

Maintenance Labor

The maintenance labor costs are computed per kilometer as the maintenance hours consumed (maintenance hours per thousand kilometers) times the appropriate unit cost component (cost per hour in financial, economic and foreign exchange terms) divided by one thousand.

2.4.2.3 Annual Fixed Costs

The annual fixed costs of vehicle operations include depreciation, interest, crew, and overhead costs. The total costs of these items are assumed as fixed within reasonable ranges around the average annual kilometrage driven, but their allocation on a per kilometer basis will vary with the number of kilometers actually driven during a year, which generally increases with road improvements.

Depreciation

The costs of vehicle depreciation depend upon the vehicle age spectrum option. All options compute the financial costs of vehicle depreciation in the same manner on a per kilometer basis as a vehicle depreciation factor times the new financial vehicle price divided by the average annual kilometrage.

The TRRL and DeWeille Relations for economic vehicle depreciation are identical on a per kilometer basis, being computed as a vehicle depreciation factor times the new economic vehcile cost divided by the average annual financial kilometrage. The MIT Relations and the Constant Age Spectrum Relation are identical on a per kilometer basis in that annual economic depreciation cost is calculated as a periodic payment to a sinking fund. Using the economic rate of interest (ERI), a stream of N equal annual payments (where N is the vehicle's life expectancy) is calculated whose present value after discounting is equal to the economic cost of the new vehicle. This annual payment is the annual economic depreciation cost. The formula for this is:

$$\text{Annual Depreciation, Economic} = \left[\frac{\text{Economic Cost}}{\frac{1}{1 + ERI}} \quad \frac{\left[1 - \frac{1}{1 + ERI}\right]}{\left[1 - \left(\frac{1}{1 + ERI}\right)^N\right]} \right] \quad (2\text{-}17)$$

The TRRL and DeWeille Relations for foreign exchange vehicle depreciation are identical on a per kilometer basis, being computed as a vehicle depreciation factor times the new foreign exchange vehicle cost divided by the average annual kilometrage. The MIT and Constant Age spectrum Relations are identical on a per kilometer basis in that the annual foreign exchange depreciation cost is calculated as a periodic payment to a sinking fund. Using the economic rate of interest discussed above, a stream of equal annual payments is calculated whose present value after discounting is equal to the foreign exchange cost of the new vehicle, using an equation of the same form as Equation(2-17).

Financing Costs

In purchasing a passenger car or truck the owner either borrows money or must lose the interest on the money that could have been saved or used elsewhere. The annual financial cost is the market money rate times one-half of the financial cost of the new vehicle, prorated over the financial kilometrage to obtain a per kilometer financial interest cost. The one-half represents, once again, the assumption that all vehicles have on the average aged halfway.

The economic financing charges are zero for the DeWeille and Constant Age Spectrum Relations. For the TRRL and MIT Relations, they are computed as the economic rate of capital times one-half the economic cost of the new vehicle, prorated over the financial kilometrage to obtain a per kilometer economic interest cost.

The foreign exchange financing charges are zero for all vehicle age spectrum options.

Crew Costs

The Model treats crew costs as a fixed annual expense. The costs are computed as the annual crew hours times the appropriate cost component (crew cost per hour in financial, economic, and foreign exchange terms) divided by the appropriate annual kilometrage (financial, economic, and foreign exchange).

Overhead Costs

The overhead costs of vehicle operation may be calculated in one of two ways, at the option of the User, by vehicle type: (i) as average absolute overhead costs in financial, economic, and foreign exchange terms) prorated over the annual kilometrage (in financial, economic, and foreign exchange terms); or (ii) as an annual percentage of vehicle operating costs (in financial, economic, and foreign exchange terms).

Travel Time Costs

Travel time costs are assumed to consist of the value of consumed passenger time and of cargo holding costs. Passenger travel time costs are computed in financial and economic terms as the average number of passengers per vehicle times the hourly value of time per passenger (in financial or economic terms), times the average travel time for the road section divided by the length of the section to obtain the prorated financial and economic travel time costs for passengers on a per kilometer basis. No account is made of the foreign exchange value of passenger travel time.

Cargo holding costs are computed as the travel time over the road (hours per kilometer) times the appropriate cargo holding cost component (cost per hour in financial, economic, and foreign exchange terms) divided by the road length, to obtain the proper financial, economic, and foreign exchange cargo holding costs per kilometer. This hourly cost will vary depending upon the type of cargo being carried - higher for perishable goods cargo and goods that will be placed in service or otherwise used as soon as they arrive, and lower for other goods.

2.5 TRAFFIC ASSIGNMENT AND EXOGENOUS COSTS/BENEFITS

This chapter describes the methods used within the Model to assign and grow traffic volumes and exogenous costs/benefits on the links currently under analysis.

2.5.1 Link Analysis

Up to twenty distinct sets of traffic may be defined by the User, with any combination of sets being assigned to each link alternative. Each set must be either normal or generated traffic.

Normal Traffic

Normal traffic is that traffic which would use the link regardless of any road improvements, with benefits being calculated as the reduction in operating and travel time costs. The forecasts of normal traffic volumes may be given in either of two ways in each of up to three periods of the analysis horizon:

a) The User may specify an annual percentage growth rate for each vehicle class at which this traffic will grow during the period being defined.

b) The User may alternatively specify a constant annual increment for each vehicle class at which this traffic will increase each year during the period being defined.

Whichever options are used in any or all of the traffic periods, the base year average daily traffic for each vehicle class is provided by the User. In addition, different growth rates or annual increments may be specified for each of the vehicle classes and in each traffic period. Normal traffic is then aggregated over all normal traffic sets which are active on this link in the current year, by vehicle class.

Generated Traffic

Generated traffic is that traffic which is drawn to the link due to changes in the travel costs of this link and/or neighboring links. In this sense,the term generated traffic includes both "generated" and "diverted" traffic, and benefits are calculated as one-half the reduction in operating and travel time costs. The forecasts of generated traffic volumes may be given in one of three ways in each of up to three periods of the analysis horizon:

a) The User may specify an annual percentage growth rate for each vehicle class at which this traffic will grow during the period being defined.

b) The User may alternatively specify a constant annual increment for each vehicle class at which this traffic will increase each year during the period being defined.

c) The User may alternatively specify a percentage of current normal traffic for each vehicle class at which this generated traffic will increase each year during the period being defined. Care should be taken if this option is used for long periods because it may predict an unrealistically large traffic growth rate. We recommend that this option be used only in the initial year of the generated traffic set, and that either (a) or (b) be used subsequently.

For generated traffic sets, no base year average daily traffic is provided by the User, since the year of generation may be tied to completion of construction projects. Similarly to normal traffic, different growth rates, annual increments, or percentages of current normal traffic may be specified for each vehicle class in each traffic period. Generated traffic is then aggregated over all generated traffic sets which are active on this link in the current year, by vehicle class.

2.5.2 Network Analysis

The traffic assignment model assigns the origin-destination (O-D) flows to the links of the network, based on the operating and travel time costs of the relevant paths and the vehicle diversion parameters. It also grows the traffic O-D demands for the current year. The most recent vehicle operating costs and travel times over the various links will be used in conjunction with the origin-destination demands and the network data (available paths) to predict the link volumes. These volumes will be measured as vehicles per day, for use in the construction and unpaved roads deterioration models, and as equivalent single axle loads per day, for use in the paved roads deterioration models. Each

link's volume (vehicles per day) will be used by the construction model to trigger demand responsive projects. Each link's volume, its characteristics, and the exercised maintenance will be used by the deterioration models to calculate the maintenance costs incurred and the condition of the link at the end of the year. This information will be used to calculate the level of service (road users' costs and travel times) of the link. The financial users' costs and travel times will be part of the generalized price used by the assignment procedure to load the network flows in the successive year, while the economic costs will be stored for later use in the economic analysis of the investment alternative.

The inputs to the submodel are the following:

1. Network description - available paths between all origin-destination pairs
2. Traffic demands - base volumes and growth projections and load factors for all origin-destination pairs
3. Previous levels of service - operating costs and travel times for all links of the network
4. Assignment parameters - diversion intensities and elasticity parameters

The outputs from the assignment submodel are the link flows, in vehicles per day by vehicle type, both normal and generated, and the equivalent axle loads per day. In addition, the perceived and actual financial costs and travel times are computed for each link.

2.5.2.1 Description of the Submodel

The traffic assignment algorithm incorporated into the Model is stochastic, as human behavior is much more realistically modelled stochastically than deterministically. Thus, we have a procedure that will predict the probability of choosing any given path out of the set of possible alternative paths between any given origin-destination pair.

To formalize the problem, we assume that each path is associated with some travel disutility that is distributed according to some probability law:

$$U_i \sim F_{U_i}(u_i) \tag{2-18}$$

According to the utility maximization principle, the probability P_i of choosing path i between an arbitrary origin-destination pair for an arbitrary motorist out of the set A of all available paths between this origin and destination is given by:

$$\begin{aligned} P_i &= \Pr(\text{choose } i/A) = \Pr(U_i \leq U_j \ \forall\, j \varepsilon A) \\ &= \Pr(U_i = \min_{j \varepsilon A}' \{U_j\}) \end{aligned} \tag{2-19}$$

where U_i denotes the disutility associated with travelling over path i.

Given this criterion of path choice, the Stochastic User Equilibrium (15) can be formalized on the basis of the law of large numbers:

$$P_i = \Pr(U_i \leq U_j;\ \forall_j \varepsilon A) = \frac{x_i}{\sum_j x_j} \tag{2-20}$$

where x_i = the traffic flow over path i

Σx_j = the total number of trips between the origin and destination under consideration

This equation states that, at equilibrium, the fraction of flow choosing path i equals the probability of choosing this path.

A Logit-Based Model of Path Choice

It is generally assumed that the disutilities associated with the set of alternatives are linear in the parameters with additive disturbance term (16). We assume that each alternative path's disutility is composed of a deterministic, measurable part, termed the "generalized price" (GP_i) and an additive disturbance term ξ_i:

$$U_i = GP_i + \xi_i \tag{2-21}$$

We further assume that the generalized price is a linear combination of travel time and travel cost:

$$GP_i = \alpha(\text{Travel Time}) + \beta(\text{Travel Cost}) \tag{2-22}$$

where α and β are parameters to be estimated from observed path choice situations.

To obtain the Logit model of choice among alternatives, we assume that the disturbances, or error terms, are independently and identically distributed Gumbel variates, i.e.:

$$Pr\ (\xi_i \leq \omega) = \exp(e^{(a+\omega)}) \tag{2-23}$$

for any real value of ω.

Using this distribution, McFadden (17) demonstrated that Equation 2-19 can be written as:

$$P_i = e^{-U_i}/(\sum_{j\varepsilon A} e^{-U_j}) \tag{2-24}$$

For path choice problems, we rewrite the above equation as:

$$P_i = e^{-\theta GP_i}/\sum_j e^{-\theta GP_j} \tag{2-25}$$

Note that when the model is expressed in this way, the measurable portion of the disutility functions can be written in terms of θ and a new parameter VT:

$$\theta GP_i = \theta[(\text{Travel Cost}) + VT\ (\text{Travel Time})] \tag{2-26}$$

which is equivalent to Equation (2-22) but has a more intuitive appeal, since θ can be interpreted as the diversion intensity parameter and VT as the value of time. Thus we modify the definition of generalized price to:

$$GP_i = (\text{Travel Cost}) + VT(\text{Travel Time}) \tag{2-27}$$

and the path choice criterion is given by Equation (2-25) which is the basis of the assignment model.

In order to find the proper measure of the network performance, and formalize it, we denote the set of feasible alternative paths for an

arbitrary tripmaker going from origin i to destination j by A^{ij}. Each alternative path k is associated with a perceived disutility U_k^{ij}, and we assume that an individual selects that member of A^{ij} which minimizes his perceived disutility. The disutilities are assumed to be random variables, and the choice set A^{ij} is mutually exclusive and collectively exhaustive.

Since each individual selects the alternative which is perceived as minimum, the perceived travel cost $\overline{U}^{ij}$ becomes:

$$\overline{U}^{ij} = \min_{k \varepsilon A^{ij}} \{ U_k^{ij} \} \qquad (2\text{-}28)$$

However, since the GP_k^{ij} are random variables, this value is not measurable, and the quantity to be used becomes the expectation of the above expression, i.e.:

$$\overline{GP} = E[\min_{k \varepsilon A^{ij}} \{ GP_k^{ij} \}] \qquad (2\text{-}29)$$

The expected value of the minimum perceived generalized price (disutility) has two properties that are highly desirable in traffic assignment:

1. It is monotonically increasing with respect to the mean (measured) disutility of each alternative path (i.e., the generalized price).
2. It is monotonically decreasing with respect to the size of the choice set.

The first property implies that when any link of the network is improved (its generalized price decreases), the expected minimum perceived cost decreases as well. Sheffi and Daganzo (18) prove that the marginal expected minimum disutility with respect to the mean disutility (the generalized price) on any path equals the probability of using that path:

$$\frac{\partial E[\overline{U}^{ij}]}{\partial GP_k^{ij}} = P_k^{ij} \qquad (2\text{-}30)$$

Since P_k^{ij} is the probability of choosing path k, it is always non-negative, and thus the first property above holds. Substituting Equation (2-25), Equation (2-30) yields:

$$\frac{\partial E[\bar{U}^{ij}]}{\partial GP_k^{ij}} = \frac{e^{-\theta GP_k^{ij}}}{\sum_m e^{-\theta GP_m^{ij}}} \tag{2-31}$$

which, upon integration, produces

$$E[\bar{U}^{ij}] = -\frac{1}{\theta} \ln \sum_m e^{-\theta GP_m^{ij}} \tag{2-32}$$

The constant of integration is shown to be zero by introducing the boundary condition:

$$E[\bar{U}^{ij}] = GP^{ij} \text{ for } N^{ij} = 1 \tag{2-33}$$

The secondary property of the expected minimum disutility implies its reduction when any new alternative route is provided. A general proof of this property is offered by Williams (19) which is not restricted to any specific model.

Economic Interpretation

The attractiveness of the new measure of benefits, $E[\bar{U}]$, would have been limited had it not had an appealing economic interpretation. Using a binary choice example, consider the share of motorists that will choose path 2, P_2, as a function of the generalized price over path 2, as GP_1 remains constant:

$$\frac{x_2}{x_1 + x_2} = P_2(GP_2) = \frac{e^{-\theta GP_2}}{e^{-\theta GP_1} + e^{-\theta GP_2}} \tag{2-34}$$

where x_i is the number of users choosing path i. This function represents the demand for the use of path 2, and is plotted in Figure 2-16. Now consider an investment in upgrading path 2 which decreases the generalized price over it from GP_2' to GP_2''. The consumer surplus in the first situation is given by:

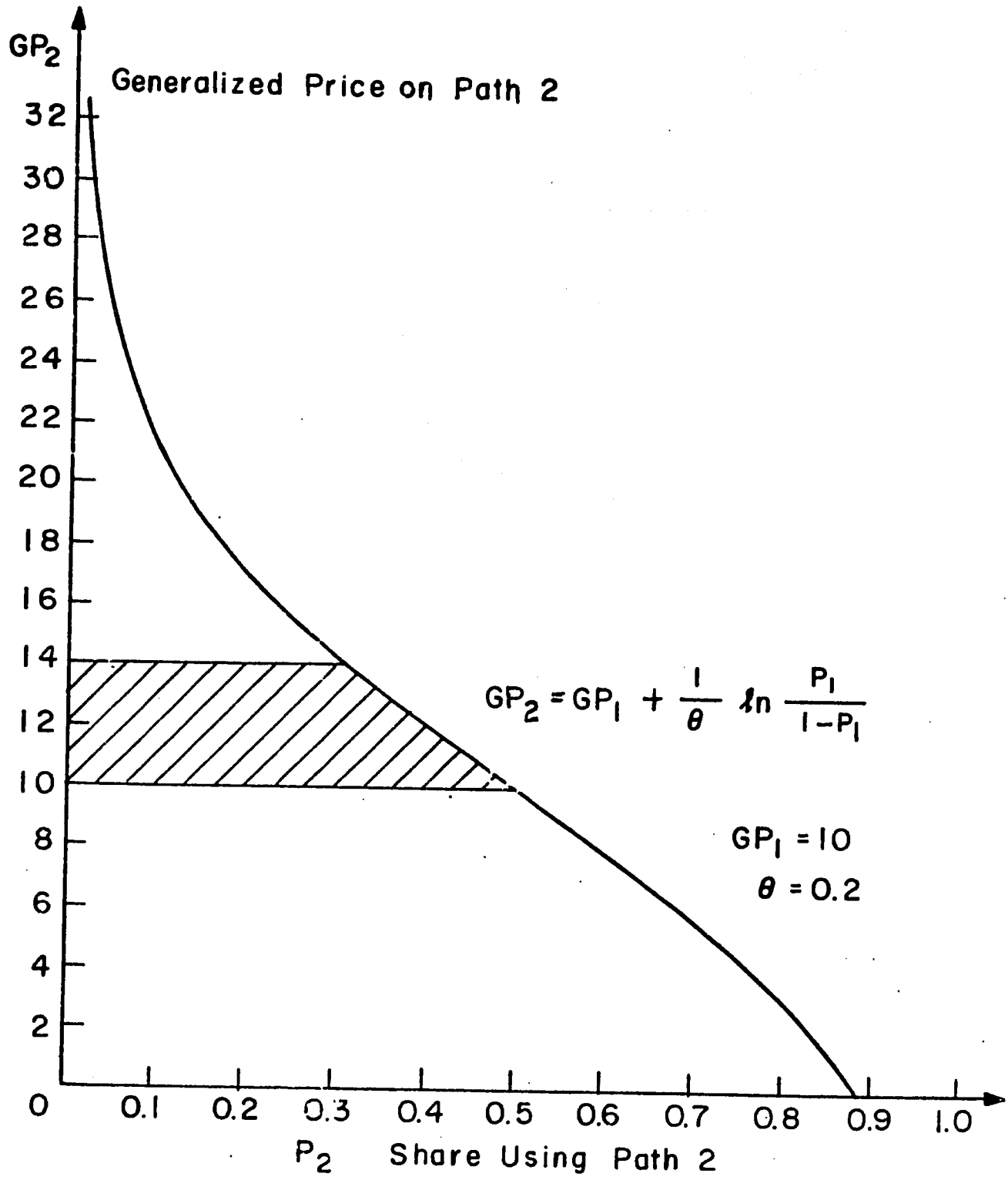


FIGURE 2-6 DEMAND CURVE FOR THE USE OF PATH 2

$$-GP_2'P_2' + \int_0^{P_2'} (GP_1 + \frac{1}{\theta} \ln \frac{P_1}{P_2})\, dP_2 \tag{2-35}$$

and after the investment, the total consumer surplus in the system is given by:

$$-GP_2''P_2'' + \int_0^{P_2''} (GP_1 + \frac{1}{\theta} \ln \frac{P_1}{P_2})\, dP_2 \tag{2-36}$$

The increase in the consumer surplus, ΔCS, is the difference between the above quantities, or the integral:

$$\Delta CS = -GP_2''P_2'' + GP_2'P_2' + \int_{P_2'}^{P_2''} GP_2\, dP_2 \tag{2-37}$$

which corresponds to the shaded area in Figure 2-12. However, as evidenced by the figure, the same area can be calculated by intergrating $P_2(GP_2)$ along the generalized price axis. The change in consumer surplus gained by lowering the generalized price from GP_2' to GP_2'' is

$$\Delta CS = \int_{GP_2'}^{GP_2''} P_2(GP_2)dGP_2 \tag{2-38}$$

Upon substituting the first property of the expected minimum disutility (Equation 2-30) the change in the consumer surplus becomes:

$$\Delta CS = E[\overline{U}]\Big|_{GP_2=GP_2''} - E[\overline{U}]\Big|_{GP_2=GP_2'} \tag{2-39}$$

which result extends directly to the miltinomial case. For the demand curve in Figure 2-12, the change in consumer surplus is:

$$\Delta CS = \frac{1}{\theta} \ln(e^{-\theta GP_2'} + e^{-\theta GP_1}) - \frac{1}{\theta} \ln(e^{-\theta GP_2''} + e^{-\theta GP_1}) \tag{2-40}$$

Thus, the difference between the expected minimum disutilities of two network configurations exactly equals the amount of consumer surplus gained by the change.

The above formula is also the proper measure of network performance for all O-D pairs and all vehicle types. When comparing two network configurations, the metric is given by:

$$E[\overline{U}'] - E[\overline{U}''] = -\frac{1}{\theta} \ln \sum_j e^{-\theta GP_j'} + \frac{1}{\theta} \ln \sum_j e^{-\theta GP_j''} \tag{2-41}$$

This difference can be shown to equal the difference in total consumer surplus in the system between the two configurations, and the total consumer surplus for a given configuration is given by:

$$E[\overline{U}] = -\frac{1}{\theta} \sum_{\substack{\text{all} \\ \text{users}}} \sum_{\substack{\text{all} \\ \text{O-D} \\ \text{pairs}}} \ln \sum_{\substack{\text{all} \\ \text{paths} \\ j}} e^{-\theta GP_j} \tag{2-42}$$

2.5.3 Congestion

The relationships used in the model to predict vehicle speeds and fuel consumptions were developed under almost free-flow conditions (3) where the only constraints on speed were the physical characteristics of the road and the characteristics of the vehicles, and they are therefore not valid when traffic interaction takes place. A knowledge of the relationship between speed and traffic flow is of fundamental importance in many aspects of traffic engineering, and much research has been undertaken in developed countries on this subject. During the simulation of the life of the road, it is possible that the vehicle flows will increase until critical levels of hourly flow and average daily traffic are reached, causing traffic interaction and its resultant reductions in vehicle speeds.

2.5.4 Exogenous Costs/Benefits

Exogenous costs and benefits sets are regarded as the parallel of traffic sets, in that the forces which give rise to traffic are often the same forces which give rise to production, and hence to exogenous costs and benefits. Accordingly, the structure of this submodel is analogous to that of traffic described in Section 2.5.1. The User may define exogenous cost/benefit "sets" as streams of costs and benefits applicable to specific links, with the streams being either normal or generated.

Normal Exogenous Costs/Benefits are the costs and benefits streams which would occur in the vicinity of the link regardless of any road improvements and which are not directly related to the road itself (construction or maintenance) such as the cost and benefit streams associated with the installation and operation of an irrigation system in an area already having road access. The forecasts of normal exogenous cost and benefit streams may be provided in one of three ways:

a) The User may specify a one-shot lump sum amount which would apply during the period being defined.

b) The User may alternatively specify a constant annual increment at which costs or benefits will increase each year during the period being defined.

c) The User may alternatively specify an annual percentage growth rate at which costs or benefits will grow during the period being defined.

Normal costs/benefits sets are defined as applicable to only one link, due to their localized nature, and would be applied to that link as scheduled in the link-alternative. Costs and benefits are then aggregated over all normal cost/benefit sets active on the link in the current year.

Generated Exogenous Costs/Benefits are those cost and benefit streams which occur due to construction activities on the link, such as increased agricultural production and marketing caused by provision of an all-weather access road. The forecasts of generated exogenous cost and benefit streams may be provided in the same manner as for normal cost/benefit sets. Generated costs and benefits are then aggregated over all generated cost/benefit sets active on the link in the current year, and added to the normal cost and benefit totals to produce the total costs and benefits by cost component (financial, economic, and foreign exchange).

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CHAPTER 3. DATA AVAILABILITY AND COLLECTION

3.1 DEFINITION OF THE STUDY AREA

The area chosen for study is flat, mainly cultivated land lying to the north of Cairo, which contains the Monofia and Qalubia Governorates road network (see Figure 3-1). This area was chosen for the study zone for the following reasons:

1. Availability of records concerning construction and maintenance of the road network;
2. Physical homogeneity of the link characteristics;
3. Diversity of traffic volumes and compositions providing a cross-section of the spectrum of traffic conditions found on the Egyptian road network;
4. Possibility of a route-choice study, since the zone contains the Monofia highway, which parallels the Cairo-Alexandria agricultural expressway, and numerous perpendicular connecting links; and
5. Economic importance of the road network to the highway authority in Egypt.

In order to produce a study of manageable size, given the time and resource constraints of this research effort, the study zone has been abstracted into the major links in the area bounded on the west and south by the roads on the west bank of the Rasheid Branch of the Nile between the towns of Tawfikieh, Tamaly, Khatatba, and Kanater, and on the east and north by the Cairo-Alexandria agricultural expressway, between the cities of Qalub (immediately north of Cairo) and Tawfikieh. The resulting network, comprising twenty-five links, is close to the maximum size which the model is capable of analyzing at present. Specific constraints considered in the choice of the links in this zone include:

1. The physical boundaries facilitate the definition of an external zoning system for the origin-destination flows;
2. The time and manpower requirements needed for data collection, which necessitated the elimination of unpaved roads from the

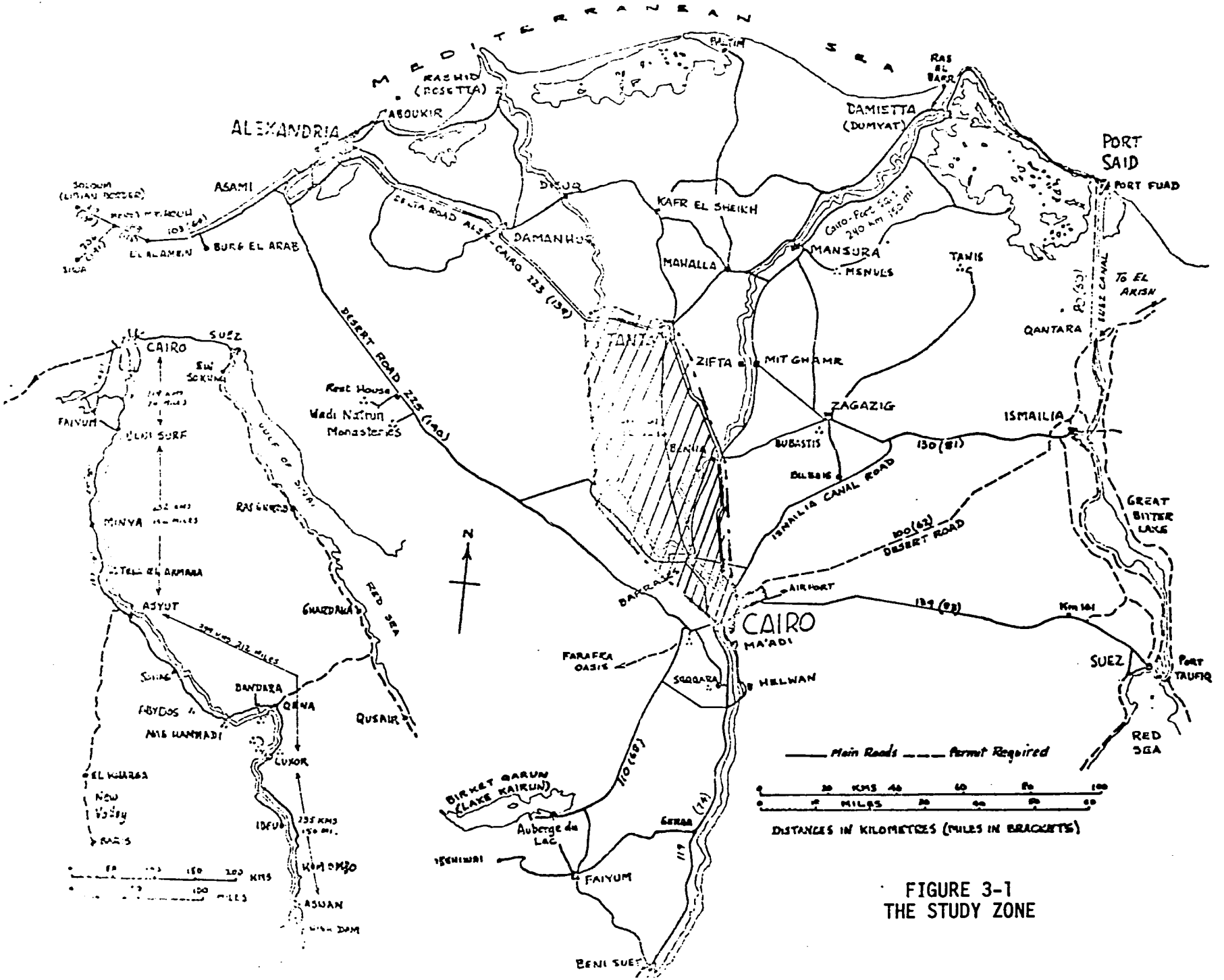


FIGURE 3-1
THE STUDY ZONE

study network;

3. the model's capabilities to analyze a specific number of links.

The idealized road network to be analyzed consists of the following links, which have been arranged in order of decreasing life-expectancy to facilitate the presentation of results:

1. Qalub -- Touck (QB-TK)
2. Touck -- Banha (TK-BN)
3. Tanta -- Tawfikieh (TN-TW)
4. Banha -- Quesna (BN-QS)
5. Quesna -- Berket-el-Saab (QS-BS)
6. Berket-el-Saab -- Tanta (BS-TN)
7. Quesna -- Shibean-el-Koam (QS-SH)
8. Bagour -- Tamaly (BG-TM)
9. Qalub -- Kanater (QB-KN)
10. Kanater -- Tamaly (KN-TM)
11. Kanater -- Biltan (KN-BL)
12. Biltan -- Touck (BL-TK)
13. Biltan -- Banha (BL-BN)
14. Ashmoon -- Santriss (AS-SN)
15. Shohda -- Babel (SD-BB)
16. Berket-el-Saab -- Shibean-el-Koam (BS-SH)
17. Babel -- Tanta (BB-TN)
18. Kanater -- Santriss (KN-SN)
19. Santriss -- Bagour (SN-BG)
20. Bagour -- Shibean-el-Koam (BG-SH)
21. Shibean-el-Koam - Kom-el-Akder (SH-KM)
22. Kom-el-Akder -- Babel (KM-BB)
23. Banha -- Bagour (BN-BG)
24. Kom-el-Akder -- Shohda (KM-SD)
25. Tamaly -- Tawfikieh (TM-TW)

3.2 DATA ON EXISTING LINK CONDITIONS

Personnel within the Ministry of Transport gathered all data required to describe the existing link characteristics, the various items of which were obtained from the following sources:

1. Geometric data (road rise, road fall, horizontal curvature, and road length) were collected from field surveys and existing design drawings;
2. Soil data (subgrade CBR) were taken from previous tests executed during road construction;
3. Weather data (annual rainfall, dry and wet season lengths) were taken from the Department of Meteorology information;
4. Pavement data (surface type, shoulder and carriageway width and thickness, initial condition, structural number) were developed from construction records, measurements, and visual inspections.
5. AASHO Regional factors were assumed as unity except on the Cairo-Alexandria agricultural expressway, where they were taken as 0.55 to reflect the slower deterioration of the four-lane road (the model is calibrated to two-lane roads).

The data collected were for road condition, road inventory, and geometric standard, and were dependent on the following:

1. Actual information taken from the field surveys and laboratory tests.
2. Adoption of the AASHO Interim Guide (1) methods for calculation of both the Equivalent Single Axle Load Factors and the Structural Number.
3. AASHO Road Test Results applied to pavement design in Illinois(2).

In determining the structural number (SN), the following equation was used:

$$SN = a_1D_1 + a_2D_2 + a_3D_3 \qquad (3\text{-}1)$$

where a_1,a_2, and a_3 are coefficients of relative strength of the surface, base, and subbase, respectively, and D_1,D_2, and D_3 are the thickness (in inches) of the surface, base, and subbase, respectively, of the pavement structure. For the coefficients a_1, a_2, and a_3, the following tables were used:

- AASHO Interim Guide coefficients (Table 3-1)
- AASHO Road Test Results applied to pavement design in Illinois (Table 3-2).

For converting the traffic count data into equivalent 18-kip single-axle load applications, Table 3-3, taken from the AASHO Interim Guide, was used.

The relevant data items for existing link conditions are summarized in Table 3-4.

3.3 CONSTRUCTION PROJECT DATA

Data on construction costs have been taken from recently completed highway project contract awards. Two construction projects were considered as applicable on all links: a premix overlay of sixty millimeters, and a double overlay consisting of a premix overlay of sixty millimeters followed by an asphalt concrete overlay of fifty millimeters. The quality control of the overlays was taken to be moderately poor, resulting in roughness measures after the overlays of 3500 mm/km for the premix overlay and 3000 mm/km for the asphalt concrete overlay. The duration of the projects were taken as one and two years, respectively. Economic costs were assumed to be ninety percent of financial costs, with foreign exchange costs twenty-two percent of economic costs. Salvage values were taken as sixty percent of the premix overlay costs and seventy percent of the double overlay costs. Costs for the double overlay are assumed to be distributed sixty percent in the first year and forty percent in the second year. The premix overlay resulted in an increase in pavement strength (structural number) of 0.80, while the double overlay added 1.68. The projects were scheduled to begin in 1980. The relevant data items are summarized in Table 3-5.

3.4 MAINTENANCE DATA

Maintenance data consists of maintenance policies, standards, and unit costs. The costs of maintenance operations in each year are estimated based on the quantities of maintenance performed and the appropriate unit costs. These unit costs provide the breakdown of activity costs into labor, equipment, materials, and overhead components. Each of these

TABLE 3-1

COEFFICIENTS OF RELATIVE STRENGTH OF PAVEMENT COMPONENTS

PAVEMENT COMPONENT	COEFFICIENT (3)		
	a_1	a_2	a_3
Surface course:			
Road mix (low stability)	0.20		
Plantmix (high stability)	0.44 (4)*		
Sand asphalt	0.40		
Base course:			
Sandy gravel		0.07 (2)	
Crushed stone		0.14	
Cement treated (no. soil cement);			
650 psi or more (1)		0.23 (2)	
400 psi to 650 psi		0.20	
400 psi or less		0.15	
Bituminous treated:			
Course graded		0.34 (2)	
Sand asphalt		0.30	
Lime treated		0.15-0.30	
Subbase:			
Sandy gravel			0.11 (4)*
Sand or sandy-clay			.05-0.10

1. Compressive strength at 7 days
2. This value has been estimated from AASHO Road Test data, but not to the accuracy of those factors marked with an asterisk.
3. It is expected that each state will study these coefficients and make such changes as their experience indicates necessary. (Sources AASHO 127, P, 22)
4. After AASHO ROAD TEST Equation

TABLE 3-2

MINIMUM COEFFICIENTS FOR PAVEMENT STRUCTURE MATERIALS

MATERIALS	Min, Strength Requirements			Coefficients		
	MS	CBR	PSI	a_1	a_2	a_3
Bituminous surface subclass						
B-1, B-2; B-3 and B-4	300			0.2		
B-5 and I-1	900			0.3		
I-11	1,700			0.4		
Base Course						
Granular						
Gravel, Grade 7		50			0.10	
Gravel, Grade 9		70			0.12	
Crushed stone, Grade 8		90			0.13	
Water bound macadam		110			0.14	
Selected soil stabilized W/P6			300[c]		0.15	
Granular material stabilized W/PC plant mix	]		1450[c]		0.20	
			650[c]		0.23	
Granular material stabilized W/lime flyash	]		450[c]		0.20	
			650[c]		0.23	
Granular material stabilized W/bit materials						
Emulsified asphalts	300				0.16	
Liquid asphalts	400				0.18	
Paving asphalts	600				0.20	
	900				0.24	
PC concrete (new)	1,700		2,500[c]		0.50	
Subbase						
Gravel						
Grade 11		30				0.11
Grade 7		50				0.12
Grade 4		70				0.13
Crushed stone						
Grade 8		90				0.14

TABLE 3-3

AXLE LOAD EQUIVALENCY FACTORS

AXLE LOAD	Equivalent Factors *	
	Single Axles	Tandem Axles
2000 - 8000	0.0006	———
8000 - 16000	0.18	0.02
16000 - 20000	1.00	0.08
20000 - 24000	2.35	0.17
24000 - 30000	5.80	0.42
30000 - 34000	12.00	0.83
34000 - 38000	20.00	1.38
38000 - 44000	33.00	2.40
44000 - 48000	———	3.5
Passenger Cars	0.0002	

* Serviceability index expected to be reached at the end of the design period: 2.0.

The following assumptions have been adopted in calculating the number of equivalent axle loads for each vehicle type:

Type of Vehicle	No. of Axles	Axle Load (lbs)	Equivalency Factor
Private Cars	2	2000 - 8000	0.0012
Inter-City Taxi	2	2000 - 8000	0.0012
Buses	2	8000 - 16000	0.36
Trucks	2	8000 - 16000	0.36
Trucks with Trailer	4 { 2	8000 - 16000	0.36 } 1.20
	2 (tandem)	24000 - 30000	0.84

Further study is needed to more accurately determine the average number of axles per vehicle and the average equivalency factors.

TABLE 3-4

EXISTING LINK CONDITIONS

No.	Link	Length (km)	Curve °/km	Carriage-way Width (m)	Shoulder Width (m)	Carriage-way Thick-ness (mm)	Shoulder Thickness (mm)	CBR	SN	Regional Factor	$\overline{SN}$
1	QB-TK	20	6	15	3	735	215	3	6.96	.55	7.62
2	TK-BN	15	6	15	3	710	215	3	5.08	.55	5.88
3	TN-TW	26	20	15	3	700	215	3	5.14	.55	5.65
4	BN-QS	12	18	15	3	675	215	3	4.62	.55	5.09
5	QS-BS	12	0	15	3	675	215	3	4.62	.55	5.09
6	BS-TN	20	0	15	3	675	215	3	4.62	.55	5.09
7	QS-SH	12	0	6	3	370	120	3	4.34	1	4.40
8	BG-TM	23	15	6	3	310	0	8	1.76	.55	3.20
9	QB-KN	9.6	12	7	3	380	0	3	2.80	1	2.90
10	KN-TM	56	8	6	3	350	170	5	.82	1	2.53
11	KN-BL	21.9	5	6	1	300	1	3	1.3	1	2.33
12	BL-TK	4	5	6	3	300	0	3	1.3	1	2.33
13	BL-BN	9.1	2	6	1	300	0	3	1.3	1	2.33
14	AS-AN	9	0	6	2	250	0	5	1.37	1	2.30
15	SD-BB	17	33	6	3	250	0	3	1.37	.55	2.25
16	BS-SH	12	36	6	3	250	0	3	1.37	1	2.05
17	BB-TN	11	0	6	3	200	0	3	1.62	.55	1.90
18	KN-SN	18	2	6	3	200	0	3	1.62	1	1.80
19	SN-BG	14	14	6	3	200	0	3	1.62	1	1.80
20	BG-SH	13	23	6	3	200	0	3	1.61	1	1.80
21	SH-KM	5	0	6	3	200	0	3	1.61	1	1.80
22	KM-BB	9	0	6	3	200	0	3	1.61	1	1.80
23	BN-BG	18	45	5	3	200	0	3	1.37	1	1.80
24	KM-SD	19	10	6	3	260	0	3	.82	1	1.80
25	TM-TW	36	8	6	3	310	170	5	1.37	1	1.60

TABLE 3-5

CONSTRUCTION DATA

	Premix Overlay (60 mm)	Double Overlay (110 mm) Premix(60mm)	AC(50mm)	Total
Cost per cubic meter in place: (L.E.)				
Financial	83.33	83.33	50.00	68.18
Economic	75.00	75.00	45.00	61.36
Foreign Exchange	16.50	16.50	9.90	13.50
Project Duration (Years)	1	1	1	2
Cost Distribution	100	60	40	100
Salvage Value (%)	60		70	
Initial Roughness	3500		3000	
Incremental Structural Number	0.80		1.68	

components is further broken down into financial, economic, and foreign exchange costs. These costs are intended to represent national averages for the various activities, and were derived by Road and Waterway Authority personnel from existing maintenance records. The unit costs are summarized in Table 3-6.

Five maintenance standards were defined for analysis, as follows:

1. The existing standard (CAEX), consisting of routine patching of 10 sq. m./km/yr with surface dressing every two years;
2. A scheduled premix standard (HPMX), consisting of medium level patching of 50 sq.m/km/yr, surface dressing every two years, and overlay every ten years;
3. A scheduled asphalt concrete standard (HDAC), consisting of low level patching of 10 sq.m/km/yr, surface dressing every five years, and overlay every fifteen years;
4. A responsive premix standard (HRPM), consisting of patching 80% of new cracks, surface dressing when 8% of the roadway is cracked, and overlay at a roughness of 3500 mm/km;
5. A responsive asphalt concrete standard (HRAC), consisting of patching 80% of new cracks, surface dressing when 5% of the roadway is cracked, and overlay at a roughness of 3000 mm/km.

The cost adjustment factors for the activities of the various standards reflect engineering judgments. These five standards were grouped into three maintenance policies: existing (CAEX), scheduled (HSCH), and responsive (HRSP). The maintenance standards are summarized in Table 3-7.

3.5 VEHICLE CHARACTERISTICS DATA

The available data items regarding vehicle characteristics and costs were initially derived from the Berger-Dorsch Egypt National Transport Study, Phase I, interim report (3). The vehicle classification scheme of the RIAM proposes five different vehicle categories to be distributed among up to seven vehicle types: passenger cars, light goods vehicles, buses, medium good vehicles, and heavy goods vehicles. In view of the nature of the different types of vehicles operating on the road network in Egypt, the following classification was introduced.

TABLE 3-6

MAINTENANCE UNIT COST

[Costs Per Application (not annual costs) in L.E.]

Maintenance Operation			Maintenance Unit Costs in Egyptian Pounds				
Description	Unit	Cost Type	Labor	Equipment	Materials	Overhead	Total
PATCHING	SQ.M.	Financial	00.30	0.70	0.90	0.10	2.00
		Economic	0.30	0.35	0.81	0.10	1.56
		Foreign Ex.	0.0	0.14	0.0	0.0	0.14
SURFACE DRESSING	SQ.M.	Financial	0.02	0.08	0.09	0.01	0.20
		Economic	0.02	0.04	0.81	0.01	0.15
		Foreign Ex.	0.0	0.02	0.0	0.0	0.02
OVERLAYING	CU.M	Financial	6.0	14.00	18.80	1020.00	40.00
		Economic	6.0	7.00	16.92	1020.00	31.12
		Foreign Ex.	0.0	5.60	0.0	0.0	5.60
REHABILI-TATION	KM	Financial	6400.0	11200.00	13440.00	960.00	32000.00
		Economic	6400.0	5600.00	12096.00	960.00	25056.00
		Foreign Ex.	0.00	4480.00	0.0	0.0	4480.00
ROUTINE MAINTENANCE PAVED ROADS	KM	Financial	1000.00	300.00	600.00	100.00	2000.00
		Economic	1000.00	90.00	540.00	100.00	1730.00
		Foreign Ex.	0.0	60.00	0.0	0.0	60.00

TABLE 3-7

MAINTENANCE STANDARDS

Standard ID: CAEX

1. Surface type: EXIS

This standard applies to Traffic range 0 - ***** ADT.

No.	Maintenance Activity	Unit	Standard	Cost Adjustment Factor
6	Patching	SQ.M.	Patch 10 SQ.M/KM/YR	1.10
7	Surface Dressing	SQ.M.	Surface dressing every 2 years but not after analysis year 18	0.20
10	Routine Maintenance Paved Road	KM	Includes drainage, vegetation, shoulder, and miscellaneous activity	1.00

MAINTENANCE STANDARDS

Standard ID: HPMX

2. Surface type: HPMX

This standard applies to Traffic range 0 - ***** ADT.

No.	Maintenance Activity	Unit	Standard	Cost Adjust-Ment Factor
6	Patching	SQ.M.	Patch 50 SQ.M/KM/YR	1.00
7	Surface Dressing	SQ.M.	Surface dress every 2 years but not after analysis year 19	1.00
8	Overlaying	CU.M.	Overlay every 10 years but not after analysis year 18 using ashpalt paving of 40. MM	1.00
10	Routine Maintenance Paved Road	KM	Includes drainage, vegetation shoulder, and miscellaneous activity	1.00

TABLE 3-7 (cont'd)
Page 2.

MAINTENANCE STANDARDS

Standard ID: HDAC

3. Surface type: HQAC

This standard applies to Traffic range 0 - ***** ADT.

No.	Maintenance Activity	Unit	Standard	Cost Adjustment Factor
6	Patching	SQ.M.	Patch 10 SQ.M/KM/YR	1.00
7	Surface Dressing	SQ.M.	Surface dress every 5 years but not after analysis year 19	1.00
8	Overlaying	CU.M.	Overlay every 15 years but not after analysis year 17 using asphalt paving of 40.MM	1.00
10	Routine Maintenance Paved Road	KM	Includes drainage, vegitation, shoulder, and miscellaneous	1.00

MAINTENANCE STANDARDS

Standard ID: HRPM

4. Surface type: HPMX

This standard applies to Traffic range 0 - ***** ADT.

No.	Maintenance Activity	Unit	Standard	Cost Adjustment Factor
6	Patching	SQ.M.	Patch 80% of unpatched cracks but not more than 150 SQ.M/KM/YR	1.00
7	Surface Dressing	SQ.M.	Surface dress when C+P exceed 8% but not less than 1 years/ dressing; but not more than 5 years/dressing; but not after analysis year 18	1.00
8	Overlaying	CU.M.	Overlay when roughness exceed 3500 MN/KM. But not less than 5 years/overlay; but not more than 10 years/overlay; but not after analysis year 18 using asphalt paving of 40.MM	1.00
10	Routine Maintenance Paved Road	KM	Includes drainage, vegetation, shoulder, and miscellaneous activity	1.00

TABLE 3-7 (cont'd)
Page 3.

MAINTENANCE STANDARDS

Standard ID: HRAC

5. Surface type: HQAC

This standard applied to Traffic range 0 - ***** ADT.

No.	Maintenance Activity	Unit	Standard	Cost Adjustment Factor
6	Patching	SQ.M.	Patch 80%of unpatched cracks but not more than 50 SQ.M/KM/YR	1.00
7	Surface Dressing	SQ.M.	Surface dress when C+P exceeds 5% but not less than 1 years/ dressing; but not more than 5 years/dressing; but not after analysis year 19	1.00
8	Overlaying	CU.M.	Overlay when roughness exceeds 3000 MM/KM but not less than 5 years/overlay, but not more than 10 years/overlay, but not after analysis year 18, using asphalt paved of 40.MM	1.00
10	Routine Maintenance Paved Road	KM	Includes drainage, vegitation, shoulder and miscellaneous activity.	1.00

A. Passenger Cars

Passenger cars under the proposed RIAM scheme include passenger vehicles seating not more than nine passengers. Estate cars, taxis, and hired cars are also included, but not "Land-Rover" or mini-bus types of vehicles. The data provided by the Berger report, however, illustrates some basic differences between the operating characteristics of private cars and inter-city taxi cabs (ICTC). This is primarily due to the annual kilometrage of each type, which was estimated to be over 100,000 km for ICTC, whereas for private cars this would normally not exceed 15,000 km. Hence, it was considered appropriate to include two types of passenger cars in the analysis:

- private cars: includes all passenger vehicles having a plate number with "P" registration.
- inter-city taxi cabs: includes all non-metered taxis operating outside urban areas.

B. Light Goods Vehicles

The Berger report indicates that this category of vehicles does not represent any appreciable percentage of the Egyptian vehicle fleet. This type was not, therefore, considered in the present study.

C. Buses, Medium Goods, and Heavy Good Vehicles

These vehicle types were analyzed in accordance with the requirements of the RIAM classification.

3.5.1 Operating Costs

As previously mentioned, the preliminary data concerning the vehicle operating costs were taken directly from the Berger report. As the accuracy of these data limited model application, the Transport Planning Authority decided to carry out a detailed study, whose objective was the achievement of realistic figures concerning the operating costs of the different vehicle types.

The first phase of this investigation was directed towards the operating costs of the inter-city taxis, followed by surveys of inter-city freight transport lorries and inter-city passenger transport buses. The results are summarized in Table 3-8.

TABLE 3-8

FINANCIAL OPERATING COST/VEHICLE (L.E./YEAR)

Item	Inter-City Taxi	Lorry	Bus	Private Car
Fuel	732.0	787.5	750.0	128.7
Oil	13.3	250.0	105.0	10.6
Lubrication	28.0	100.8	20.0	22.4
Tires	311.9	2363.0	900.0	23.6
Batteries	—	72.0	72.0	16.5
Spare Parts	250.0	2100.0	2600.0	66.0
Service Parts	—	210.0	—	—
Driver	500.2	1368.0	1200.0	—
Helper	—	504.0	—	—
Conductor	—	—	864.0	—
Operation and Traffic	—	—	456.0	—
Maintenance Labor	332.0	564.0	2184.0	94.0
Administration	154.8	684.0	1008.0	—
Non-skilled Labor	—	—	456.0	—
Overheads	316.8*	945.0	1000.0	84.2
Insurance	—	600.0	640.0	—
License	120.0	616.0	260.0	24.8
Depreciation	856.0	3662.5	4050.0	450.0
Interest	291.0	1360.0	1742.5	540.0
TOTAL	3906.0	16086.8	18307.5	1460.8
Annual kilometers	(70,180)	(70,000)	(100,000)	(16,500)
Cost per/km	.056	.230	.183	.089

* Includes fines, garage, and parking costs

The data as it was presented to the analysis is as shown in Table 3-9 for all five vehicle types.

3.6 TRAFFIC DATA

Traffic counts have been carried out on all links in the study zone for a period of one week. The results of this survey have been converted to annual daily traffic volumes for each of the five vehicle classes representative of the Egyptian fleet:

1. 1.2 Liter Car
2. 2 Liter Inter-city Taxi
3. 42 Passenger Bus
4. 9 Ton Truck
5. 20 Ton Truck with Trailer

The resulting link volumes and compositions are presented in Table 3-10, along with their projected growth rates.

3.7 DEVELOPMENT OF THE ORIGIN-DESTINATION MATRICES

An origin-destination survey was conducted in the study zone on the 8th of August, 1977. The interview was designed to obtain information on vehicle type and route choice. Besides requesting where the vehicle was coming from and going to, which were at the governorate and markaz level, the questions were aimed at determining route choice behavior: what are the major cities on your route? Will you stop at any city en route? If so, for how long? Do you normally take this route? If so, why? If not, why this time; and what is your estimate of your total travel time? The intent of the interview was to determine as completely as possible any previous knowledge of O-D route alternatives, perception of travel time, and pre-trip route decision.

The study area was divided into 16 zones, corresponding to the markaz boundaries. The external area surrounding the study areas was divided into 11 zones, using natural boundaries, such as a canal, where possible and such that each external zone contained a major highway which entered the study area. The external zones' traffic (generation and attraction) was then assigned to the neighboring zone centroid in the study area to convert all the survey demands to demands within the study area. The zoning system is shown in Figure 3-2.

TABLE 3-9

VEHICLE CHARACTERISTICS AND COSTS

Costs in Egyptian Pounds

A. VEHICLE DESCRIPTION

NAME	1.2L-CAR	2L-INTC	42P-BUS	9TTR	20TTT
Vehicle Type Code	1	1	3	4	5
Fuel Type	gasoline	gasoline	diesel	diesel	diesel
Brake Horsepower	50.00	100.00	280.00	260.00	520.00
Gross Veh. Wght. (Metric ton)	1.5	3.00	10.00	10.00	18.60
Axel Equivalency Factor	0.01	0.01	0.36	0.36	1.20

B. FINANCIAL COSTS (L.E.)

New Vehicle	3400.00	7000.00	24000.00	20500.00	27700.00
Cost/tire	25.00	38.00	85.00	96.00	96.00
Maintenance Labor Cost/Hr	0.40	0.40	0.40	0.40	0.40
Crew Cost/Hr	0.0	0.20	0.60	0.52	0.68
Value of time/Hr	0.0	0.0	0.0	0.0	0.0
Annual Overhead Costs. (Tot.)	0.0	0.0	0.0	0.0	0.0
Annual Overhead Costs % of Operating Costs	3.0	5.00	25.0	20.0	20.0
Interest Rate (%)	8.5	8.5	8.5	8.5	8.5

Fuel & Lubricants (Cost/litres)

Petrol = 0.08

Diesel fuel = 0.02

Engine oil = 0.27

TABLE 3-9 (cont'd)
Page 2.

C. ECONOMIC COSTS

NAME	1.2L-CAR	2L-INTC	42P-BUS	9TTR	20TTT
New Vehicle	1530.00	3500.00	19200.00	15200.00	20500.00
Cost/tire	17.50	25.00	60.00	69.00	69.00
Maintenance Labor Cost/Hr	0.40	0.40	0.40	0.40	0.40
Crew Cost/Hr	0.0	0.20	0.60	0.52	0.68
Value of time/Hr	0.0	0.0	0.0	0.0	0.0
Annual Overhead Costs (tot.)	0.0	0.0	0.0	0.0	0.0
Annual Overhead Costs % of Operating Costs	0.0	2.0	20.00	15.00	15.00
Interest Rate (%)	12.0	12.0	12.00	12.00	12.00
Ratio of Spare Parts to New Vehicle Costs	0 8	0.8	0.8	0.8	0.8

Fuel and Lubricants (cost/liter)

Petrol = 0.04
Diesel fuel = 0.02
Engine oil = 0.27

D. FOREIGN EXCHANGE COMPONENT OF ECONOMIC COSTS

New Vehicle	1350.00	3500.00	19200.00	13500.00	18500.00
Cost/tire	5.00	6.00	18.0	21.00	21.00
Maintenance Labor Cost/Hr	0.0	0.0	0.0	0.0	0.0
Crew Cost/Hr	0.0	0.0	0.0	0.0	0.0
Annual Overhead Costs (tot.)	0.0	0.0	0.0	0.0	0.0
Annual Overhead Costs % of Operating Costs	0.0	0.0	0.0	0.0	0.0
Ration of Spare Parts to New Vehicle Cost	0.90	0.90	0.90	0.90	0.9

Fuel and Lubricants (cost/liter)

Petrol = 0.0
Diesel fuel = 0.0
Engine oil = 0.0

TABLE 3-9 (cont'd)
Page 3.

E. VEHICLE UTILIZATION

NAME	1.2L-CAR	2L-INTC	42P-BUS	9TTR	20TTT
Average No. of Passengers per Vehicle	3	6	37	0	0
Annual Crew Hours	0	2500	2000	2000	2000
Annual Operating Hours	700	2000	1200	1200	1750
Annual Kilometers Driven	12500	70180	60000	55000	70000
Average Vehicle Life (Years)	12	8	10	11	11

F. VEHICLE AGE DISTRIBUTION

	VEHICLE TYPE			
AGE (Yrs)	CARS	LIGHT COMMERCIAL	BUSES	HEAVY GOODS
1	18.2	18.2	15.4	15.4
2	16.4	16.4	14.1	14.1
3	14.5	14.5	12.8	12.8
4	12.7	12.7	11.5	11.5
5	10.9	10.9	10.3	10.3
6	9.1	9.1	9.3	9.0
7	7.3	7.3	7.7	7.7
8	5.5	5.5	6.4	6.4
9	3.6	3.6	5.1	5.1
10	0.0	0.0	3.8	3.8
11	0.0	0.0	2.6	2.6
12	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0

TABLE 3-10

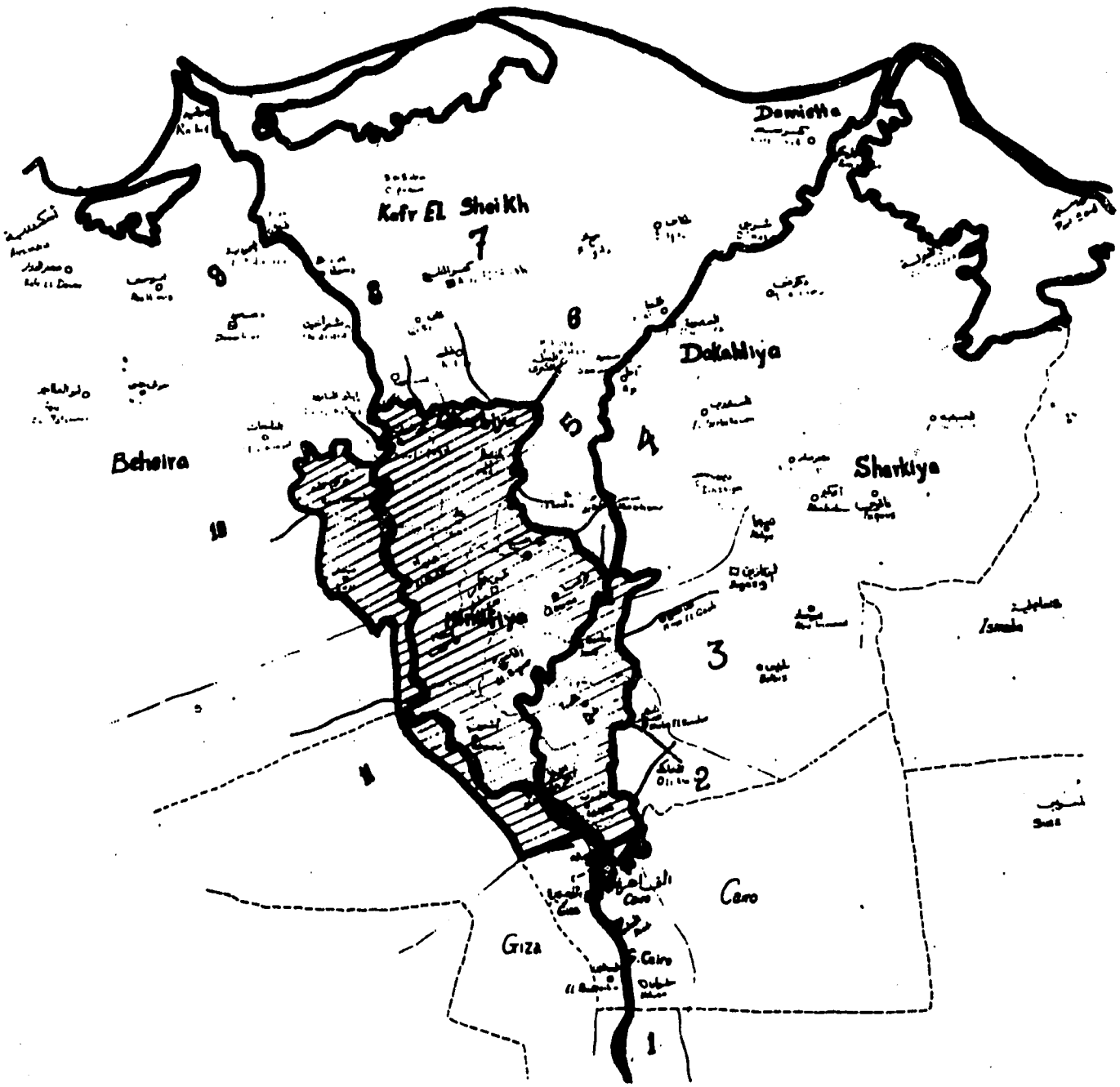
BASE YEAR VOLUMES (1977) AND ANNUAL GROWTH RATES

LINK NO.	I.D.	CAR	INTC	BUS	TRUCK	TRUCK & TRAILER
1	QB-TK	12949	7962	1008	4240	1828
2	TK-BN	13152	7775	1008	4240	1828
3	TN-TW	5951	4766	564	2998	1484
4	BN-QS	5978	3713	552	2194	820
5	QS-BS	8174	4556	552	2124	820
6	BS-TN	6183	4477	552	2124	820
7	QS-SH	996	465	337	499	90
8	BG-TM	582	387	157	350	111
9	QB-KN	861	320	153	285	34
10	KN-TM	357	128	44	309	442
11	KN-BL	1354	153	82	512	386
12	BL-TK	362	41	32	622	172
13	BL-BN	1354	153	82	512	386
14	AS-SN	932	197	138	472	121
15	SD-BB	396	58	73	203	32
16	BS-SH	388	447	259	663	145
17	BB-TN	756	443	153	285	34
18	KN-SN	2149	370	469	537	175
19	SN-BG	1898	622	469	537	175
20	BG-SH	382	611	154	265	145
21	SH-KM	756	443	153	285	34
22	KM-BB	756	443	153	285	34
23	BN-BG	132	198	103	195	81
24	KM-SD	434	62	73	203	32
25	TM-TW	319	160	182	718	601

ANNUAL GROWTH RATES (%)

YEAR	PASSENGER CAR	INTC	BUS	TRUCK	TRUCK & TRAILER
1977-1987	6	6	6	4	4
1988-1997	8	8	8	5	5

FIGURE 3-2
NORTHERN EGYPT AND THE STUDY ZONE



After the data had been collected, manual processing was carried out. Since five vehicle types were interviewed (private cars, inter-city taxis, buses, trucks and trucks with trailers), there are five O-D matrix sheets for every interview station. As the sample size interviewed for each vehicle type was considered as representative of the daily traffic for the corresponding vehicle type at the interview station, the O-D matrix was expanded by the Average Daily Traffic (ADT) for a certain vehicle type at the interview station divided by the sample size for that vehicle type. Each cell in the O-D matrix was then multiplied by this factor, producing five enlarged O-D matrices for each interview station.

Traffic generated or attracted to a specific zone within the study area was considered to be accurately given in the resulting O-D matrices of stations on road links crossing the zone in question. Traffic originating and destinating at any specific zone was generated by the addition of the zone O-D cells given in the enlarged O-D matrices of the corresponding interview stations.

An investigation of the values given in the origin-destination matrices revealed that for many O-D pairs the survey results differed in the two directions of travel. One explanation of this descrepancy may be the sampling from different traffic volumes, resulting in different sampling frequencies at the various interview stations. To stress the results from the low-volume links, where sampling densities were largest, the O-D cells were filled beginning with the low-demand zones and progressing to the highest-demand zone which was Cairo. The two-way demands were combined to produce an average overall daily demand between each O-D pair.

The resulting O-D matrices by vehicle type and the traffic volumes by vehicle type on the links of the study area are given in Tables 3-11 through 3-16.

Once the O-D matrices were in hand, they had to be calibrated to the measured link traffic volumes to determine the traffic assignment diversion intensity parameter incorporated within the Road Investment Analysis Model. This parameter is vehicle type specific (but not a function of time or origin and destination), and was estimated using

Table 3-11

O-D SURVEY RESULTS FOR PRIVATE CARS (1977)

	QLUB	TOKH	BNHA	QSNA	BRSB	TNTA	TWFK	KMHM	BADR	TALA	SHDA	SBKM	MNUF	BAGR	ASHM	KNTR
QLUB	QLUB															
TOKH	386	TOKH														
BNHA	4287	---	BNHA													
QSNA	200	15	95	QSNA												
BRSB	55	---	---	---	BRSB											
TNTA	1133	---	61	---	52	TNTA										
TWFK	2864	---	61	---	13	494	TWFK									
KMHM	28	---	---	---	---	41	---	KMHM								
BADR	2	---	---	---	---	---	---	---	BADR							
TALA	10	---	---	---	[illegible]	23	---	---	---	TALA						
SHDA	3	---	---	[illegible]	---	3	---	---	---	---	SHDA					
SBKM	310	---	103	---	---	187	90	---	---	13	---	SBKM				
MNUF	240	9	18	8	---	56	---	17	---	---	---	84	MNUF			
BAGR	192	---	---	---	---	8	8	---	---	---	---	16	57	BAGR		
ASHM	120	---	3	---	---	---	3	---	---	---	---	---	10	49	ASHM	
KNTR	208	25	12	---	---	11	6	---	---	---	---	---	11	11	11	KNTR

Table 3-12
O-D SURVEY RESULTS FOR
TAXI (1977)

QLUB	QLUB															
TOKH	1174	TOKH														
BNHA	3906	12	BNHA													
QSNA	679	---	576	QSNA												
BRSB	490	---	---	---	BRSB											
TNTA	1372	12	125	21	145	TNTA										
TWFK	2929	36	82	---	26	435	TWFK									
KMHM	163	21	---	---	---	63	---	KMHM								
BADR	---	---	---	---	---	---	---	---	BADR							
TALA	70	---	6	---	---	233	---	---	---	TALA						
SHDA	61	---	---	---	---	32	---	---	---	---	SHDA					
SBKM	400	---	30	257	34	622	45	---	---	21	167	SBKM				
MNUF	434	---	---	20	---	---	28	33	116	---	---	17	MNUF			
BAGR	1030	15	20	---	---	---	---	---	---	---	---	---	66	BAGR		
ASHM	458	---	---	---	---	---	11	---	---	---	---	54	267	15	ASHM	
KNTR	634	18	18	---	---	9	---	---	---	---	---	---	---	---	90	KNTR

Table 3-13
O-D SURVEY RESULTS FOR
BUSES (1977)

	QLUB	TOKH	BNHA	QSNA	BRSB	TNTA	TWFK	KMHM	BADR	TALA	SHDA	SBKM	MNUF	BAGR	ASHM	KNTR
QLUB	QLUB															
TOKH	---	TOKH														
BNHA	233	---	BNHA													
QSNA	61	---	20	QSNA												
BRSB	---	---	---	---	BRSB											
TNTA	345	---	---	---	---	TNTA										
TWFK	248	---	---	---	---	---	TWFK									
KMHM	---	---	---	---	---	---	---	KMHM								
BADR	---	---	---	---	---	---	---	---	BADR							
TALA	6	---	18	---	---	36	---	---	---	TALA						
SHDA	14	---	---	---	---	---	---	---	---	---	SHDA					
SBKM	169	---	91	---	34	115	16	---	---	---	48	SBKM				
MNUF	45	---	9	---	---	---	---	---	---	---	---	54	MNUF			
BAGR	34	---	---	---	---	---	---	---	---	---	---	34	---	BAGR		
ASHM	132	---	---	---	---	---	---	---	---	---	---	---	---	---	ASHM	
KNTR	91	7	---	---	---	---	7	---	---	---	---	---	---	---	---	KNTR

Table 3-14
O-D SURVEY RESULTS FOR
TRUCKS
(light goods vehicles, 1977)

	QLUB	TOKH	BNHA	QSNA	BRSB	TNTA	TWFK	KMHM	BADR	TALA	SHDA	SBKM	MNUF	BAGR	ASHM	KNTR
QLUB	QLUB															
TOKH	220	TOKH														
BNHA	1887	46	BNHA													
QSNA	99	28	29	QSNA												
BRSB	---	---	---	---	BRSB											
TNTA	525	---	245	180	41	TNTA										
TWFK	1068	---	129	---	---	466	TWFK									
KMHM	32	---	54	---	---	120	---	KMHM								
BADR	---	---	---	---	---	---	---	---	BADR							
TALA	27	---	16	27	---	82	---	---	---	TALA						
SHDA	31	---	11	44	---	36	10	---	---	---	SHDA					
SBKM	172	---	173	196	29	269	30	---	---	42	6	SBKM				
MNUF	68	---	42	40	---	---	24	12	110	---	---	62	MNUF			
BAGR	126	51	---	21	---	7	---	12	---	---	---	14	36	BAGR		
ASHM	390	9	32	7	---	---	24	9	---	---	13	15	32	86	ASHM	
KNTR	106	4	7	---	---	---	---	---	---	---	---	---	---	---	8	KNTR

Table 3-15
O-D SURVEY RESULTS FOR
TRUCK + TRAILER (1977)

	QLUB	TOKH	BNHA	QSNA	BRSB	TNTA	TWFK	KMHM	BADR	TALA	SHDA	SBKM	MNUF	BAGR	ASHM	KNTR
QLUB	QLUB															
TOKH	---	TOKH														
BNHA	597	---	BNHA													
QSNA	42	---	---	QSNA												
BRSB	---	---	---	---	BRSB											
TNTA	140	---	41	---	---	TNTA										
TWFK	922	---	41	---	---	201	TWFK									
KMHM	---	---	67	---	---	67	---	KMHM								
BADR	---	---	---	---	---	---	---	---	BADR							
TALA	32	---	---	---	---	16	24	---	---	TALA						
SHDA	---	---	---	---	---	---	---	---	---	---	SHDA					
SBKM	25	---	29	55	9	55	---	---	---	---	---	SBKM				
MNUF	22	---	---	---	---	---	95	---	---	---	12	11	MNUF			
BAGR	25	---	---	---	---	---	---	---	---	---	---	---	22	BAGR		
ASHM	73	---	---	---	---	---	12	---	---	---	---	24	24	25	ASHM	
KNTR	4	---	---	---	---	---	---	---	---	---	---	88	---	---	---	KNTR

Table 3-16
STATION-LINK VOLUMES

Link	Car	Taxi	Bus	Truck	Trailer	Total
QLUB-TOKH	7,963	12,949	1,008	4,240	1,828	27,988
TOKH-BNHA	7,770	13,152	1,008	4,240	1,828	27,998
BNHA-QSNA	4,084	6,576	552	2,124	820	14,156
QSNA-BRSB	4,556	6,174	552	2,124	820	14,226
BRSB-TNTA	4,477	6,183	552	2,124	820	14,156
TNTA-TWFK	4,706	5,951	654	2,998	1,484	15,793
KNTR-TMLY	128	351	44	309	242	1,074
KNTR-SNTR	370	2,149	469	534	175	3,697
SNTR-ASHM	197	932	133	472	121	1,855
SNTR-BAGR	622	1,898	469	537	175	3,701
BAGR-BNHA	198	132	103	195	81	709
BAGR-MNUF	387	580	157	350	111	1,585
BAGR-SBKM	611	382	154	265	145	1,557
SBKM-QSNA	465	996	337	499	90	2,387
SBKM-BRSB	447	388	259	663	144	1,901
KMAK-BABL	443	756	153	285	34	1,671
KMAK-SHDA	62	433	73	203	32	803
BABL-TALA	58	396	73	203	32	762
MNUF-TMLY	341	629	157	350	111	1,588
QLUB-KNTR	320	861	153	285	34	1,653

the disaggregate route-choice data obtained from the O-D survey. The values of time used for Egypt were taken as zero for private cars, taxis, and trucks; LE 1.85/hr. for buses; and LE 10/hr. for trucks with trailers; which were obtained from Transport Planning Authority estimates.

As a first trial, the diversion parameter was taken as 1.0 for all vehicle types. The resulting traffic flows showed less traffic than measured on all links leading to Tawfikieh (which actually represents demand to Alexandria). Therefore, each cell containing Tawfikieh as an origin or destination was increased by 62% to overcome this deficiency. This produced good agreement on the major links in the study zone, and trials with the diversion parameter assuming values of 0.6 and 0.7 were analyzed to see if the diversion parameter could be adjusted to correct the flows on the minor links. These runs indicated that the traffic flow pattern was clearly sensitive to the values of the diversion parameter, verifying the presence of route-choice alternatives in the study zone.

The traffic flow patterns predicted in these runs were judged unsatisfactorily, with the traffic demand to Cairo seeming too high and that to Alexandria too low (note that these two nodes were the last cells filled in the derivation of the original O-D matrices.) For these reasons and in order to reduce the cost of computer runs, the following modifications were made:

- Traffic demand to Cairo (Qalub) was reduced and traffic demand to Alexandria (Tawfikieh) was increased.
- O-D pair available routes were modified to include only the four "most reasonable" routes, and not all possible routes.
- All O-D pairs with traffic demand of less than 30 vehicles per day were eliminated.

Once these modifications were completed, sensitivity runs were performed on the diversion intensity parameter until the discrepancies between measured and predicted link volumes could no longer be attributed to route choice behavior. This resulted in a diversion parameter of 1.0. Local traffic was then added between some neighboring O-D pairs to bring all predicted link volumes within ten percent of the measured volumes. The resulting O-D matrices are given in Tables 3-17 through 3-21.

The following conclusions were drawn from this calibration effort:

- The final assignment was reached with a diversion intensity parameter of 1.0.
- The network flow pattern is sensitive to the value of the diversion parameter, and any significant change from 1.0 would result in a decrease in the overall accuracy of the predicted link volumes.
- The final assignment reached with a diversion parameter of 1.0 necessitated the addition of some local traffic to the system.
- The average error between the actual traffic measurements and the predicted traffic flows on the network from the final assignment was 5.2%.

3.8 ADAPTATION OF THE MODEL TO EGYPTIAN CONDITIONS

Further enhancement of the data base involved two research efforts: a traffic count and axle load survey and the calibration of road deterioration relations to local conditions, which were required to fill gaps in the current data inventories.

3.8.1 Calculating the Truck Factor in Egypt

In Egypt, as in most developing countries, axle-load spectrum of the vehicle population has not been adequately determined for use in modern

Table 3-17

FINAL O-D MATRIX FOR PRIVATE CARS (1977)

	QLUB	TOKH	BNHA	QSNA	BRSB	TNTA	TWFK	KMHM	BADR	TALA	SHDA	SBKM	MNUF	BAGR	ASHM	KNTR
QLUB	QLUB															
TOKH	132	TOKH														
BNHA	4938	---	BNHA													
QSNA	50	15	.95	QSNA												
BRSB	50	---	---	---	BRSB											
TNTA	1020	---	61	---	52	TNTA										
TWFK	3983	---	98	---	21	1422	TWFK									
KMHM	91	---	---	---	---	41	---	KMHM								
BADR	---	---	---	---	---	---	---	---	BADR							
TALA	10	---	---	---	---	27	---	---	---	TALA						
SHDA	3	---	---	---	---	3	---	---	---	---	SHDA					
SBKM	279	---	151	---	36	135	145	---	---	13	101	SBKM				
MNUF	186	---	18	8	---	---	---	49	---	---	---	47	MNUF			
BAGR	196	---	---	---	---	---	---	---	---	---	---	16	57	BAGR		
ASHM	110	---	3	---	---	---	4	---	---	---	---	---	10	49	ASHM	
KNTR	208	25	12	---	---	---	---	---	---	---	---	---	---	---	11	KNTR

Table 3-18

FINAL O-D MATRIX FOR

TAXI (1977)

	QLUB	TOKH	BNHA	QSNA	BRSB	TNTA	TWFK	KMHM	BADR	TALA	SHDA	SBKM	MNUF	BAGR	ASHM	KNTR
QLUB	QLUB															
TOKH	402	TOKH														
BNHA	4499	12	BNHA													
QSNA	171	---	576	QSNA												
BRSB	441	---	---	---	BRSB											
TNTA	1235	---	125	21	145	TNTA										
TWFK	3985	58	133	---	42	1251	TWFK									
KMHM	528	---	---	---	---	63	---	KMHM								
BADR	---	---	---	---	---	---	---	---	BADR							
TALA	70	---	6	---	---	264	---	---	---	TALA						
SHDA	61	---	---	---	---	32	---	---	---	---	SHDA					
SBKM	360	---	44	257	122	448	73	---	---	21	421	SBKM				
MNUF	337	---	---	20	---	---	131	96	337	---	---	10	MNUF			
BAGR	517	15	---	---	---	---	---	---	---	---	---	3	66	BAGR		
ASHM	419	---	---	---	---	---	15	---	---	---	---	54	267	15	ASHM	
KNTR	634	18	18	---	---	---	---	---	---	---	---	---	---	---	90	KNTR

Table 3-19
FINAL O-D MATRIX FOR
BUSES (1977)

	QLUB	TOKH	BNHA	QSNA	BRSB	TNTA	TWFK	KMHM	BADR	TALA	SHDA	SBKM	MNUF	BAGR	ASHM	KNTR
QLUB	QLUB															
TOKH	---	TOKH														
BNHA	269	---	BNHA													
QSNA	15	---	20	QSNA												
BRSB	---	---	---	---	BRSB											
TNTA	311	---	---	---	---	TNTA										
TWFK	320	---	---	---	---	---	TWFK									
KMHM	---	---	---	---	---	---	---	KMHM								
BADR	---	---	---	---	---	---	---	---	BADR							
TALA	6	---	18	---	---	43	---	---	---	TALA						
SHDA	14	---	---	---	---	---	---	---	---	---	SHDA					
SBKM	152	---	134	---	122	83	25	---	---	---	121	SBKM				
MNUF	35	---	9	---	---	---	---	---	---	---	---	30	MNUF			
BAGR	17	---	---	---	---	---	---	---	---	---	---	34	---	BAGR		
ASHM	121	---	---	---	---	---	---	---	---	---	---	---	---	---	ASHM	
KNTR	91	7	---	---	---	---	---	---	---	---	---	---	---	---	---	KNTR

Table 3-20

FINAL O-D MATRIX FOR TRUCKS

(light goods vehicles, 1977)

	QLUB	TOKH	BNHA	QSNA	BRSB	TNTA	TWFK	KMHM	BADR	TALA	SHDA	SBKM	MNUF	BAGR	ASHM	KNTR
QLUB	QLUB															
TOKH	75	TOKH														
BNHA	2173	46	BNHA													
QSNA	25	28	29	QSNA												
BRSB	---	---	---	---	BRSB											
TNTA	473	---	245	180	41	TNTA										
TWFK	1426	---	209	---	---	1340	TWFK									
KMHM	104	---	---	---	---	120	---	KMHM								
BADR	---	---	---	---	---	---	---	---	BADR							
TALA	27	---	16	---	---	97	---	---	---	TALA						
SHDA	31	---	---	44	---	36	---	---	---	---	SHDA					
SBKM	155	---	254	196	104	194	48	---	---	42	15	SBKM				
MNUF	53	---	42	40	---	---	113	35	319	---	---	35	MNUF			
BAGR	63	51	---	---	---	---	---	---	---	---	---	14	36	BAGR		
ASHM	357	---	32	---	---	---	34	---	---	---	---	15	32	86	ASHM	
KNTR	106	4	7	---	---	---	---	---	---	---	---	---	---	---	8	KNTR

Table 3-21
FINAL O-D MATRIX FOR
TRUCK & TRAILER (1977)

	QLUB	TOKH	BNHA	QSNA	BRSB	TNTA	TWFK	KMHM	BADR	TALA	SHDA	SBKM	MNUF	BAGR	ASHM	KNTR
QLUB	QLUB															
TOKH	---	TOKH														
BNHA	687	---	BNHA													
QSNA	11	---	---	QSNA												
BRSB	---	---	---	---	BRSB											
TNTA	126	---	41	---	---	TNTA										
TWFK	1298	---	66	---	---	577	TWFK									
KMHM	---	---	---	---	---	67	---	KMHM								
BADR	---	---	---	---	---	---	---	---	BADR							
TALA	32	---	---	---	---	19	---	---	---	TALA						
SHDA	---	---	---	---	---	---	---	---	---	---	SHDA					
SBKM	23	---	43	55	32	40	---	---	---	---	5	SBKM				
MNUF	17	---	---	---	---	---	447	---	---	---	---	6	MNUF			
BAGR	13	---	---	---	---	---	---	---	---	---	---	---	22	BAGR		
ASHM	67	---	---	---	---	---	17	---	---	---	---	24	24	25	ASHM	
KNTR	4	---	---	---	---	---	---	---	---	---	---	88	---	---	8	KNTR

pavement design. This report indicates the results of the first stage of an axle-load weighing program, initiated to provide adequate information on pavement loads for design and maintenace purposes in the country. The study covers 4 sites on the major roads, three are approach roads to the city of Cairo and the fourth to Alexandria.

The equipment for the study consisted of a portable weighing system. The size of the weigh bridge (75 cm x 30 cm x 15 cm) meant that only one wheel (single or double tyres) could be weighed at a time. In many axle-load surveys, as in this one, the small errors introduced in raising one wheel by 15 cm are ignored. Two scales were used in this operation, one for each end of the axle.

The working group consisted of eight men working as follows:

- One for recording data
- Four for weighing
- Two for stopping cars and regulating traffic
- One driver.

The stations selected were:

1. Cairo - Alexandria Agricultural Road (Cairo entry)
2. Cairo - Alexandria Agricultural Road (Alexandria entry)
3. Cairo - Ismailia Desert Road (Km 21 from Cairo)
4. Guiza - Badrashin Road (Guiza entry)

Representative samples of trucks were weighed for a period of one week on the above stations.

Basically, the survey procedure is weighing each axle. This was done by weighing each wheel of the axle at the same time. The drivers were interviewed to get empty and loaded weight and kind of cargo. In the interest of highway safety, vehicles travelling in only one direction were stopped for weighing and interviewing. To avoid inadequate and hazardous lighting conditions, weighing was conducted between 8 a.m. and 4 p.m. Because of high traffic volumes, it was impossible to weigh each weighable vehicle passing the survey site. Hence, it was necessary to select vehicles intermittently to maintain a steady flow and to avoid long queues of waiting vehicles.

The total number of axles analyzed during this exercise was 1150. This corresponded to 367 vehicles altogether. The axle-loads ranged as follows:

Axle-load in lbs	Percentage
2000 - 8000	13.22%
8000 -16000	36.52%
16000 -20000	14.09%
20000 -24000	14.35%
24000 -30000	14.95%
30000 -34000	5.22%
34000 -38000	1.30%
38000 -44000	0.35%

This shows that most axle-loads are between 8000 and 16000 lb. Axle-loads over 20000 lbs are 36.17% and this causes 90% of the damage to the roads.

The truck factor for each type of vehicle was calculated so as to give the equivalent numbers of 18000 lb axles per vehicle. The calculations are shown below:

TRUCK FACTOR

Type of Vehicle	entry of Cairo-Alex. agricul.road Alex-station	entry of Cairo-Alex. agricul.road Cairo-station	Ismailia Cairo	Guiza Badrashin
Truck	1.4022	0.3844	0.1947	0.3020
Truck with Trailer	1.851	0.8769	1.0883	1.1751

Assumed Truck Factors for Buses & Passenger Cars

For Buses per Axle = .15

For Passenger Cars Axles = .0006

Remarks

- Near Alexandria harbor we have the highest truck factor due to trucks carrying heavy cargoes to all of Egypt (1.4 for trucks and 1.85 for trucks with trailers).
- On principal roads we have a truck factor of 0.38 for trucks and .88 for trucks with trailers.
- On secondary roads, we have a truck factor of about .25 (.1947-.3020) for trucks and 1.1 (1.0883-1.173) for trucks with trailers.

3.8.2 Calibration of the Road Deterioration Relations

The calibration of the road deterioration relations to local conditions involved a research investigation aimed at calculating the AASHO regional and drainage factors for Egypt. The objective of the study was to match subjective present condition, axle load history, and structural strength against predicted condition to determine the AASHO Regional Factor for the Nile Delta region of Egypt. Preliminary analyses indicated the Delta had an AASHO Regional Factor of 0.4 (meaning that a pavement in the Egyptian Delta will last 2.5 times as long as a similar pavement in Indiana under similar traffic loadings) and by including the height of embankment in the structural strength of the pavement.

The study resulted in a number of significant results. However, it must be emphasized that the conclusions pertain to the constraints and inference conditions used in this study. Justifiable extrapolation of the results should be made only after further studies. The following is a brief summary of the significant findings of the study.

1. The best suited regional and drainage factor (REGFAC) for Egyptian conditions (Delta region and cultivated areas) is 0.4.
2. Pavemement structural numbers (SN) that are less than 3 must be adjusted by incorporating the effective subgrade layer as part of the pavement structure and using subgrade strength coefficient (a_5) of 0.05.

$$SN^* = SN + a_5 \Delta$$

Where SN^* = adjusted structural number

SN = pavement structural number

a_5 = subgrade strength coefficient

Δ = height difference between bottom of pavement structure and surrounding land in inches.

3. The inclusion of the effect of the subgrade layer in adjusting the pavement structural number, together with the fact that subgrade CBR values for the study area were about the same as the standard CBR_0, nullifies the effect of CBR The $(CBR/CBR_0)^{0.14744}$ term has been considered as unity.

4. For pavement structural numbers (SN) of 3 or less, the modified (effective) structural number ($\overline{SN}$) will be:

$$(1+\overline{SN}) = (1+SN^*) * (REGFAC)^{-0.10684}$$

and $(REGFAC) = 0.4$

therefore $(1+\overline{SN}) = 1.10\ (1+SN^*)$

Where SN = modified structural number

SN^* = adjusted structural number

These findings pertain to the following conditions:

1. These concepts are valid for roadway links located within the Delta region and cultivated areas. Desert roads are not incorporated in the study.
2. Roadway links do not have adjacent irrigation canals.
3. Embankment height ranges between 50 cm and 150 cm.
4. Pavement structural number ranges between 1.5 and 3.0.

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1. American Association of State Highway and Transportation Officials, "AASHTO Interim Guide for Design of Pavement Structures," Washington, D.C., 1972.

2. Highway Research Board, "The AASHO Road Test," Special Report 61E, Publication No. 954, Washington, D.C., National Research Council, 1962.

3. Egypt National Transport Study, Interim Report-1977, Phase I, by Louis Berger International, Inc., in association with Dorsch Consult Ingenieurgesellschaft, mbH, prepared for Transport Planning Authority, Ministry of Transport, Arab Republic of Egypt.

CHAPTER 4. LINK EVALUATION AND RESULTS

4.1 ANALYSIS

Five alternatives were analyzed for each of the twenty-five links in the study zone. These were:

1. No construction and the existing maintenance policy, EXIS: (low patching, surface dressing every 2 years);
2. A 60 mm premix overlay in 1980 followed by a scheduled premix maintenance policy, PMXS: (medium patching, surface dressing every 2 years, and overlay every 10 years);
3. A 110 mm double overlay (asphalt concrete over premix) in 1980-81 followed by a scheduled asphalt concrete maintenance policy, HACS: (Low patching, surface dressing every 5 years, and overlay every 15 years);
4. A 60 mm premix overlay in 1980 followed by a responsive premix maintenance policy, PMXR (patching 80% of new cracks, surface dressing when 8% of the roadway is cracked or patched, and overlay at a roughness of 3500 mm/km); and
5. A 110 mm double overlay (asphalt concrete over premix) in 1980-81 followed by a responsive asphalt concrete maintenance policy, HACR: (patching 80% of new cracks, surface dressing when 5% of the roadway is cracked or patched, and overlay at a roughness of 3000 mm/km).

Traffic on the links was as given in Table 3-10. No exogenous costs or benefits were included in the analysis. The existing maintenance policy was assumed to hold until completion of the construction activities (1981 for the premix overlay, 1982 for the double overlay) in all cases. The analysis horizon was 19 years, from 1977 to 1995.

4.2 RESULTS

The economic results of these alternatives are summarized in Table 4-1, which presents the construction, maintenance, vehicle operating, and

TABLE 4-1
ECONOMIC COST SUMMARY
(Million Egyptian Pounds Discounted at 12%)

No.	Link	Alt.	Construction Costs	Maintenance Costs	Vehicle Operating Costs	Total Costs	Net Present Value*
1	QBTK	EXIS	0.000	0.327	209.313	209.641	0.000
		PMXS	0.843	0.486	225.953	227.283	-17.642
		HACS	1.174	0.336	192.333	193.843	15.798
		PMXR	0.843	0.440	224.437	225.721	-16.080
		HACR	1.174	0.407	189.120	190.702	18.939
2	TKBN	EXIS	0.000	0.245	193.405	193.651	0.000
		PMXS	0.632	0.365	178.260	179.258	14.393
		HACS	0.881	0.252	150.138	151.271	42.380
		PMXR	0.632	0.368	171.890	172.890	20.761
		HACR	0.881	0.306	146.514	147.701	45.950
3	TNTW	EXIS	0.000	0.420	226.564	226.985	0.000
		PMXS	1.096	0.631	206.379	208.106	18.879
		HACS	1.526	0.430	175.706	177.662	49.323
		PMXR	1.096	0.648	198.913	200.658	26.327
		HACR	1.526	0.524	171.780	173.830	53.155
4	BNQS	EXIS	0.000	0.196	78.185	78.381	0.000
		PMXS	0.506	0.292	67.988	68.786	9.595
		HACS	0.705	0.201	57.603	58.509	19.872
		PMXR	0.506	0.294	65.715	66.515	11.866
		HACR	0.705	0.245	56.309	57.258	21.123
5	QSBS	EXIS	0.000	0.196	87.339	87.535	0.000
		PMXS	0.506	0.292	74.949	75.747	11.788
		HACS	0.705	0.201	62.790	63.696	23.839
		PMXR	0.506	0.294	72.259	73.059	14.476
		HACR	0.705	0.245	61.258	62.207	25.328
6	BSTN	EXIS	0.000	0.327	137.143	137.470	0.000
		PMXS	0.843	0.486	117.863	119.192	18.278
		HACS	1.174	0.336	98.581	100.091	37.379
		PMXR	0.843	0.490	113.620	114.953	22.517
		HACR	1.174	0.408	96.163	97.745	39.725
7	QSSH	EXIS	0.000	0.182	12.477	12.659	0.000
		PMXS	0.202	0.222	12.459	12.884	-0.225
		HACS	0.282	0.184	10.867	11.334	1.325
		PMXR	0.202	0.208	12.459	12.871	-0.212
		HACR	0.282	0.201	10.718	11.200	1.459

TABLE 4-1 (cont'd)

Page 2.

No.	Link	Alt.	Construction Costs	Maintenance Costs	Vehicle Operating Costs	Total Costs	Net Present Value*
8	BGTM	EXIS	0.000	0.347	35.754	36.101	0.000
		PMXS	0.388	0.426	26.278	27.091	9.010
		HACS	0.540	0.352	23.373	24.266	11.835
		PMXR	0.388	0.480	23.725	24.593	11.508
		HACR	0.540	0.392	22.871	23.803	12.298
9	QBKN	EXIS	0.000	0.146	11.380	11.526	0.000
		PMXS	0.162	0.184	7.091	7.438	4.088
		HACS	0.225	0.149	6.850	7.225	4.301
		PMXR	0.162	0.183	6.805	7.150	4.376
		HACR	0.225	0.165	6.742	7.133	4.393
10	KNTM	EXIS	0.000	0.844	107.234	108.078	0.000
		PMXS	0.944	1.032	93.180	95.156	12.922
		HACS	1.315	0.857	81.780	83.952	24.126
		PMXR	0.944	1.265	83.336	85.546	22.532
		HACR	1.315	0.971	79.500	81.786	26.292
11	KNBL	EXIS	0.000	0.327	51.961	52.288	0.000
		PMXS	0.369	0.395	44.021	44.785	7.503
		HACS	0.514	0.332	38.608	39.455	12.833
		PMXR	0.369	0.480	38.844	39.693	12.595
		HACR	0.514	0.372	37.429	38.316	13.972
12	BLTK	EXIS	0.000	0.060	5.815	5.875	0.000
		PMXS	0.067	0.074	4.723	4.864	1.011
		HACS	0.094	0.061	4.251	4.407	1.468
		PMXR	0.067	0.086	4.235	4.388	1.487
		HACR	0.094	0.068	4.175	4.337	1.538
13	BLBN	EXIS	0.000	0.137	21.678	21.815	0.000
		PMXS	0.153	0.165	18.361	18.679	3.136
		HACS	0.214	0.139	16.909	16.452	5.363
		PMXR	0.153	0.200	16.198	16.551	5.264
		HACR	0.214	0.155	15.607	15.976	5.839
14	ASSN	EXIS	0.000	0.136	14.358	14.494	0.000
		PMXS	0.152	0.166	11.854	12.172	2.322
		HACS	0.211	0.138	10.050	10.400	4.094
		PMXR	0.152	0.197	10.215	10.564	3.930
		HACR	0.211	0.154	9.767	10.132	4.362
15	SDBB	EXIS	0.000	0.256	10.470	10.726	0.000
		PMXS	0.287	0.314	7.739	8.340	2.386
		HACS	0.399	0.260	7.165	7.824	2.902
		PMXR	0.287	0.327	7.322	7.936	2.790
		HACR	0.399	0.285	7.063	7.748	2.978

TABLE 4-1 (cont'd)

Page 3.

No.	Link	Alt.	Construction Costs	Maintenance Costs	Vehicle Operating Costs	Total Costs	Net Present Value*
16	BSSH	EXIS	0.000	0.181	26.184	26.365	0.000
		PMXS	0.219	0.221	22.167	22.590	3.775
		HACS	0.305	0.184	18.290	18.755	7.610
		PMXR	0.219	0.273	19.019	19.494	6.871
		HACR	0.305	0.208	17.442	17.932	8.433
17	BBTN	EXIS	0.000	0.166	15.069	15.235	0.000
		PMXS	0.186	0.203	11.700	12.088	3.147
		HACS	0.258	0.168	9.456	9.882	5.353
		PMXR	0.186	0.238	9.670	10.094	5.141
		HACR	0.258	0.188	9.133	9.579	5.656
18	KNSN	EXIS	0.000	0.271	49.934	50.205	0.000
		PMXS	0.304	0.330	45.440	46.074	4.131
		HACS	0.423	0.276	37.806	38.505	11.700
		PMXR	0.304	0.409	39.899	40.611	9.594
		HACR	0.423	0.333	34.163	34.919	15.286
19	SNBG	EXIS	0.000	0.211	41.920	42.131	0.000
		PMXS	0.236	0.257	37.914	38.407	3.724
		HACS	0.329	0.214	31.119	31.662	10.469
		PMXR	0.236	0.318	32.962	33.517	8.614
		HACR	0.329	0.259	27.849	28.437	13.694
20	BGSH	EXIS	0.000	0.196	22.611	22.807	0.000
		PMXS	0.219	0.239	18.743	19.201	3.606
		HACS	0.305	0.199	14.897	15.402	7.405
		PMXR	0.219	0.288	15.640	16.147	6.660
		HACR	0.305	0.225	14.088	14.619	8.188
21	SHKM	EXIS	0.000	0.075	6.850	6.925	0.000
		PMXS	0.084	0.092	5.318	5.495	1.430
		HACS	0.117	0.077	4.298	4.492	2.433
		PMXR	0.084	0.108	4.396	4.588	2.337
		HACR	0.117	0.085	4.151	4.354	2.571
22	KMBB	EXIS	0.000	0.136	12.329	12.465	0.000
		PMXS	0.152	0.166	9.573	9.890	2.575
		HACS	0.211	0.138	7.736	8.085	4.380
		PMXR	0.152	0.195	7.911	8.258	4.207
		HACR	0.211	0.154	7.472	7.838	4.627
23	BNBG	EXIS	0.000	0.269	15.547	15.816	0.000
		PMXS	0.304	0.320	12.470	13.093	2.723
		HACS	0.423	0.273	10.508	11.203	4.613
		PMXR	0.304	0.370	10.674	11.348	4.468
		HACR	0.423	0.299	10.241	10.963	4.853

TABLE 4-1 (cont'd)
Page 4.

No.	Link	Alt.	Construction Costs	Maintenance Costs	Vehicle Operating Costs	Total Costs	Net Present Value
24	KMSD	EXIS	0.000	0.284	11.988	12.271	0.000
		PMXS	0.320	0.339	9.188	9.847	2.424
		HACS	0.446	0.288	8.202	8.936	3.335
		PMXR	0.320	0.360	8.205	8.885	3.386
		HACR	0.446	0.315	8.057	8.818	3.453
25	TMTW	EXIS	0.000	0.542	110.556	111.099	0.000
		PMXS	0.607	0.657	107.833	109.098	2.001
		HACS	0.845	0.550	102.134	103.529	7.570
		PMXR	0.607	0.780	102.127	103.515	7.584
		HACR	0.845	0.774	88.181	89.800	21.299

*Net Present Value is with respect to alternative EXIS

total economic costs for each link-alternative, discounted to 1977 at 12% (the nominal social cost of capital in Egypt). The net present values of the various alternatives are obtained as the difference between the total costs of the existing option (EXIS) and the various overlay options.

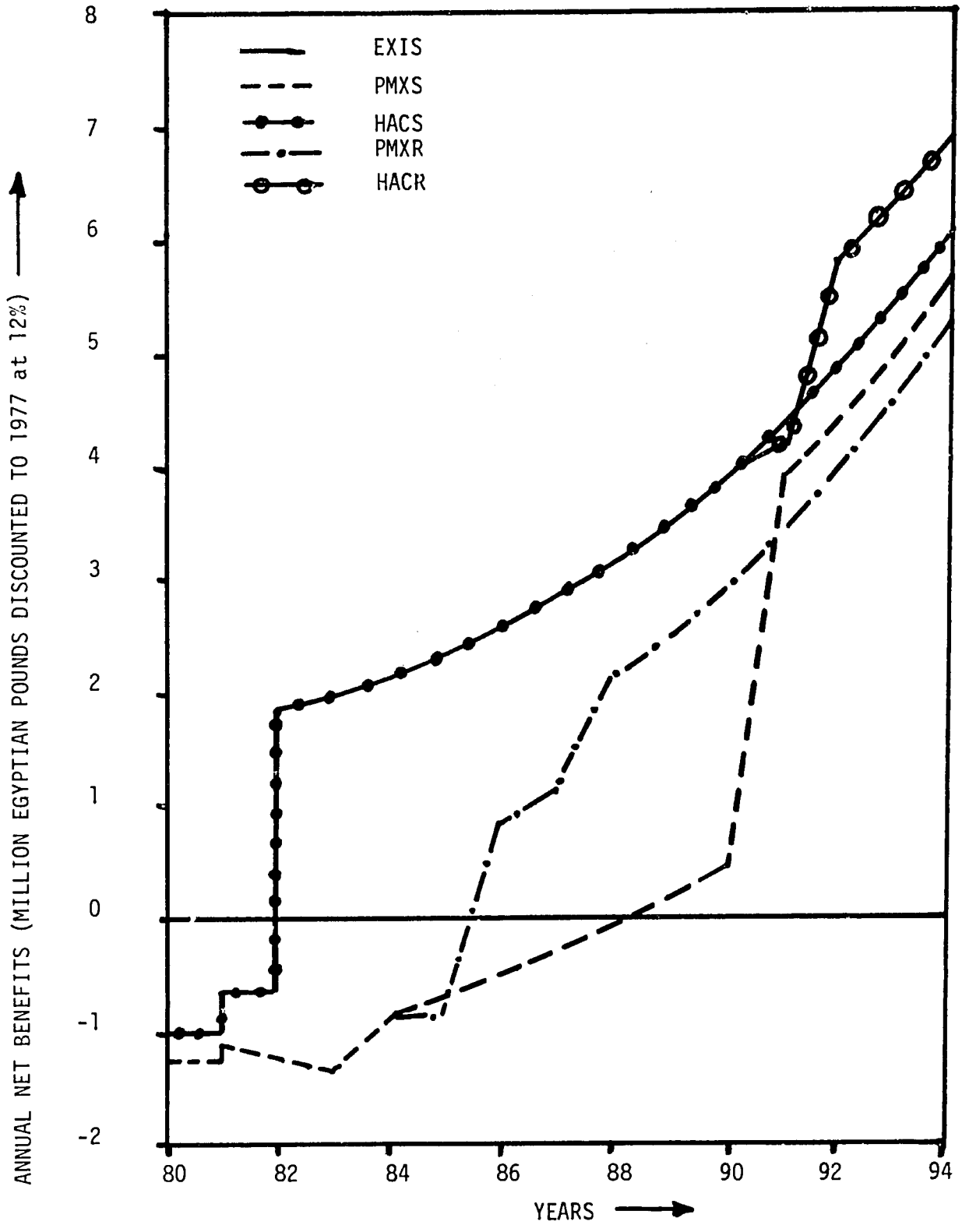
Inspection of Table 4-1 suggests that the study zone contains four classes of link (with respect to the proposed alternatives). These are:

1. Links for which the proposed investments may be postponed;
2. Links for which the proposed investments are adequate;
3. Links for which the proposed investments are marginal; and
4. Links for which the proposed investments are inadequate.

These are examined in depth below.

4.2.1 Links with Postponable Overlays

These seven links, which represent the structurally strongest links in the study zone (as measured by modified structural number), at first glance at Table 4-1 appear to have responded extremely favorably to the proposed investments, since reductions in total costs for the various overlay options are quite large. However, as may be seen from Figure 4-1, it is not always the construction overlays which make for the majority of these savings, but more often the savings produced by future overlays done through maintenance. Figure 4-1 presents the total net benefits for the four alternatives (discounted to 1977 value at 12%) on a year-by-year basis for a typical link in this group, Tanta-Tawfikieh (TNTW). From this figure, one can see that the proper timing of an overlay is dependent on its costs, and the road surface conditions before and after the overlay. The present worth difference between the asphalt concrete and pre-mix operating benefits is 3 million Egyptian pounds in 1982 (the first year in which both overlays would be open to traffic) which reflects a roughness difference of 1000 mm/km between the two surfaces. As the present worth of the construction cost differences is roughly one-sixth this amount, the initial asphalt concrete overlay will always be superior to the initial premix overlay for links within this group. The best alternative will, of course, depend upon the subsequent maintenance policy, also.



ANNUAL NET BENEFITS FOR A TYPICAL LINK IN THE GROUP
WITH POSTPONABLE OVERLAYS, TNTW

FIGURE 4-1

Table 4-2 presents the economic indicators computed for the links in this group, discounting to 1977 at 12%. These include the total cost, net present value, first year benefits, and internal rate of return. In most cases, the first year benefits, which are often used to determine the appropriate timing of an investment, are extremely large and negative for the premix overlays and large and positive for the double overlays. Their largeness reflects the great potential of the investments, but the negativity is more confusing: the surface is in worse condition after the overlay than previously. The situation was produced by the strict scheduling of the construction for 1980, regardless of surface conditions, and by the slow deterioration pattern and excellent initial conditions of the links in this group. However, it is also due in large part to the assumed quality of the overlays themselves, suggesting that the quality of the finished surface is of great importance to links with these high traffic volumes.

Table 4-3 presents a summary of the predicted existing conditions and operating costs for the links within this group, while Figure 4-2 shows the relationships between surface conditions (roughness) and unit vehicle operating costs for the representative vehicle types. It is these relationships between surface conditions and operating costs which allow maintenance and construction investments to produce such high economic returns upon these heavily trafficked roads.

For all of the links in this group, greater economic returns to investment could be made by postponing the proposed overlays for several years and/or improving the surface quality produced by the overlays. Also, the recommended subsequent maintenance policy is the asphalt concrete responsive policy, which was the most intensive policy analyzed. Indications are that even higher levels of maintenance investment on these links would be justified,but their relative priority cannot be determined from single link analyses.

Figure 4-3 presents the road roughness of one section of link TNTW over time and clearly shows that the premix overlay (initial quality of 2500 mm/km) would not be economical until roughly 1986 at the earliest, while the double, asphalt-over-premix overlay (initial quality of 1500 mm/km) is apparently justifiable at the scheduled time of 1980. This large discrepancy in performance indicates the need for accurate

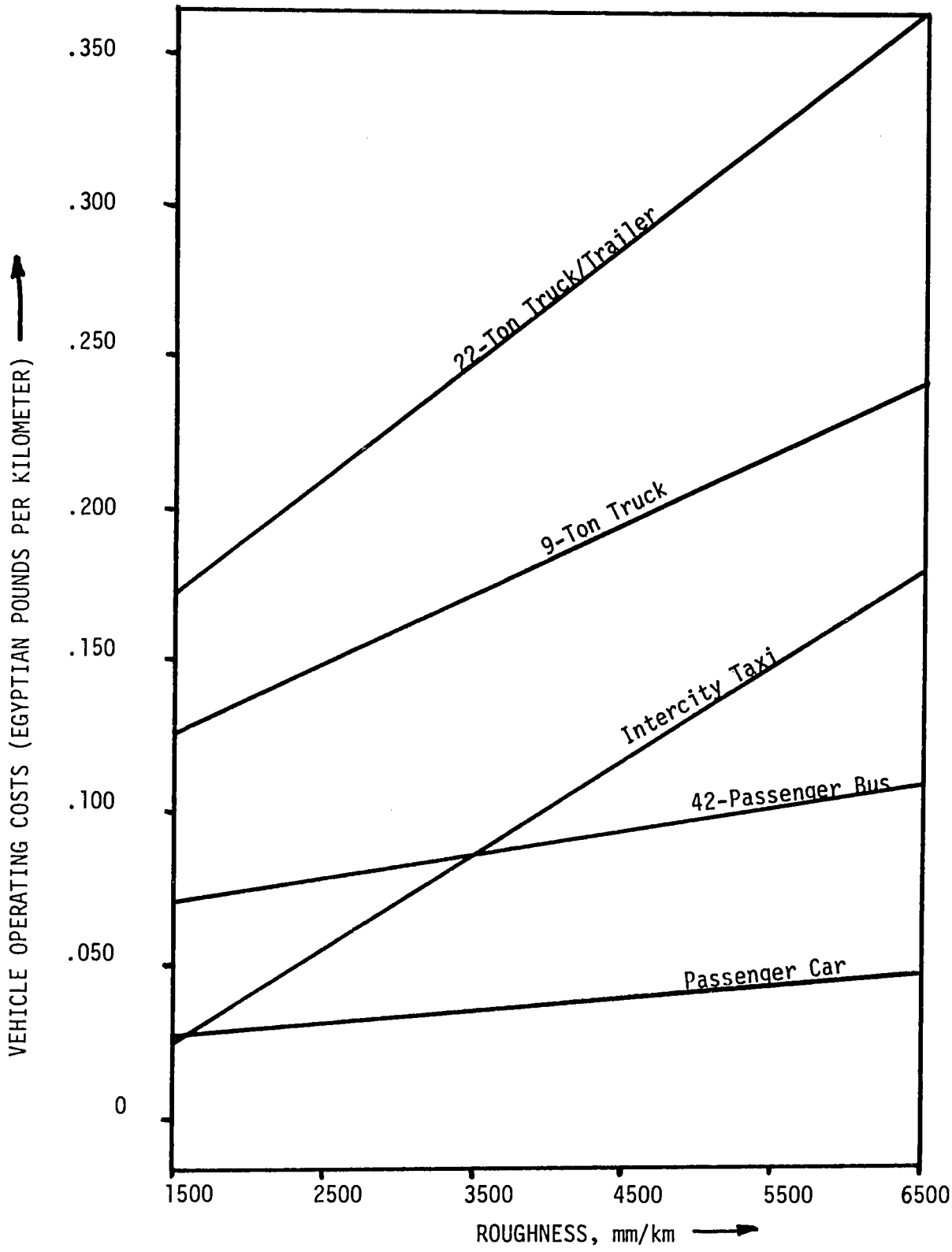
TABLE 4-2
ECONOMIC INDICATORS* FOR LINKS WITH POSTPONABLE OVERLAYS
(Millions of Egyptian Pounds Discounted at 12%)

No.	Link	Alternative	Total Cost	Net Present Value	First Year Benefits %	Internal Rate of Return %
1	QBTK	EXIS	209.641	0.000	----	----
		PMXS	227.282	-17.646	-277.4	- 9.7
		HACS	193.843	15.797	69.0	67.9
		PMXR	225.721	-16.080	-277.7	- 9.1
		HACR	190.702	18.939	69.0	68.4
2	TKBN	EXIS	193.651	0.000	----	----
		PMXS	179.258	14.393	-168.7	25.3
		HACS	151.271	42.380	171.4	>100.0
		PMXR	172.890	20.761	-168.9	31.9
		HACR	147.701	45.950	171.3	>100.0
3	TNTW	EXIS	226.985	0.000	----	----
		PMXS	208.106	18.879	- 97.9	27.0
		HACS	177.662	49.323	115.0	98.7
		PMXR	200.658	26.327	- 98.2	34.0
		HACR	173.830	53.155	114.9	98.7
4	BNQS	EXIS	78.381	0.000	----	----
		PMXS	68.786	9.595	- 55.4	33.4
		HACS	58.509	19.872	99.4	90.9
		PMXR	66.515	11.866	- 55.6	38.7
		HACR	57.258	21.123	99.3	90.9
5	QSBS	EXIS	87.535	0.000	----	----
		PMXS	75.747	11.788	- 63.0	35.0
		HACS	63.696	23.839	116.7	>100.0
		PMXR	73.059	14.476	- 63.3	40.6
		HACR	62.207	25.328	116.6	>100.0
6	BSTN	EXIS	137.470	0.000	----	----
		PMXS	119.192	18.278	- 61.0	34.3
		HACS	100.091	37.379	110.6	Many
		PMXR	114.953	22.517	- 61.2	39.8
		HACR	97.745	39.725	110.6	97.0
7	QSSH	EXIS	12.659	0.000	----	----
		PMXS	12.884	-0.225	-44.8	8.6
		HACS	11.334	1.325	22.4	37.1
		PMXR	12.871	-0.212	-45.2	8.8
		HACR	11.200	1.459	22.4	37.7

*Economic indicators are with respect to alternative EXIS

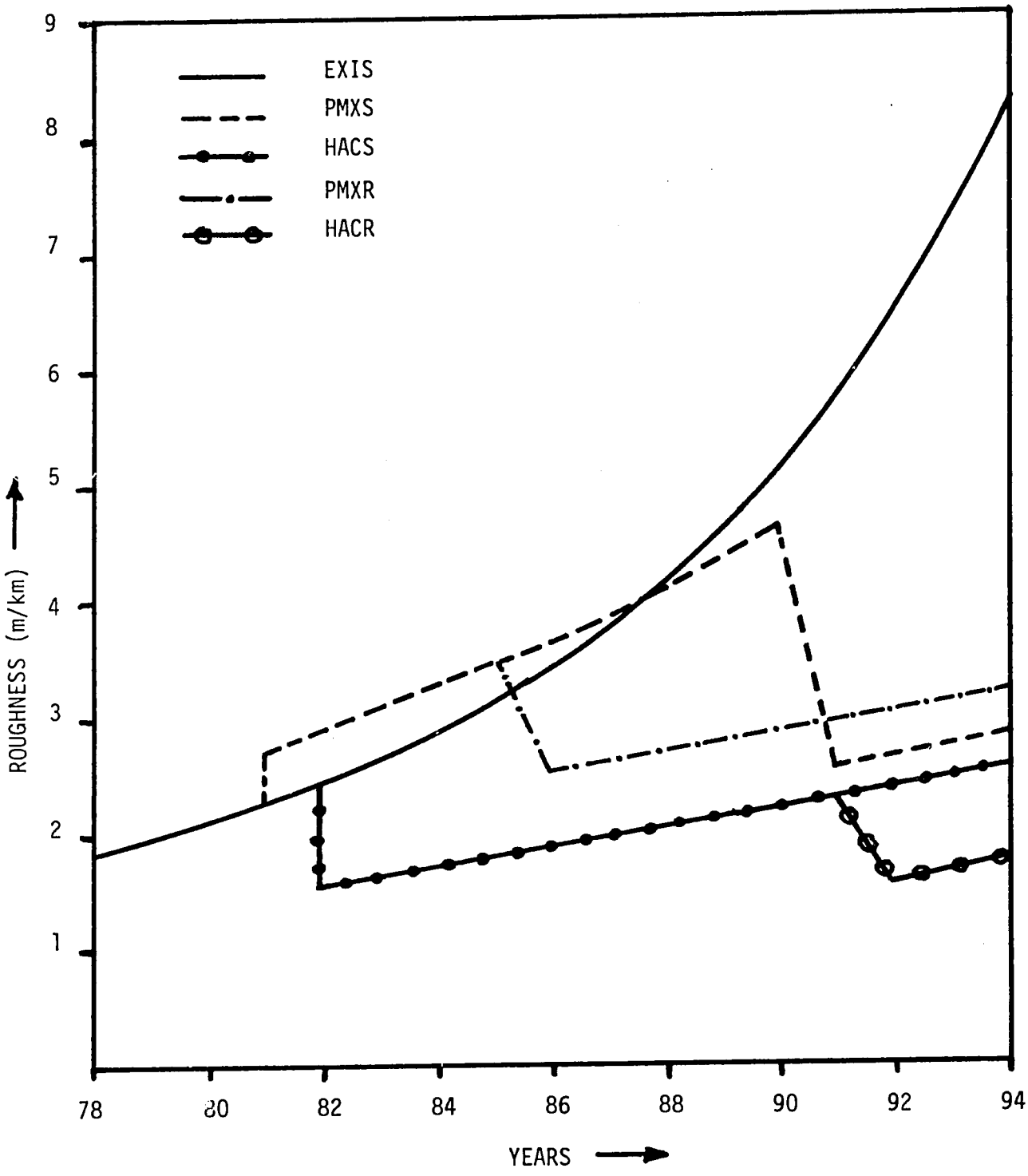
TABLE 4-3
PREDICTED EXISTING CONDITIONS AND VEHICLE OPERATING COSTS
FOR LINKS WITH POSTPONABLE OVERLAYS

No.	Link	Modified Structural Number, SN	Roughness mm/km	Vehicle Operating Costs--LE/km				
				Car	Taxi	Bus	9 Ton Truck	Truck/ Trailer
1	QB-TK	7.6	1604	0.028	0.027	0.073	0.130	0.178
2	TK-BN	5.6	1856	0.029	0.035	0.075	0.136	0.188
3	TN-TW	5.3	1936	0.030	0.038	0.076	0.137	0.192
4	BN-QS	5.1	1970	0.030	0.039	0.076	0.138	0.193
5	QS-BS	5.1	1975	0.030	0.039	0.076	0.138	0.193
6	BS-TN	5.1	1972	0.030	0.039	0.076	0.138	0.193
7	QS-SH	4.4	2030	0.030	0.041	0.077	0.140	0.195



VEHICLE OPERATING COSTS VERSUS ROAD SURFACE CONDITION

FIGURE 4-2



ANNUAL ROAD ROUGHNESS FOR A TYPICAL LINK IN THE GROUP WITH POSTPONABLE OVERLAYS, TNTW (SECTION 1)

FIGURE 4-3

determination of the quality of the riding surface both before and after a major maintenance operation.

4.2.2 Links for Which the Overlays are Adequate

Nine links showed an immediate need for the proposed investments, yielding good returns to the overlays and maintenance policies analyzed. Table 4-4 summarizes the economic performance of the various alternatives, from which it can be seen that alternative HACR (the double overlay followed by responsive maintenance) provides the superior economic return in all cases. These links have modified structural numbers less than 3.0, but the traffic volume, particulary that of heavy vehicles, is not so high.

Since the first year benefits are extremely large and positive for all alternatives on all links in this group, the overlays should be performed even earlier than 1980, if possible. However, one should note that this last point is quite sensitive to the initial conditions assumed, which in this case were extremely bad.

Figure 4-4 presents the total net benefits for the four alternatives (discounted to 1977 value at 12%) on a year-by-year basis for a typical link in the group, Bagour-Tamaly (BGTM). Similar results would be obtained for the other links. From this figure, one can see that the premix overlay deteriorates to the "do-nothing" conditions in 8 years, while the aspahlt concrete overlay performs adequately throughout the analysis. However, the superior alternative is again the asphalt concrete-responsive maintenance alternative, the most intensive of the options analyzed.

The predicted initial roughness for the links in this group was more than four times those of the previous group (links with postponable overlays), resulting in vehicle operating costs roughly twice as high, and nearly six times for inter-city taxis.* Thus, extremely large savings resulted from improving the riding surface of the links in this group.

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*This large fluctuation in inter-city taxi cab operating costs is partly due to the high average kilometrage of these vehicles and the extreme roughness of the road, both of which values are beyond the range of vehicle cost regression date represented in the Road Investment Analysis Model.

TABLE 4-4

ECONOMIC INDICATORS* FOR LINKS RESPONDING WELL TO OVERLAYS**

(Millions of Egyptian Pounds Discounted at 12%)

No.	Link	Alternative	Total Cost	Net Present Value	First Year Benefits %	Internal Rate of Return %
8	BGTM	EXIS	36.101	0.000	----	----
		PMXS	27.091	9.010	311.4	>100.0
		HACS	24.266	11.835	239.7	>100.0
		PMXR	24.593	11.508	310.8	>100.0
		HACR	23.803	12.298	239.7	>100.0
9	QBKN	EXIS	11.526	0.000	----	----
		PMXS	7.438	4.088	262.8	>100.0
		HACS	7.225	4.301	201.1	>100.0
		PMXR	7.150	4.376	262.2	>100.0
		HACR	7.133	4.393	201.1	>100.0
10	KNTM	EXIS	108.078	0.000	----	----
		PMXS	95.156	12.922	291.7	>100.0
		HACS	83.952	24.126	227.5	>100.0
		PMXR	85.546	22.532	287.7	>100.0
		HACR	81.786	26.292	227.3	>100.0
11	KNBL	EXIS	52.288	0.000	----	----
		PMXS	44.785	7.503	384.1	>100.0
		HACS	39.455	12.833	299.9	>100.0
		PMXR	39.693	12.595	380.5	>100.0
		HACR	38.316	13.972	299.7	>100.0
12	BLTK	EXIS	5.875	0.000	----	----
		PMXS	4.864	1.011	244.8	>100.0
		HACS	4.407	1.468	188.0	>100.0
		PMXR	4.388	1.487	244.2	>100.0
		HACR	4.337	1.538	187.9	>100.0
13	BLBN	EXIS	21.815	0.000	----	----
		PMXS	18.679	3.136	386.3	>100.0
		HACS	16.452	5.363	301.5	>100.0
		PMXR	16.551	5.264	382.6	>100.0
		HACR	15.976	5.839	301.4	>100.0
14	ASSN	EXIS	14.494	0.000	----	----
		PMXS	12.172	2.322	292.6	>100.0
		HACS	10.400	4.094	226.2	>100.0
		PMXR	10.564	3.930	292.0	>100.0
		HACR	10.132	4.362	226.2	>100.0

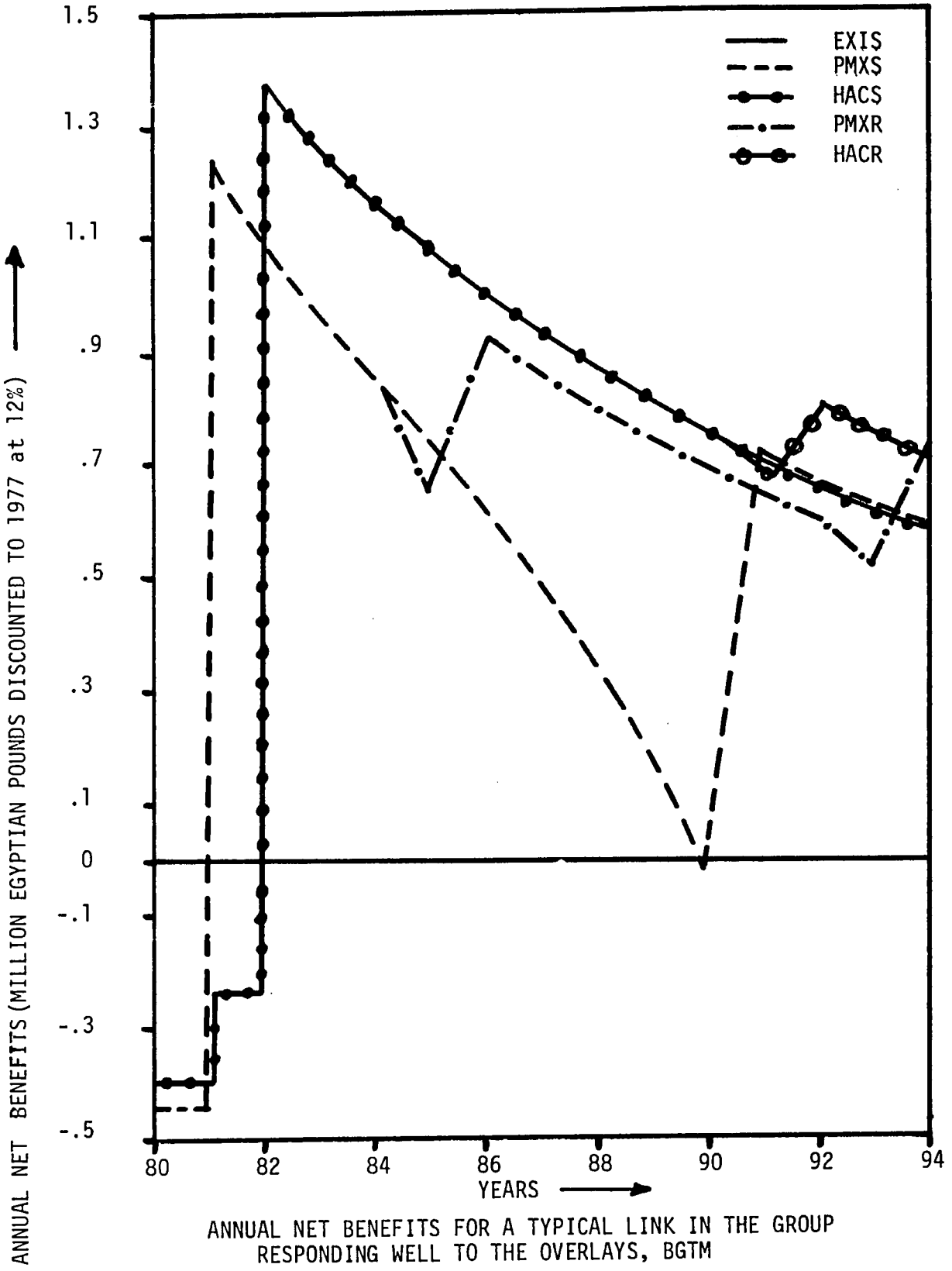
TABLE 4-4 (continued)

No.	Link	Alternative	Total Cost	Net Present Value	First Year Benefits %	Internal Rate of Return %
15	SDBB	EXIS	10.726	0.000	----	----
		PMXS	8.340	2.386	113.3	>100.0
		HACS	7.824	2.902	86.2	69.3
		PMXR	7.936	2.790	113.0	>100.0
		HACR	7.748	2.978	86.2	69.3
24	KMSD	EXIS	12.271	0.000	----	----
		PMXS	9.847	2.424	117.2	100.0
		HACS	8.936	3.335	89.3	71.0
		PMXR	8.885	3.386	117.0	100.0
		HACR	8.818	3.453	89.3	MANY ***

*Economic indicators are with respect to alternative EXIS.

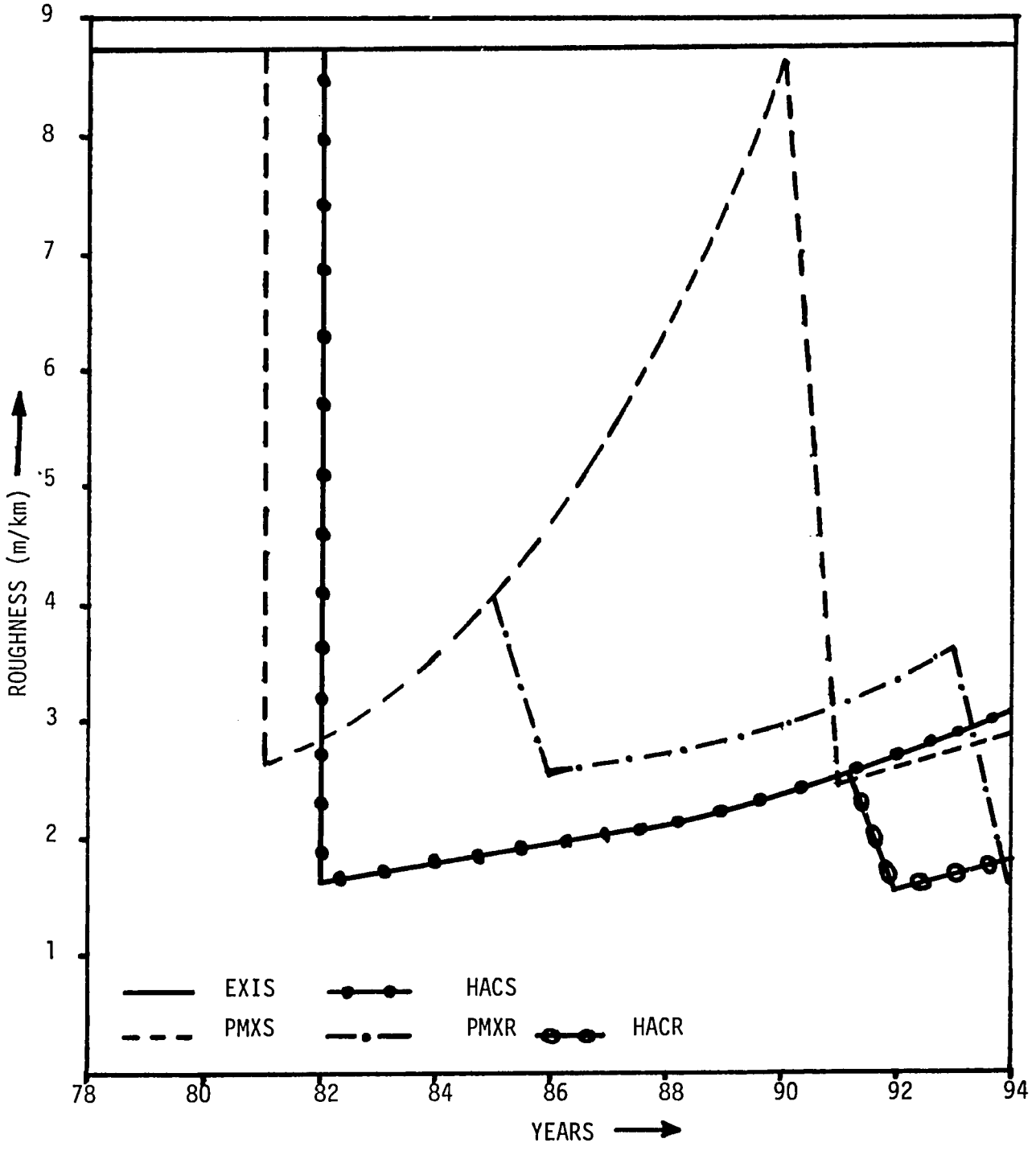
**These are links on which the asphalt concrete overlay performs satisfactorily for at least 15 years

***More than one discount rate between -20 and 100 percent produced an NPV of zero.



ANNUAL NET BENEFITS FOR A TYPICAL LINK IN THE GROUP RESPONDING WELL TO THE OVERLAYS, BGTM

FIGURE 4-4



ANNUAL ROAD ROUGHNESS FOR A TYPICAL LINK IN THE GROUP RESPONDING WELL TO THE OVERLAYS, BGTM

FIGURE 4-5

Figure 4-5 shows the annual road roughness for the various alternatives on a typical link in this group, BGTM. Once again, the superiority of the double, asphalt-over-premix overlay is clearly evident, now primarily due to its added strength (ΔSN of 1.68 versus .80 for the premix overlay) rather than to the quality of the resulting riding surface. Moreover, it shows that subsequent maintenance overlays perform adequately for the remainder of the analysis period.

4.2.3 Links for Which the Overlays are Marginal

Eight links responded marginally to the proposed investments, with marginality being defined as the failure of the initial double overlay in from 5 to 14 years. A first glance at Table 4-5, which summarizes the economic performance of the various alternatives, would seem to indicate that the returns on investment were quite good, and this is indeed the case. However, the concern of this analysis is to place the limited number of options studied into an adequacy framework, thus indicating where in relation to the options at hand the optimum investment policy might lie.

Figure 4-6 presents the total net benefits for the four alternatives (discounted to 1977 value at 12%) on a year-by-year basis for a typical link in this group, Santriss-Bagour (SNBG). Similar results would be obtained for the other links. From this figure, one can see that the premix overlay is inadequate, with deterioration to the "do-nothing" conditions occuring in 3 years, while the double asphalt concrete over premix overlay fails in 12 years. Of all the options studied, again the most intensive one, HACR, was superior. This policy, however, still required an additional overlay in the sixth year after construction, which may be operationally impractical for the Road Authority to implement.

Figure 4-7 shows the annual road roughness for the various alternatives for a typical link in this group, SNBG. The superiority of the heavy initial overlay is evident, although for links in this group it is still an insufficient structural addition to handle the heavy traffic volumes which occur on these links. For links within this group an even higher initial investment, in terms of structural strength, may be preferable.

Table 4-5

ECONOMIC INDICATORS* FOR LINKS RESPONDING MARGINALLY TO OVERLAYS**
(Millions of Egyptian Pounds Discounted at 12%)

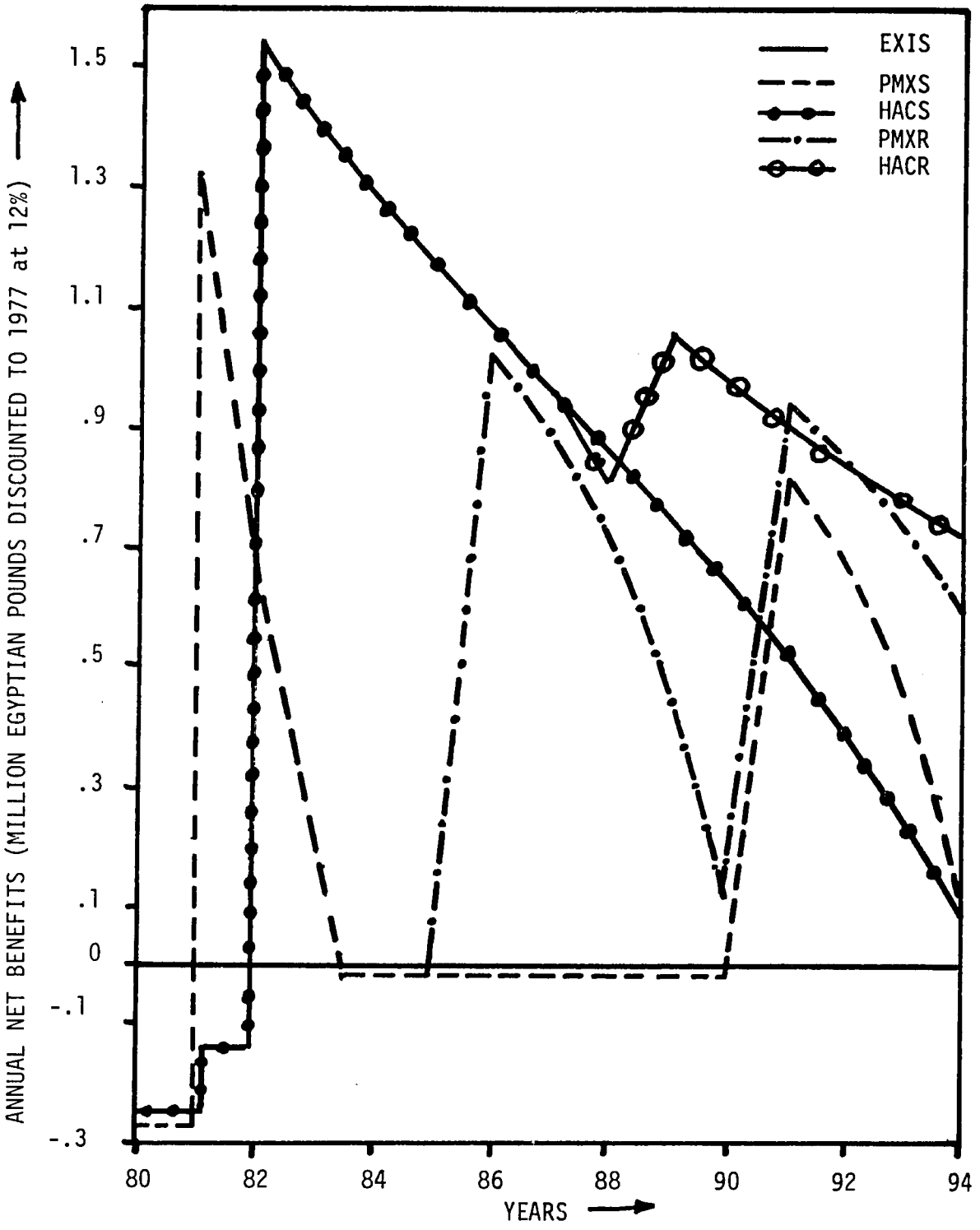
No.	Link	Alternative	Total Cost	Net Present Value	First Year Benefits %	Internal Rate of Return%
16	BSSH	EXIS	26.365	0.000	----	----
	(12) ***	PMXS	22.590	3.775	413.0	> 100.0
		HACS	18.755	7.610	324.0	> 100.0
		PMXR	19.494	6.871	409.1	> 100.0
		HACR	17.932	8.433	323.9	> 100.0
17	BBTN	EXIS	15.235	0.000	----	----
	(14) ***	PMXS	12.088	3.147	297.7	> 100.0
		HACS	9.882	5.353	229.3	> 100.0
		PMXR	10.094	5.141	297.2	> 100.0
		HACR	9.579	5.656	229.3	> 100.0
18	KNSN	EXIS	50.205	0.000	----	----
	(9) ***	PMXS	46.074	4.131	477.0	> 100.0
		HACS	38.505	11.700	390.5	> 100.0
		PMXR	40.611	9.594	473.0	> 100.0
		HACR	34.919	15.286	390.3	> 100.0
19	SNBG	EXIS	42.131	0.000	----	----
	(9) ***	PMXS	38.407	3.724	543.3	> 100.0
		HACS	31.662	10.469	445.6	> 100.0
		PMXR	33.517	8.614	539.3	> 100.0
		HACR	28.437	13.694	445.4	> 100.0
20	BGSH	EXIS	22.807	0.000	----	----
	(12) ***	PMXS	19.201	3.606	362.5	> 100.0
		HACS	15.402	7.405	283.3	> 100.0
		PMXR	16.147	6.660	361.9	> 100.0
		HACR	14.619	8.188	283.2	> 100.0
21	SHKM	EXIS	6.925	0.000	---	----
	(14) ***	PMXS	5.495	1.430	297.7	>100.0
		HACS	4.492	2.433	229.3	>100.0
		PMXR	4.588	2.337	297.2	>100.0
		HACR	4.354	2.571	229.3	>100.0

No.	Link	Alternative	Total Cost	Net Present Value	First Year Benefits%	Internal Rate of Return%
22	(14) KMRB ***	EXIS	12.465	0.000	----	----
		PMXS	9.890	2.575	297.7	>100.0
		HACS	8.085	4.380	229.3	>100.0
		PMXR	8.258	4.207	297.2	>100.0
		HACR	7.838	4.627	229.3	>100.0
23	(14) BNBG ***	EXIS	15.816	0.000	----	----
		PMXS	13.093	2.723	166.4	>100.0
		HACS	11.203	4.613	127.8	>100.0
		PMXR	11.348	4.468	165.9	>100.0
		HACR	10.963	4.853	127.7	>100.0

*Economic indicators are with respect to alternative EXIS

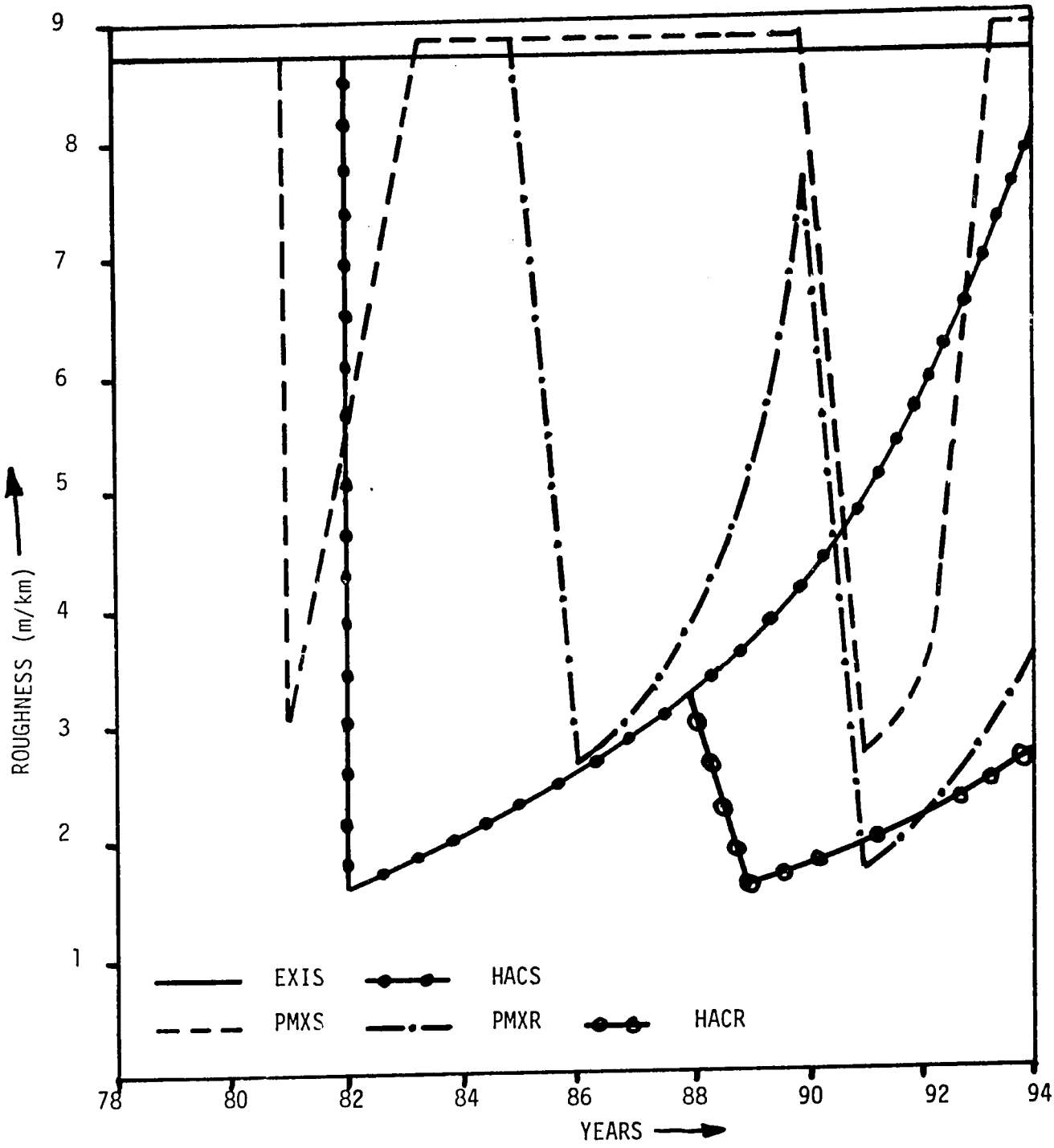
**These are links on which the asphalt concrete overlay performs satisfactorily for 5-14 years.

*** Numbers in parentheses are the years in which the asphalt concrete overlay would fail (i.e., roughness of 4000 mm/km).



ANNUAL NET BENEFITS FOR A TYPICAL LINK IN THE GROUP RESPONDING MARGINALLY TO THE OVERLAYS, SNBG

FIGURE 4-6



ANNUAL ROAD ROUGHNESS FOR A TYPICAL LINK IN THE GROUP RESPONDING MARGINALLY TO THE OVERLAYS, SNBG

FIGURE 4-7

4.2.4 Links for Which the Overlays are Inadequate

One link responded inadequately to the proposed investments, with none of the overlays surviving for even five years. A first glance at Table 4-6, which summarizes the economic performance of the various alternatives, would again seem to indicate that the returns on investment were quite good, at least for the responsive maintenance options. However, these returns are not coming from the initial construction overlays, but rather from subsequent maintenance overlays.

Figure 4-8 presents the total net benefits for the four alternatives (discounted to 1977 value at 12%) on a year-by-year basis for the only link in this group, Tamaly-Tawfikieh (TMTW). From the figure, one can see that the premix overlay policy is completely inadequate, with the initial overlay failing in 1-2 years, and subsequent maintenance overlays lasting only 3 and 4 years, respectively. The initial asphalt-concrete double overlay lasts only 4-5 years, and subsequent overlays under the responsive policy deteriorate in only five years. Thus, the pavements within this group are just too weak to perform well under the proposed alternatives and traffic levels, with the "best" alternative, again the most intensive, requiring overlays every five years, which was the maximum frequency specified in the maintenance policies.

Figure 4-9 shows the annual road roughness for the various alternatives for the only link in this group, TMTW. The inadequacy of all of the proposed investments is clearly evident from the rapid rates of road deterioration shown. The best solution for this class of roads would be a much higher initial investment primarily in increasing the structural strength of these pavements.

4.3 CONCLUSIONS

The conclusions drawn from the analyses of the links within the Egyptian study zone concern the areas of appropriate construction standards, as

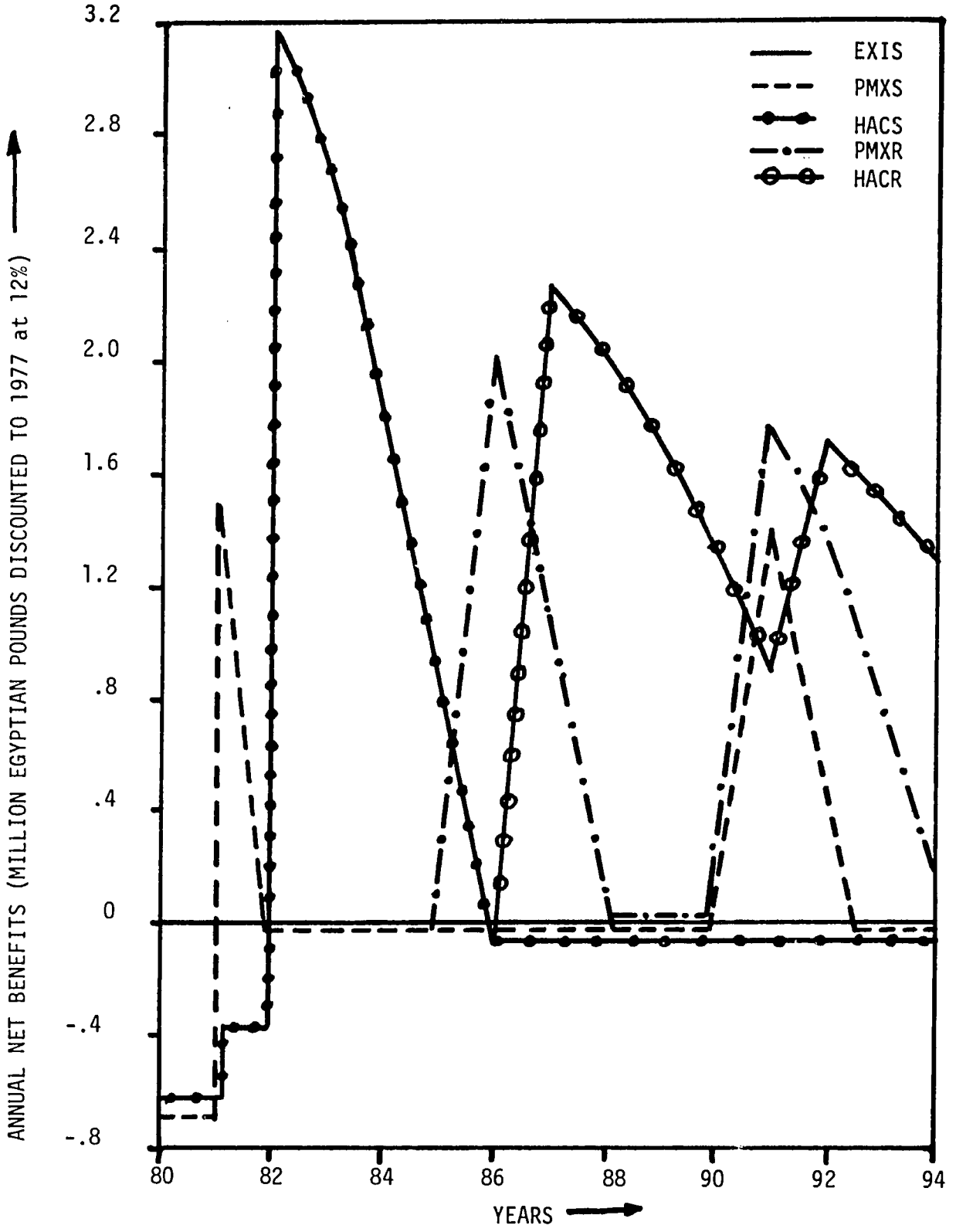
TABLE 4-6
ECONOMIC INDICATORS* FOR LINKS NOT RESPONDING TO OVERLAYS**
(Millions of Egyptian Pounds Discounted at 12%)

No.	Link	Alternative	Total Cost	Net Present Value	First Year Benefits %	Internal Rate of Return %
25	TMTW	EXIS	111.099	0.000	----	----
	(3) ***	PMXS	109.098	2.001	238.8	>100.0
		HACS	103.529	7.570	358.3	>100.0
		PMXR	103.515	7.584	234.9	>100.0
		HACR	89.800	21.299	358.2	>100.0

*Economic indicators are with respect to alternative EXIS.

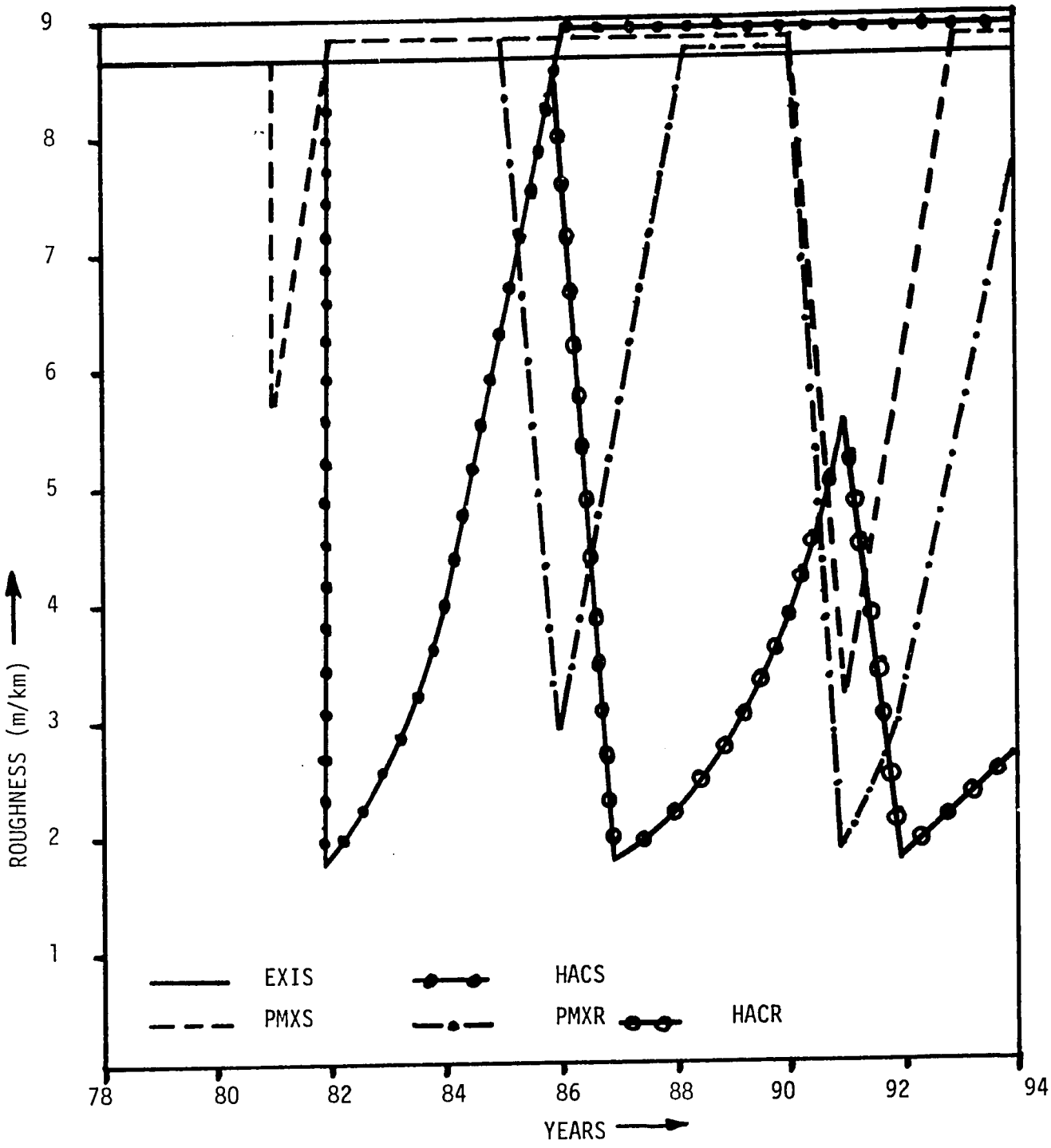
**These are links on which the asphalt concrete overlay failed in less than five years.

*** Numbers in parentheses are the years in which the asphalt concrete overlay would fail (i.e., roughness of 4000 mm/km).



ANNUAL NET BENEFITS FOR A TYPICAL LINK IN THE GROUP RESPONDING POORLY TO THE OVERLAYS, TMTW

FIGURE 4-8



ANNUAL ROAD ROUGHNESS FOR A TYPICAL LINK IN THE GROUP RESPONDING POORLY TO THE OVERLAYS, TMTW

FIGURE 4-9

regards both structural capacity and riding quality; appropriate maintenance standards, both qualitative and quantitative; and data availability and reliability. The implications of these conclusions leads to the recommendations made below.

4.3.1 Construction Standards

The results of these applications of the Road Investment Analysis Model indicated that there were four classes of link performance under the proposed structural overlays. These classes were the following:

a) Links in excellent present conditions for which the proposed investments may be postponed:
   1) QBTK Qalub--Touck
   2) TKBN Touck--Banha
   3) TNTW Tanta--Tawfikieh
   4) BNQS Banha-Quesna
   5) QSBS Quesna--Berket-el-Saab
   6) BSTN Berket-el-Saab--Tanta
   7) QSSH Quesna--Shibean-el-Koam

b) Links in poor present condition for which the proposed investments produce good results:
   8) BGTM Bagour--Tamaly
   9) QBKN Qalub--Kanater
   10) KNTM Kanater--Tamaly
   11) KNBL Kanater--Biltan
   12) BLTK Biltan--Touck
   13) BLBN Biltan--Banha
   14) ASSN Ashmoon--Santriss
   15) SDBB Shohda--Babel
   24) KMSD Kom-el-Akder--Shohda

c) Links in poor present condition which respond marginally to the proposed investments and which require heavy subsequent maintenance investments, for which heavier initial investments should be considered.

16) BSSH Berket-el-Saab--Shibean-el-Koam
17) BBTN Babel--Tanta
18) KNSN Kanater--Santriss
19) SNBG Santriss-Bagour
20) BGSH Bagour-Shibean-el-Koam
21) SHKM Shibean-el-Koam--Kom-el-Akder
22) KMBB Kom-el-Akder--Babel
23) BNBG Banha--Bagour

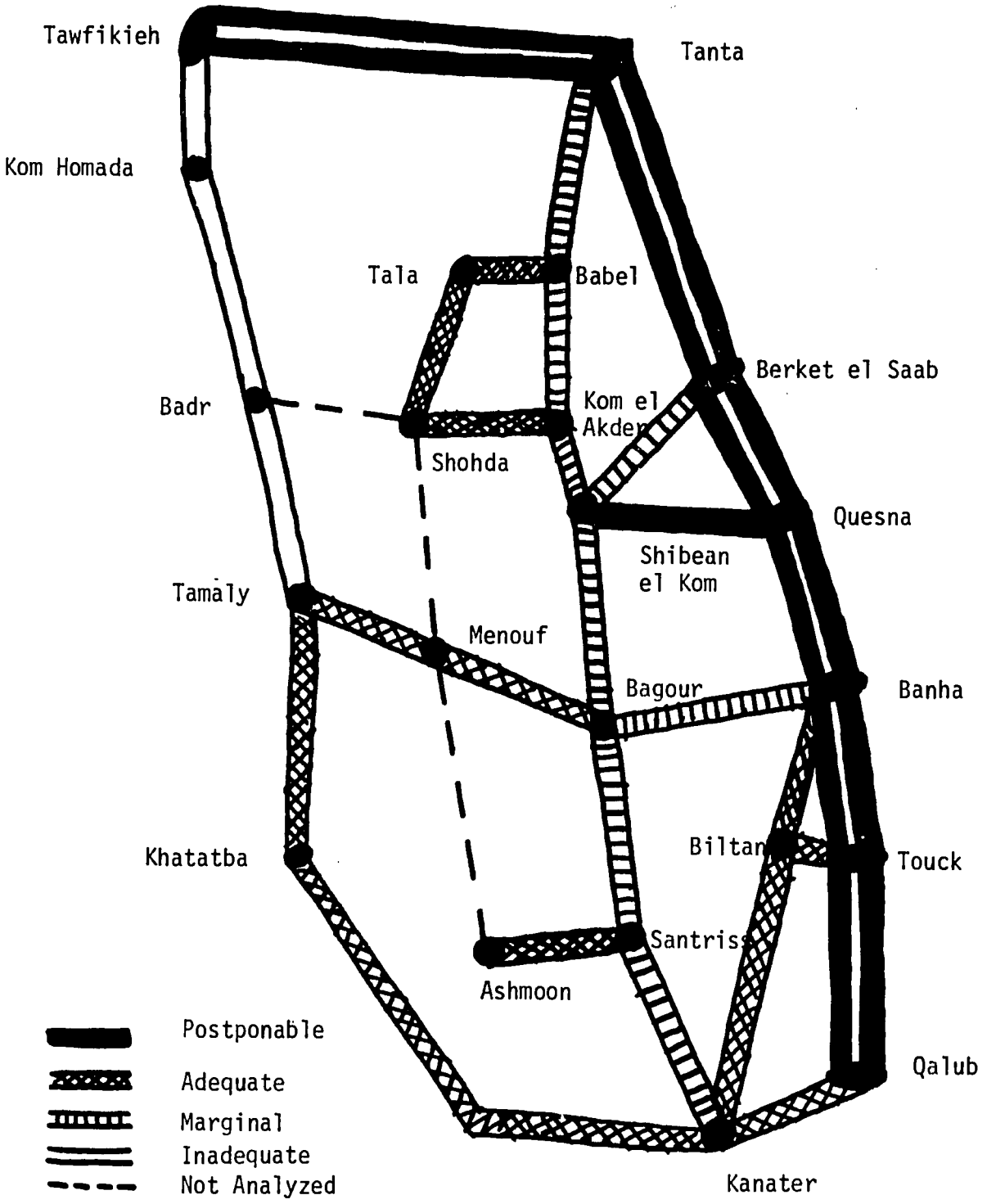
d) Links of weak structural strength and poor present condition which respond poorly to the proposed investments and where all of the net benefits accrue from subsequent maintenance investments, for which heavier initial investments or reconstruction must be considered:
25) TMTW Tamaly--Tawfikieh

The locations of these links are shown in Figure 4-10.

The precise construction standard which should be applied to each link is dependent upon three major factors: the cost of the overlay, the improvement in surface condition achieved, and the reduction in the rate of future deterioration or increment in structural strength. For the two construction overlays studied, the costs were determined by the volume of material placed; the resulting surface conditions were given; and the structural numbers of the pavements were increased by a specific amount.

The large net present values produced on those links in group a) above resulted not from the construction projects significantly reducing the rate of future deterioration, but rather through an improvement in the road surface condition produced by subsequent maintenance overlays which are assumed by the model to be of high quality. In reality, the majority of these overlays would have been postponed until these links had reached a more deteriorated condition. However, the results indicate that extremely large benefits may be obtained by minimizing the roughness on these links, so that higher quality overlays should be considered in the future.

For the links in group b) above, the selection of proper construction standard is dominated by the large improvement in surface condition



PERFORMANCE OF THE LINKS IN THE ZONE OF STUDY

FIGURE 4-10

and reduction in the rate of future deterioration, in that the structural strengths of the overlaid payments seem well suited to the traffic volumes carried. The uncertainty in the investment decision, then, is in the reliability of the existing road conditions and structural capacities.

For the links in group c) above, which performed marginally under the proposed investments, the choice of design standards should consider higher initial investments than those analyzed here. If, however, the existing structural strengths have been underestimated, the proposed investments may indeed be appropriate. For these links, an accurate measure of structural capacity is of greater importance than are measures of existing surface conditions, since even the overlaid pavements subsequently require substantial maintenance investments.

For the links in group d) above, which responded poorly to the proposed investments, a choice of upgrading standards cannot be properly made without verification of the accuracy of the data on their existing structural strengths. Although some of these links are in an existing failed state, others are not. However, given the structural strengths and traffic volumes on these links, the existing conditions are almost irrelevant, as the model predictions are that these links, even if upgraded through the proposed investments, will almost immediately fail.

4.3.2 Maintenance Standards

Four maintenance policies were proposed for the links after the overlays, the significant differences between which were in the performing of asphaltic concrete overlays of 40 mm thickness. These policies were dependent on the type of construction overlay performed, as follows:

a) Premix overlay
   - -- a scheduled overlay in 1990 (PMXS)
   - -- responsive overlays whenever the roughness exceeds 3500 mm/km, but not more frequently than every 5 years nor less frequently than every 10 years (PMXR)

b) Double (asphalt concrete over premix) overlay
   - -- no scheduled overlays (HACS)
   - -- responsive overlays whenever the roughness exceeds 3000 mm/km, but not more frequently than every 5 years nor less frequently than every 10 years (HACR)

In addition, the policies varied as to patching and surface dressing standards, but these did not contribute significantly to the outcomes of the analysis.*

Of these maintenance policies, the one most overlay-intensive, HACR, dominated the economic analysis on all links, independently of the effectiveness of the original double overlay, which was the more extensive of the two construction options analyzed. Thus, on all links studied, the heaviest construction and maintenance investments provided the greatest economic benefits. From Table 4-1, one can see that, in almost all cases, the net present values increase as the investments increase, the exceptions being the ranking of alternatives HACS and PMXR, the merits of which are dependent on the quality assumed for the construction and maintenance overlays.

Since this trend of greater returns to greater investments held across all links, which varied tremendously in their conditions, traffic volumes, and structural capacities as well as in the reliability of these data items, we can conclude that maintenance and upgrading investments will be economically justifiable at considerably higher levels than we have analyzed in the link-evaluation phase of this study.

*The Road Investment Analysis Model does not relate the level of cracking to vehicle operating costs, so these items contributed only to maintenance costs.

CHAPTER 5: NETWORK EVALUATION AND RESULTS

This section procedes from the work done at the link-evaluation level with most of the data items, including construction, maintenance, and vehicle operating costs, reported in the previous chapters. The new data items include the maintenance strategies to be analyzed, and the origin-destination matrix for the base year conditions. These will be discussed further in subsequent sections of this report.

The area chosen for study is flat, mainly cultivated land lying to the north of Cairo, and containing the Monofia and Qalubia governorates road network. This area was selected for the study zone for the following reasons:

(1) Availability of records concerning construction and maintenance of the road network;
(2) Physical homogeneity of link characteristics;
(3) Diversity of traffic volumes, providing a cross-section of the spectrum of traffic conditions likely to be encountered on the Egyptian road network;
(4) Possibilities for a route-choice study; and the
(5) Economic importance of this road network to the Highway Authority in Egypt.

The zone of study in Egypt is shown in Figure 5-1, displaying the zones into which the country was divided for purposes of the origin-destination survey, which will be discussed later. The roads analyzed within the study zone were classified into three categories, depending on their utilization, as shown in Figure 5-2. These classes were as follows: Class I is the Cairo-Alexandria Agricultural Expressway, which carries the majority of the national inter-city transport; Class II, which represents the national highways connecting the major secondary cities to the Cairo-Alexandria corridor; and Class III, which represents the paved road network connecting the minor cities with the rest of the national road system. Unpaved roads within the zone were not analyzed in this investigation.

FIGURE 5-1
NORTHERN EGYPT AND THE STUDY ZONE

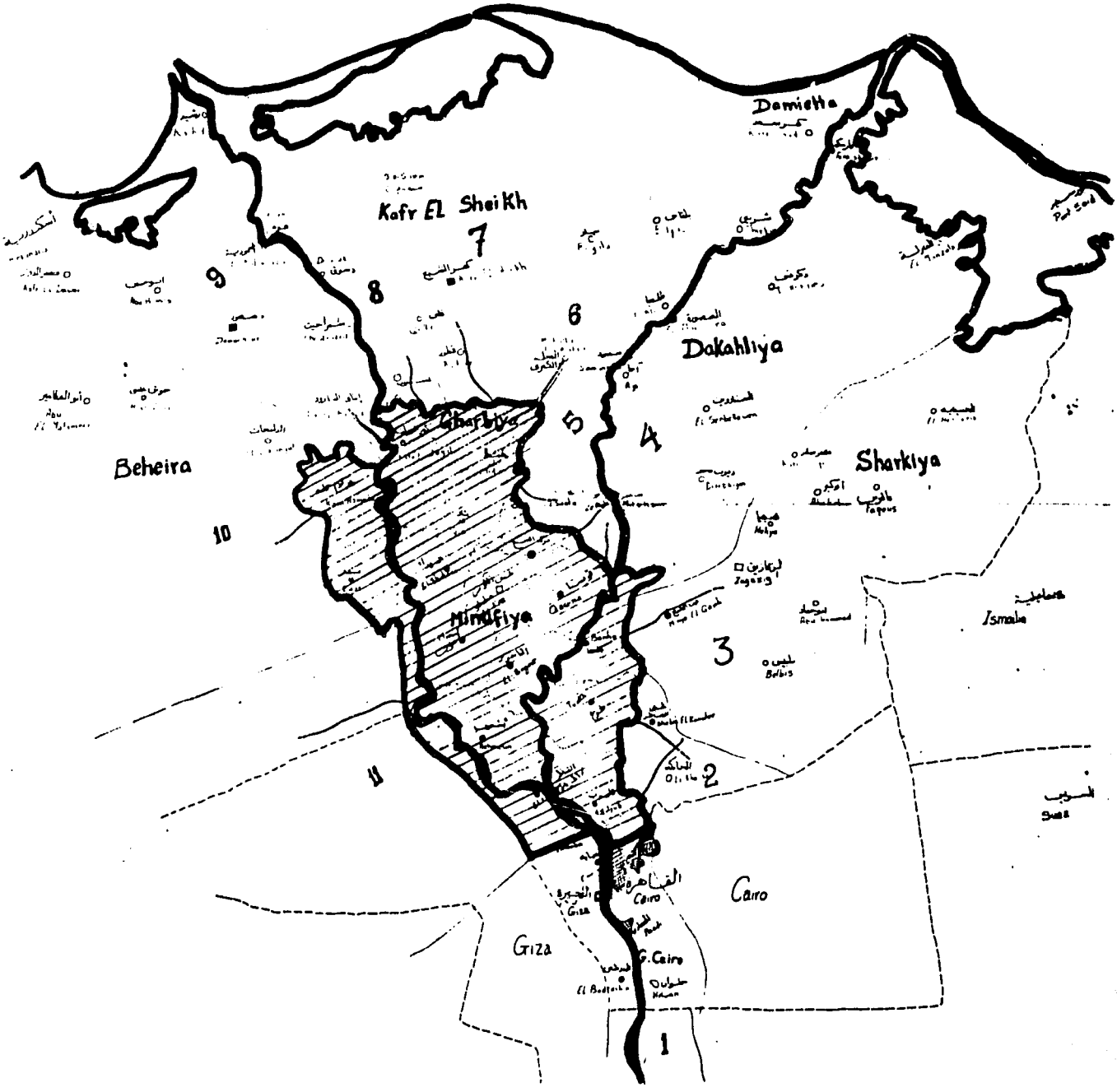
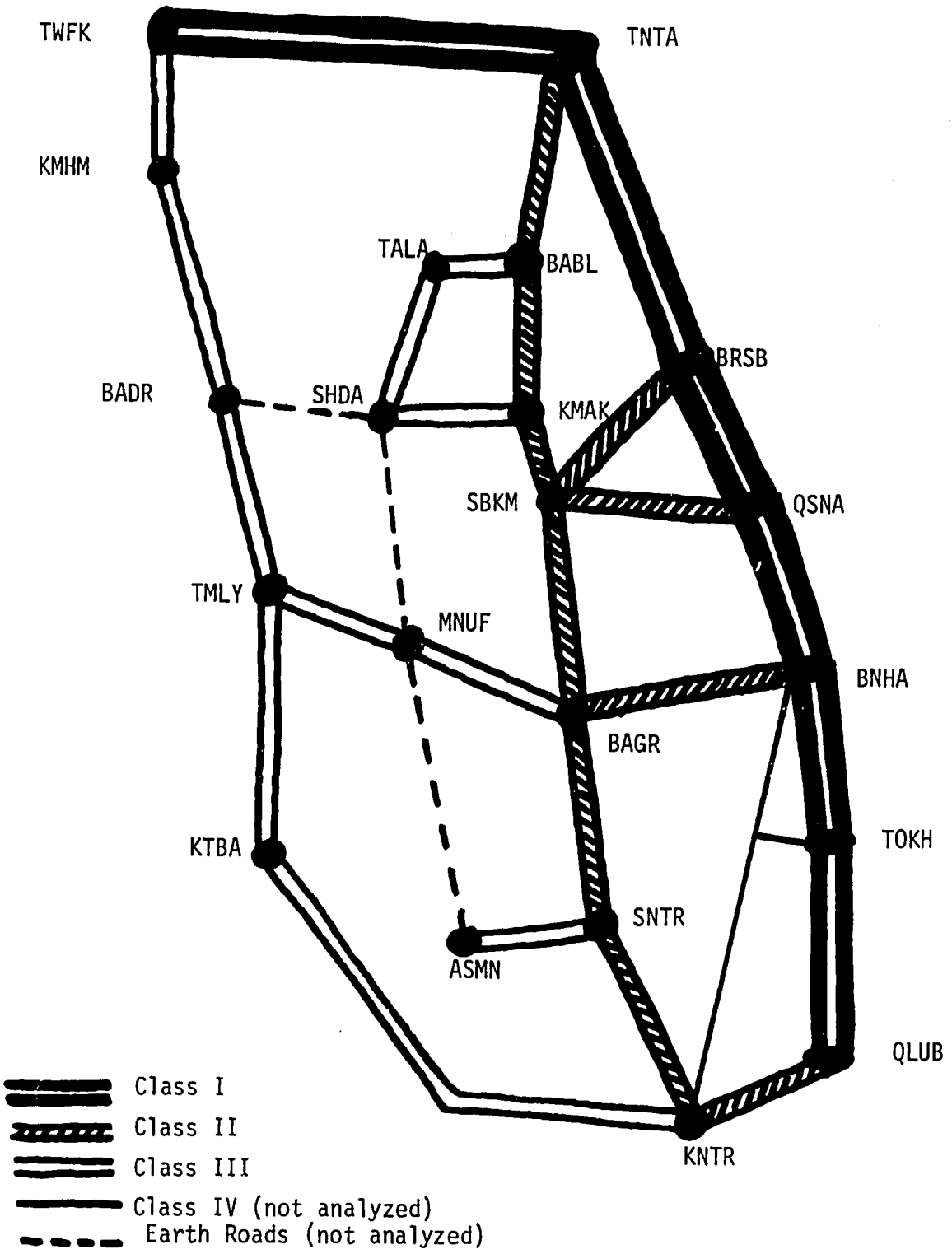


FIGURE 5-2
THE MONOFIA AND QUALUBIA GOVERNORATES
NETWORK STUDY ZONE



These classes were chosen so that investigations into the relative and absolute magnitude of investments among the various road classes could be undertaken. Specifically, we wished to address the question of, given a network investment program, where do the major benefits accumulate? And also, as a corallary, what investments should be made in the various road classes to achieve the overall optimum performance of the network?

5.1 DERIVATION OF THE MASTER ORIGIN-DESTINATION MATRICES

An origin-destination survey was conducted in the study zone on the 8th of August, 1977. The interview was designed to obtain information on vehicle type and route choice. Besides requesting where the vehicle was coming from and going to, which were at the governorate and markaz level, the questions were aimed at determining route choice behavior: What are the major cities on your route? Will you stop at any city en route? If so, for how long? Do you normally take this route? If so, why? If not, why this time? and What is your estimate of your total travel time? The intent of the interview was to determine as completely as possible any previous knowledge of O-D route-alternatives, perception of travel time, and pre-trip route decision.

The study area was divided into 16 zones, corresponding to the markaz boundaries. The external area surrounding the study area was divided into 11 zones, using natural boundaries, such as a canal, where possible and such that each external zone contained a major highway which entered the study area as shown in Figure 5-1. The external zones' traffic (generation and attraction) was then assigned to the neighboring zone centroid in the study area to convert all the survey volumes into demands within the study area.

After the data had been collected, manual processing was carried out. Since five vehicle types were interviewed (private cars, inter-city taxis, buses, trucks, and trucks with trailers), there were five O-D matrix sheets for every interview station. As the sample size interviewed for each vehicle type was considered as representative of the daily traffic for the corresponding vehicle type at the interview

station, the O-D matrix was expanded by the Average Daily Traffic (ADT) for a certain vehicle type at the interview station divided by the sample size for that vehicle type. Each cell in the O-D matrix was multiplied by this factor, producing five enlarged O-D matrices for each interview station.

Traffic generated or attracted to a specific zone within the study area was considered to be accurately given in the resulting O-D matrices from interview stations on road links crossing the zone in question. Traffic originating and destinating at any specific zone was then determined by the addition of the zone O-D cells given in the enlarged O-D matrices of the corresponding interview stations.

An investigation of the values given in the origin-destination matrices revealed that for many O-D pairs the survey results differed in the two directions of travel. One explanation of this discrepancy might be that the sampling from different traffic volumes introduced enlargement errors, resulting from different sampling frequencies at the various interview stations. To stress the results from the low-volume links, where the sampling densities were the largest, the O-D cells were filled beginning with the low-demand zones and progressing to the highest-demand zone, which was Cairo. The two-way demands were combined to produce an average, overall daily traffic demand between each O-D pair.

Once the O-D matrices were in hand, they had to be calibrated to the measured link traffic volumes, which are shown in Table 5-1, to determine the traffic assignment diversion intensity parameter incorporated within the Road Investment Analysis Model. This parameter, which has been discussed in Chapter 2, is vehicle type specific (but not a function of time or origin and destination), and was estimated using the disaggregate route-choice data obtained from the O-D survey. The values of time used for Egypt were taken as zero for private cars, taxis, and trucks; LE 1.85/hr. for buses; and LE 10/hr. for trucks with trailers; which were obtained from Transport Planning Authority estimates.

As a first trial, the diversion parameter was taken as 1.0 for all vehicle types. The resulting traffic flows showed less traffic than

TABLE 5-1

STATION-LINK VOLUMES

Link	Car	Taxi	Bus	Truck	Trailer	Total
QLUB-TOKH	7,963	12,949	1,008	4,240	1,828	27,988
TOKH-BNHA	7,770	13,152	1,008	4,240	1,828	27,998
BNHA-QSNA	4,084	6,576	552	2,124	820	14,156
QSNA-BRSB	4,556	6,174	552	2,124	820	14,226
BRSB-TNTA	4,477	6,183	552	2,124	820	14,156
TNTA-TWFK	4,706	5,951	654	2,998	1,484	15,793
KNTR-TMLY	128	351	44	309	242	1,074
KNTR-SNTR	370	2,149	469	534	175	3,697
SNTR-ASHM	197	932	133	472	121	1,855
SNTR-BAGR	622	1,898	469	537	175	3,701
BAGR-BNHA	198	132	103	195	81	709
BAGR-MNUF	387	580	157	350	111	1,585
BAGR-SBKM	611	382	154	265	145	1,557
SBKM-QSNA	465	996	337	499	90	2,387
SBKM-BRSB	447	388	259	663	144	1,901
KMAK-BABL	443	756	153	285	34	1,671
KMAK-SHDA	62	433	73	203	32	803
BABL-TALA	58	396	73	203	32	762
MNUF-TMLY	341	629	157	350	111	1,588
QLUB-KNTR	320	861	153	285	34	1,653

measured on all links leading to Tawfikieh (which actually represents demand to Alexandria). Therefore, each cell containing Tawfikieh as an origin or destination was increased by 62% to overcome this deficiency. This produced good agreement on the major links in the study zone, and trials with the diversion parameter, assuming values of 0.6 and 0.7 for all vehicle types, were analyzed to see if the diversion parameter could be adjusted to correct the flows on the minor links. These runs indicated that the traffic flow pattern was clearly sensitive to the value of the diversion parameter, verifying the presence of route-choice alternatives in the study zone.

The traffic flow patterns predicted in these runs were judged to be unsatisfactory, with the traffic demand to Cairo seeming too high and that to Alexandria too low (note that these two nodes were the last used in the deriviation of the O-D matrices.) For these reasons, and in order to reduce the cost of computer runs, the following modifications were made:

- Traffic demand to Cairo (Qalub) was reduced and traffic demand to Alexandria (Tawfikieh) was increased.
- O-D pair available-routes were modified to include only the four "most reasonable" routes, and not all possible routes.
- All O-D pairs with traffic demand of less than 30 vehicles per day were eliminated.

Once these modifications were completed, sensitivity runs were performed on the diversion intensity parameter until the discrepancies between measured and predicted link volumes could no longer be attributed to route-choice behavior. This resulted in a diversion parameter of 1.0. Local traffic was then added between some neighboring O-D pairs (less than 2 percent of all traffic demand), to bring all predicted link volumes within ten percent of the measured volumes. The resulting master O-D matrix is given in Table 5-2. Traffic was assumed to grow uniformly at 7 percent for all vehicle types throughout the analysis period, 1977-2000.

The following conclusions were drawn from this calibration effort:

TABLE 5-2

FINAL O-D MATRIX
Two-Way Average 1977 Daily Traffic
(all vehicle types)

	QLUB	TOKH	BNHA	QSNA	BRSB	TNTA	TWFK	KMHM	BADR	TALA	SHDA	SBKM	MNUF	BAGR	ASHM	KNTR
QLUB	QLUB															
TOKH	609	TOKH														
BNHA	12566	58	BNHA													
QSNA	272	43	720	QSNA												
BRSB	491	---	---	---	BRSB											
TNTA	3165	---	472	201	238	TNTA										
TWFK	11012	58	506	---	63	4590	TWFK									
KMHM	723	---	---	---	---	291	---	KMHM								
BADR	---	---	---	---	---	---	---	---	BADR							
TALA	145	---	40	---	---	450	---	---	---	TALA						
SHDA	109	---	---	44	---	71	---	---	---	---	SHDA					
SBKM	969	---	626	508	416	900	291	---	---	76	663	SBKM				
MNUF	628	---	69	68	---	---	691	180	656	---	---	128	MNUF			
BAGR	806	66	---	---	---	---	---	---	---	---	---	67	181	BAGR		
ASHM	1074	---	35	---	---	---	70	---	---	---	---	93	333	175	ASHM	
KNTR	1043	54	37	---	---	---	---	---	---	---	---	88	---	---	117	KNTR

- The final assignment was reached with a diversion intensity parameter of 1.0.
- The network flow pattern was sensitive to the value of the diversion parameter, and any significant change from 1.0 would result in a decrease in the overall accuracy of of the predicted link volumes.
- The final assignment reached with a diversion parameter of 1.0 necessitated the addition of some local traffic (less than 2 percent of the total demand) to the system.
- The average error between the actual traffic measurements and the predicted traffic flows on the network from the final assignment was 5.2%.

5.2 ANALYSIS AND RESULTS

Ten alternative maintenance policies were analyzed over the network study zone, reflecting three types of investment concerns of importance to the Egyptian Transport Planning Authority. First was the question of the relative frequency of the maintenance activities, in this case asphalt concrete overlays, which will affect the mean road surface conditions for each road class. Second, was the relative magnitude of the investments as reflected in the overlay thickness, which would affect the rate of future deterioration of the riding surface in each road class. Third, was the question of the relative levels of investment among the three road classes - primary, secondary, and tertiary - to achieve the most effective overall investment strategy in the network. The ten maintenance investment policies are summarized in Table 5-3. The road classes within the study zone were shown in Figure 5-2.

All policies were identical as regards the maintenance activities of patching, surface dressing, and miscellaneous maintenance. The patching standard was to repair 80% of all unpatched cracks each year, but not to exceed 50 square meters per kilometer per year. The surface dressing standard was to perform a surface dressing on the entire road

TABLE 5-3
MAINTENANCE STRATEGIES INVESTIGATED

Activity		Strategy	Roads in Class I	Roads in Class II	Roads in Class III
Patching	Patch 80% of unpatched cracks but not more than 50 m^2/km/year	1-10			
Surface Dressing	Surface dress when cracking plus patching exceeds 10% of the surface area, but not more frequently than every two years nor less frequently than every five years, and not after 1995	1-10			
Routine Maintenance	Includes drainage, vegetation shoulder, and miscellaneous activities	1-10			
Overlay	When roughness exceeds:_____ millimeters per kilometer using asphalt concrete pavement of: (_____) millimeters, but not after 1994	1	5000(40)	6000(40)	7000(40)
		2	4000(40)	5000(40)	6000(40)
		3	3000(40)	4000(40)	5000(40)
		4	Never	3000(40)	4000(40)
		5	3000(40)	Never	Never
		6	5000(80)	6000(100)	7000(120)
		7	4000(60)	5000(80)	6000(100)
		8	3000(40)	4000(60)	5000(80)
		9	Never	4000(60)	5000(80)
		10	3000(40)	6000(100)	7000(120)

surface whenever the total area of cracking and patching exceeded 10 percent of the total road surface area, but not more frequently than every 2 years or less frequently than every 5 years. No surface dressings were performed after the year 1995, so that major maintenance investments would not be performed in the last analysis years where they might not have sufficient time to realize their full benefits. Although these items were standardized in all policies analyzed, the actual quantities of patching and surface dressing varied slightly from strategy to strategy due to the demand-responsive nature of the maintenance. Routine maintenance of drainage structures, vegetation, shoulders, safety installations and miscellaneous items was constant over all policies analyzed.

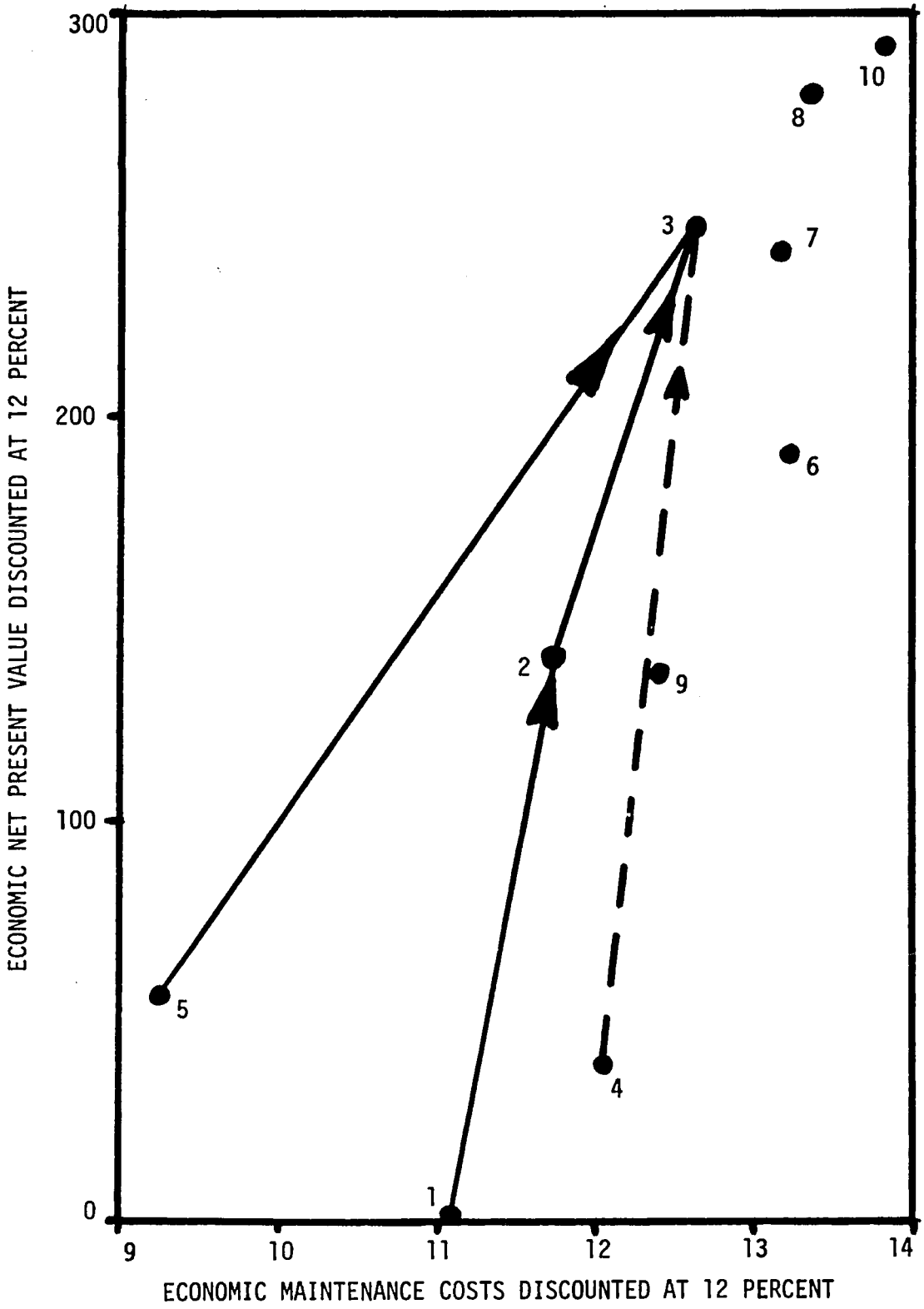
5.2.1 Economic Analysis

The primary focus of this study was on the relative frequency and thickness of overlays among the various road classes. The alternatives were selected to illustrate as thoroughly as possible the effects of the various options available in a reasonably small number of strategies. Five of the alternatives involved holding the thickness of all overlays constant at 40 mm of asphalt concrete while varying the absolute and relative frequency of overlays among the various road classes, as measured by the threshold roughness at which an overlay would be performed. The remainder of the alternatives involved varying the thickness of the applied overlays with the overlay thickness increasing by 20 mm for every 1000 mm/km of additional roughness tolerated before performing the overlay, while using similar absolute and relative frequencies of overlays among the three road classes as were analyzed in the first group of strategies. No overlays were performed after 1994, so that these major maintenance investments would not be done in the last analysis years where they might not have sufficient time to realize their full benefits.

Figure 5-3 shows the effects of overlay frequency while holding the thickness of all overlays constant, presenting the discounted net present value of all alternatives (using Alternative 1 as the base case) versus total discounted maintenance cost, discounted at 12 percent. All quantities are economic values in millions of Egyptian pounds. The

FIGURE 5-3

EFFECTS OF OVERLAY FREQUENCY ON ECONOMIC PERFORMANCE



arrows indicate the direction of increasing overlay frequency.

Alternative 1 represents a light, but relatively uniform, level of overlay investment in the network, whereby the links are overlaid at roughness levels of 5000, 6000, and 7000 mm/km in road Classes I, II and III, respectively. This policy also produces the worst economic network performance of all of the alternatives analyzed. Alternative 2 represents a heavier, but still relatively uniform, level of investment with overlays at 4000, 5000, and 6000 mm/km, respectively. This produces a great improvement over Alternative 1, yielding a net present value of roughly LE 140 million for an incremental investment cost of less than LE 1 million. Alternative 3 represents a yet heavier, but still relatively uniform, investment level with overlays at roughness levels of 3000, 4000, and 5000 mm/km, respectively. This produces an incremental net present value of LE 106 million (over Alternative 2) at an incremental investment level of only LE 1 million. Thus, from the three cases of relatively uniform investments in the three road classes, we can conclude that the returns on investment, although decreasing as the investment level increases, are very large.

Alternative 5 in Figure 5-3 represents a very non-uniform investment level among the three road classes, with links in road Classes II and III never being overlaid and links in road Class I receiving overlays at a threshold roughness of 3000 mm/km. Although this investment strategy is superior to Alternative 1, it is clearly inferior to the moderate to heavy, uniform investment strategies as represented by Alternatives 2 and 3. In addition, it produces a highly skewed traffic distribution pattern which is viewed negatively by the road users, as will be discussed in a later section of this report. Alternative 4 represents another non-uniform investment proposal, wherein links in Class I are not overlaid and thosein Classes II and III are overlaid at roughness levels of 3000 and 4000 mm/km, respectively. This strategy is inferior economically to the non-uniform investment in Class I roads (as given by Alternative 5) and is also inferior to the moderate to heavy, uniform investment proposals as given by Alternatives 2 and 3. Indeed, the heavy, uniform strategy of Alternative 3, which is in a sense a "superposition" of the

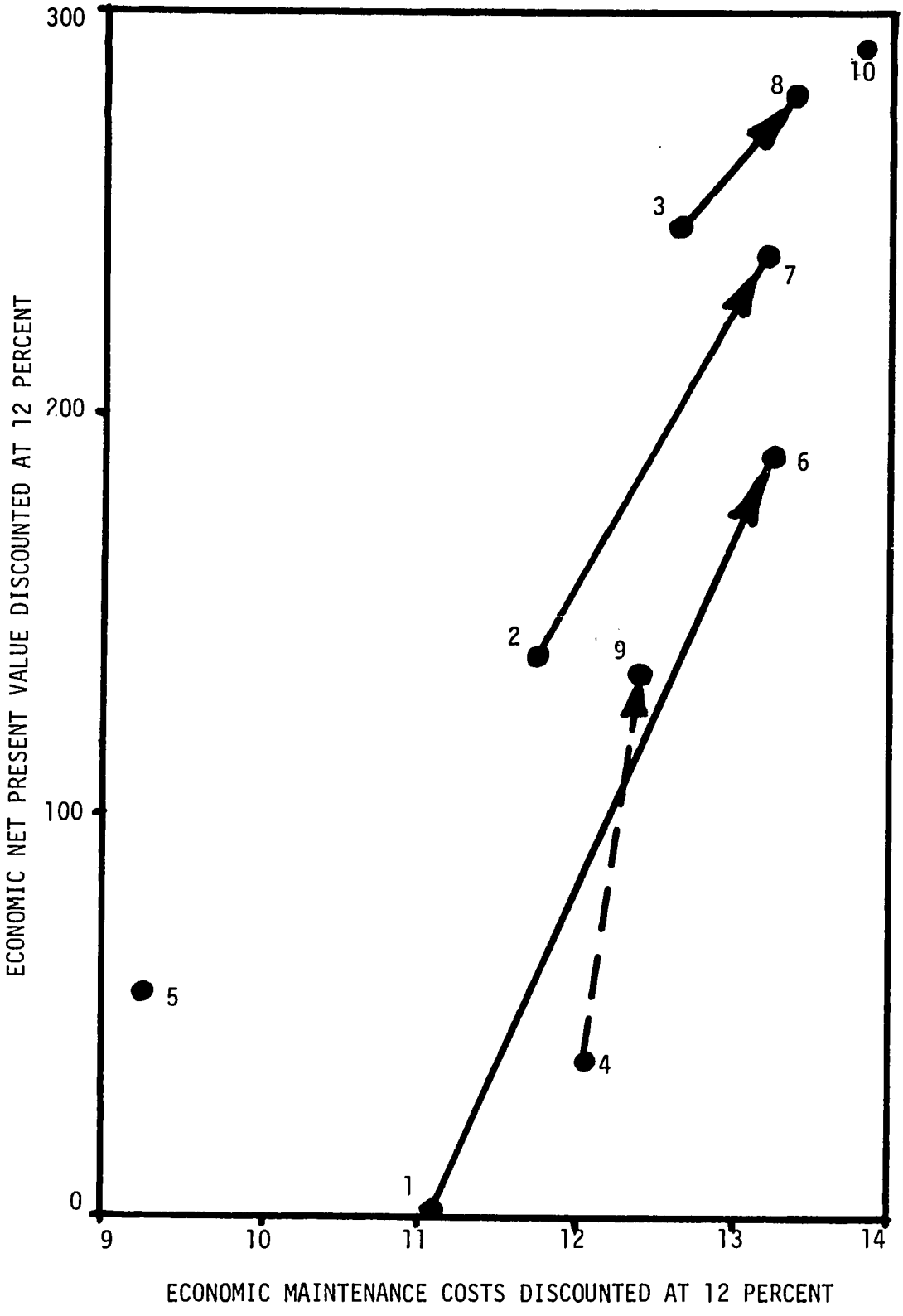
non-uniform investments, produces over twice the net present value as Alternatives 4 and 5 combined. However, Alternative 4 is preferable to Alternative 5 from the road user point of view, as measured by consumer surplus, as will be described later.

From the above, we can conclude that for the case of constant thickness of overlays throughout the system, the more intensive and uniform investment alternatives dominate the economic performance of the system. This is even more true when the consumer surplus criterion is used as a measure of network perfromance, as will be shown later.

Figure 5-4 shows the effects of varying overlay thickness while keeping the absolute and relative frequency of overlays among the three road classes constant. Alternative 6 reflects the same overlay frequencies as Alternative 1, namely at roughness levels of 5000, 6000, and 7000 mm/km, but incorporates overlays of thickness 80, 100, and 120 mm, respectively, instead of the 40 mm used in Alternatives 1 through 5. This investment strategy produces a net present value of LE 190 million at an incremental maintenance investment of slightly more than LE 2 million, producing an economic network performance inferior only to the heavy, uniform investments of Alternative 3 (of the alternatives discussed so far). Alternative 7 reflects the same overlay frequencies as Alternative 2, namely at roughness levels of 4000, 5000, and 6000 mm/km, but incorporates overlays of thickness 60, 80, and 100 mm, respectively, instead of the 40 mm overlays. Again, the economic return of the thicker overlays is impressive, LE 100 million on an incremental investment of LE 1.5 million, although, through a combination of the higher overlay frequency and thinner overlays, the transition is less massive than that indicated by the comparison of Alternatives 1 and 6. Alternative 8 reflects the uniform, heavy overlay frequencies of Alternative 3, namely at roughness levels of 3000, 4000, and 5000 mm/km, but uses overlays of thickness 40, 60, and 80 mm, respectively, rather than the uniform 40 mm overlays. Again the return is impressive, LE 34 million on an incremental investment of LE 0.7 million, although again there is less return on investment than generated through the 1-6 or 2-7 transitions. Alternative 9 reflects the same non-uniform investment distribution as Alternative 4,

FIGURE 5-4

EFFECTS OF OVERLAY THICKNESS ON ECONOMIC PERFORMANCE



namely no overlays in Class I links and frequent overlays in Class II and III links, although in this case the overlays are of thickness of 60 and 80 mm, respectively. The huge economic return of nearly LE 100 million on an incremental investment of less than one-half million indicates that, if only Class II and III links are to be overlaid, these overlays should be of substantial thickness.

From the above considerations, we can conclude that, given a relative frequency distribution for overlays in the various road classes, the heavier the overlays the greater the economic return, and the greater the user satisfaction with the system as measured by the consumer surplus criterion, which will be discussed later.

Figure 5-5 shows the economically "efficient" maintenance policy set, which is bounded by Alternatives 5, 3, 8, and 10. The common characteristic of this set of alternatives is that each specifies overlaying Class I roads at the most frequent level analyzed: i.e., 3000 mm/km with a 40 mm overlay. These overlay policies are summarized in Table 5-4. (This is not surprising, since a review of Table 5-2 indicates that 73% of the total traffic demand is between cities lying in the Class I corridor. What is surprising, however, is that so little of the potential benefits come solely from investments in this class.) From Table 5-4 and figure, we can see that the majority of the benefits come either from the high overlay frequencies on the Class II and III links contained in Policy 3 or from the increased thickness of these overlays presented by Policy 10, which performs the overlays much less frequently as measured by threshold roughness levels. This suggests that a hybrid policy consisting of the thick initial overlays of Policy 10 followed by the lighter, but more frequent overlays of Policy 3 would produce the greatest economic performance and user satisfaction with the network.

Figure 5-6 shows the discounted net present values of the various alternatives as a function of discount rate. As was expected, in a multi-link situation such as a network analysis where many separate investments may be undertaken in any given year, the ranking of the alternatives is not sensitive to the discount rate. This is shown by the "parallelness" of the net present values as indicated in the figure.

FIGURE 5-5
ECONOMICALLY "EFFICIENT" MAINTENANCE ALTERNATIVES

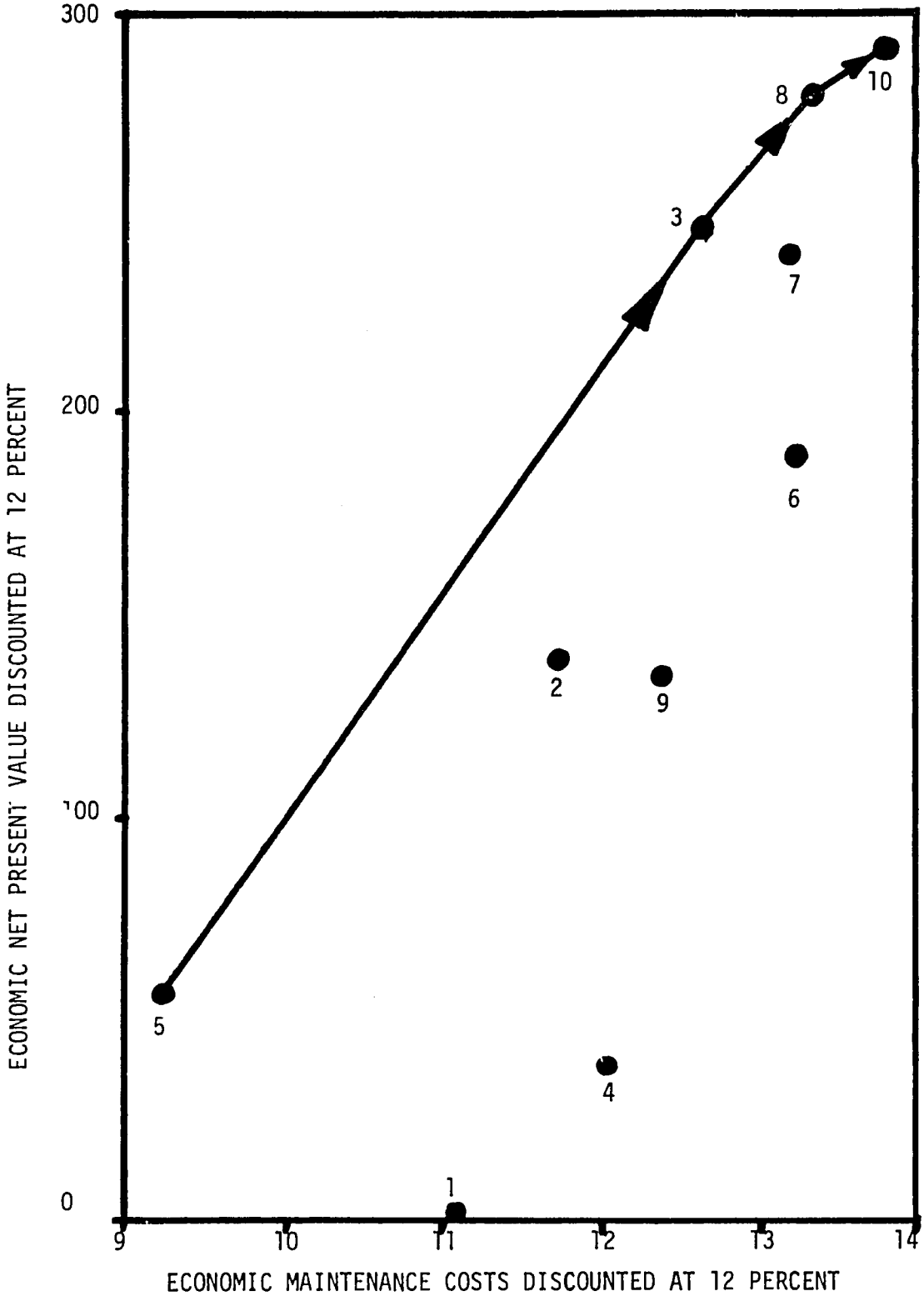


TABLE 5-4

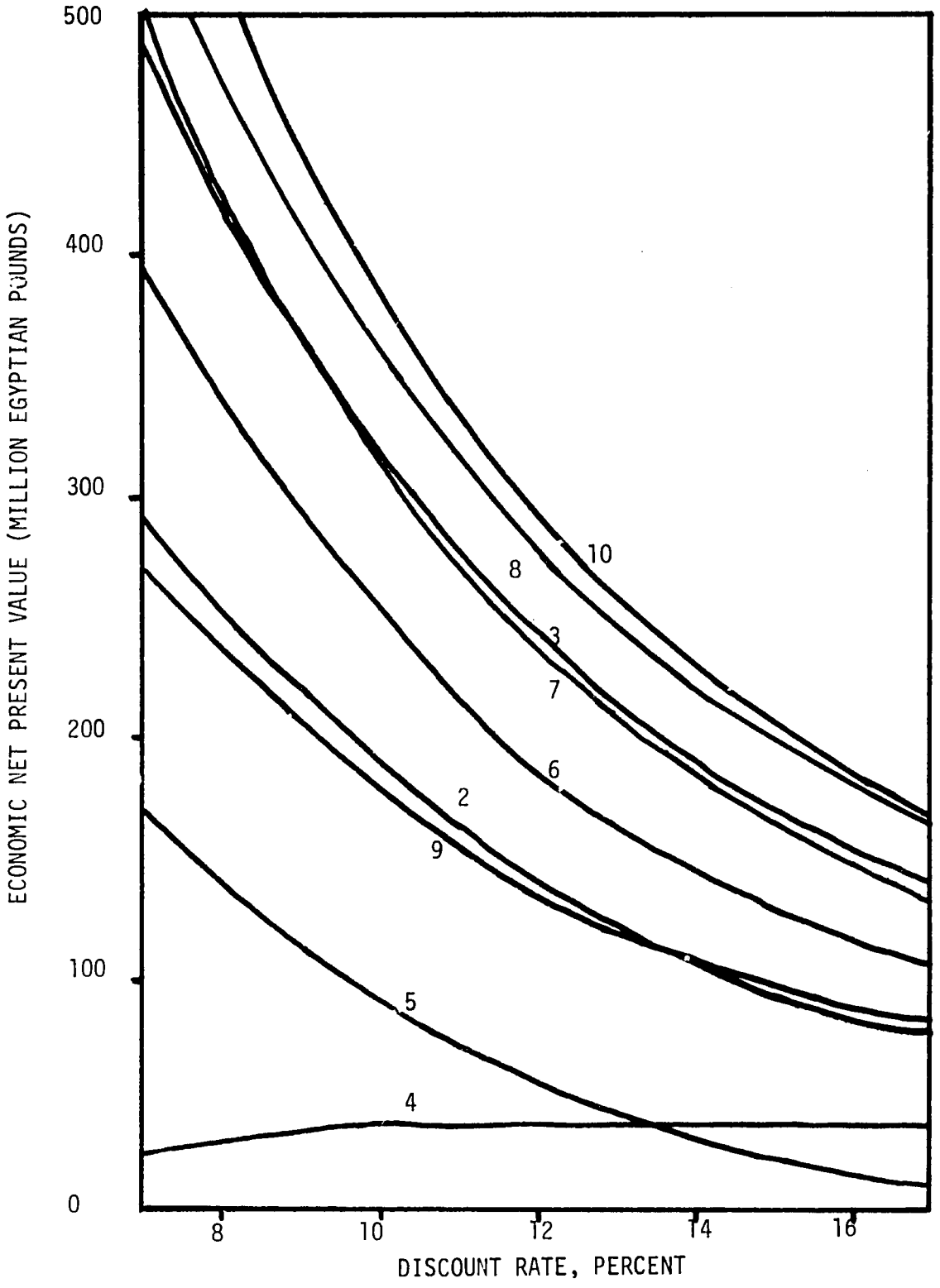
ECONOMICALLY "EFFICIENT" MAINTENANCE POLICIES

(mm/km) ⟶ (mm/km)

Policy	Net Present Value Million Egyptian Pounds Discounted at 12%	Overlay Frequency (mm/km and Thickness (mm) for: Class I	Class II	Class III
5	56	3000-40	Never	Never
3	246	3000-40	4000-40	5000-40
8	280	3000-40	4000-60	5000-80
10	293	3000-40	6000-100	7000-120

FIGURE 5-6

ECONOMIC NET PRESENT VALUE AS A FUNCTION OF DISCOUNT RATE



5.2.2 Consumer Surplus Criterion

The discounted maintenance costs, vehicle operating cost, total costs, and net present values for all alternatives are shown in Table 5-5. Also shown is the net consumer surplus of each alternative. The consumer surplus is a measure of the "user satisfaction" with they system, and in the current case is taken as the sum of the actual economic costs of the system and the difference between the actual and perceived financial costs of the system. In the terms incorporated within the Road Investment Analysis Model, the actual cost of using the system may be written as follows:

$$VOC_{actual} = \sum_{O\text{-}D} \sum_{paths\ i} \frac{e^{-\theta GP_i} . GP_i}{\sum_{paths\ i} e^{-\theta GP_i}}$$

and the perceived costs of using the system may be written as

$$VOC_{perceived} = \sum_{O\text{-}D} \frac{1}{\theta} \ln \left(\sum_{paths\ i} e^{-\theta GP_i} \right)$$

where:

VOC_{actual} = the actual cost of using the system

$VOC_{perceived}$ = the perceived cost of using the system

θ = the diversion intensity parameter discussed previously

GP_i = the actual cost of using path i between an O-D pair

and the summation is overall O-D pairs.

Thus, the difference between the actual and perceived cost of the system is a "proxy" measure for the user satisfaction with the system. The greater the difference, the less the users of the system think they are actually paying with regards to the actual cost of using the system. In another sense, the greater the difference between the actual and perceived costs, the more route-choice options are available to the user, since in the case of only one route the actual and perceived costs are identical. In the current case study, the difference between the actual and perceived costs is taken as the measure of network performance, and hence as a benefit to be added to the economic performance of the system.

Using this new measure of system performance, which is included in Table 5-5, we can again rank the network performance of the various maintenance alternatives. Figure 5-7 shows both the discounted net present value and the discounted net consumer surplus of all alternatives (measured against Alternative 1) plotted against the discounted total maintenance investment, discounted at 12 percent. From the figure, we can see that the relative ranking of the various alternatives is largely unchanged, and that the same set of maintenance alternatives which is economically "efficient" is also the efficient set from the consumer surplus criterion. All of the non-uniform investment alternatives (4, 5, and 9) perform less well under the consumer surplus criterion than under the strict economic efficiency criterion, most notably Alternative 5, which is to invest only in the primary links. This indicates that, from a user satisfaction point of view, stressing one road class over another is highly disadvantageous, and that a uniform level of investment is to be preferred. Although policies with maximum investment in the primary system, which handles at a minimum 73% of the total demand, are still dominant, those policies which also incorporate heavy investments in the secondary and tertiary networks (Alternatives 3, 8, and 10) produce much higher overall perfromance, as measured both by the economic efficiency and user satisfaction (consumer surplus) of the system.

5.3 RETURNS ON MAINTENANCE INVESTMENTS

To explain the huge returns in the road network to the proposed maintenance investments, it is useful to study Figure 5-8. The figure shows the average roughness reduction in mm/km which must be maintained over a one year period such that the resulting vehicle operating cost savings equal the cost of a 40 mm overlay. One can see why the "economically efficient" set of maintenance alternatives includes the heaviest investments in the primary links, since even an average annual roughness reduction of 500 mm/km will pay for itself in less than one year (the overlay threshold of 3000 mm/km means an average reduction of approximately 1500 mm/km, since the model assumes that an asphalt concrete overlay restores the riding surface to a roughness level of 1500 mm/km.) Figure 5-8 was derived on an annual basis so that the results would not

TABLE 5-5

ECONOMIC PERFORMANCE SUMMARY
(Million Egyptian Pounds Discounted at 12%)

Alternative	Maintenance Costs	Vehicle Operating Costs	Total Costs	Net Present Value*	Net Consumer Surplus*
1	11.13	1867	1878	0.0	0.0
2	11.73	1727	1739	139.1	137.0
3	12.65	1619	1632	246.3	254.4
4	12.07	1829	1841	37.6	35.8
5	9.24	1813	1822	56.0	11.6
6	13.27	1675	1688	189.8	190.9
7	13.18	1625	1638	240.3	243.8
8	13.41	1585	1598	279.8	292.8
9	12.43	1729	1741	136.9	130.2
10	13.86	1571	1585	293.0	295.9

*Net Present Value and Net Consumer Surplus are with respect to Alternative 1.

FIGURE 5-7

ECONOMICALLY "EFFICIENT" MAINTENANCE ALTERNATIVES FROM CONSUMER SURPLUS CRITERION

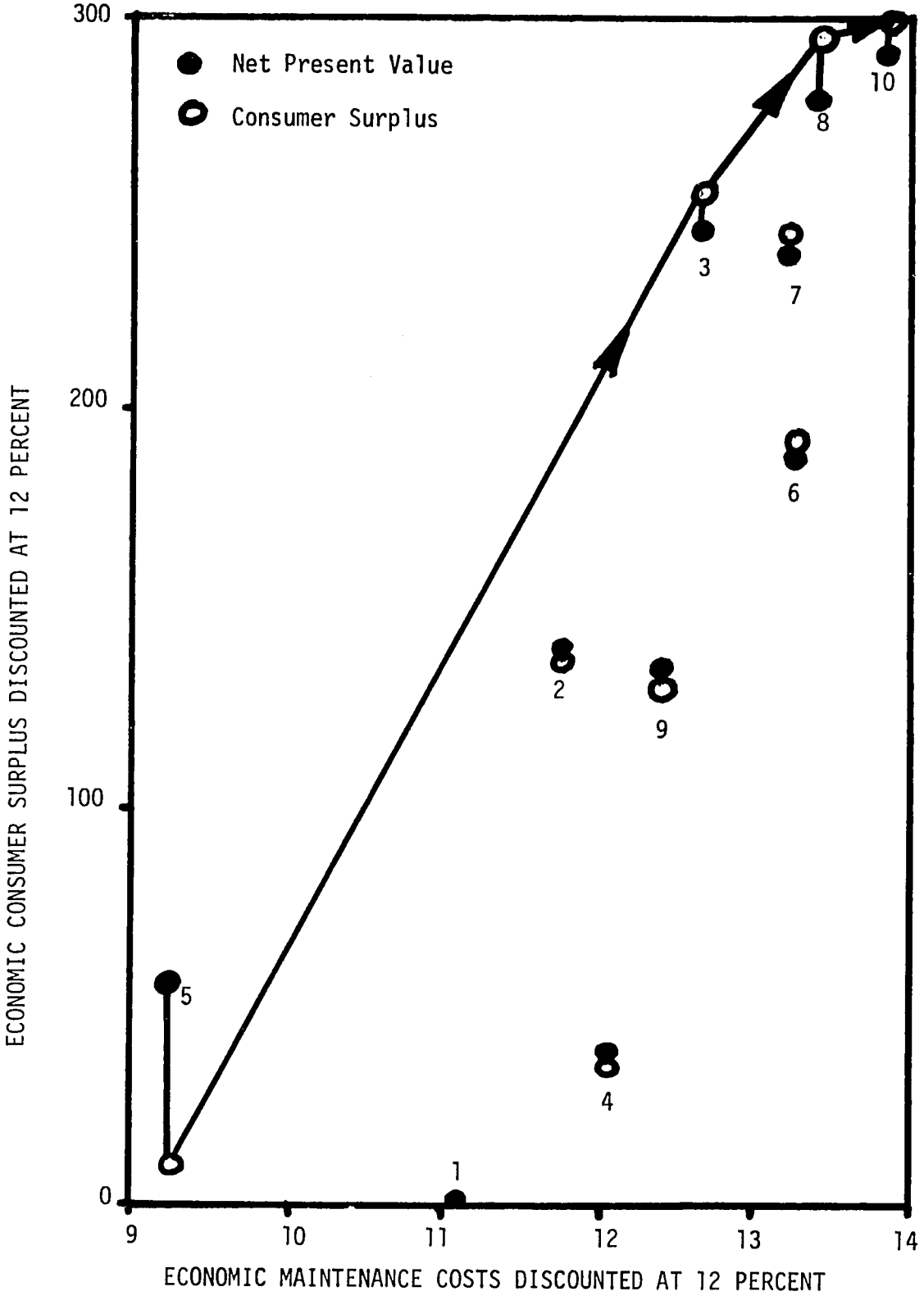
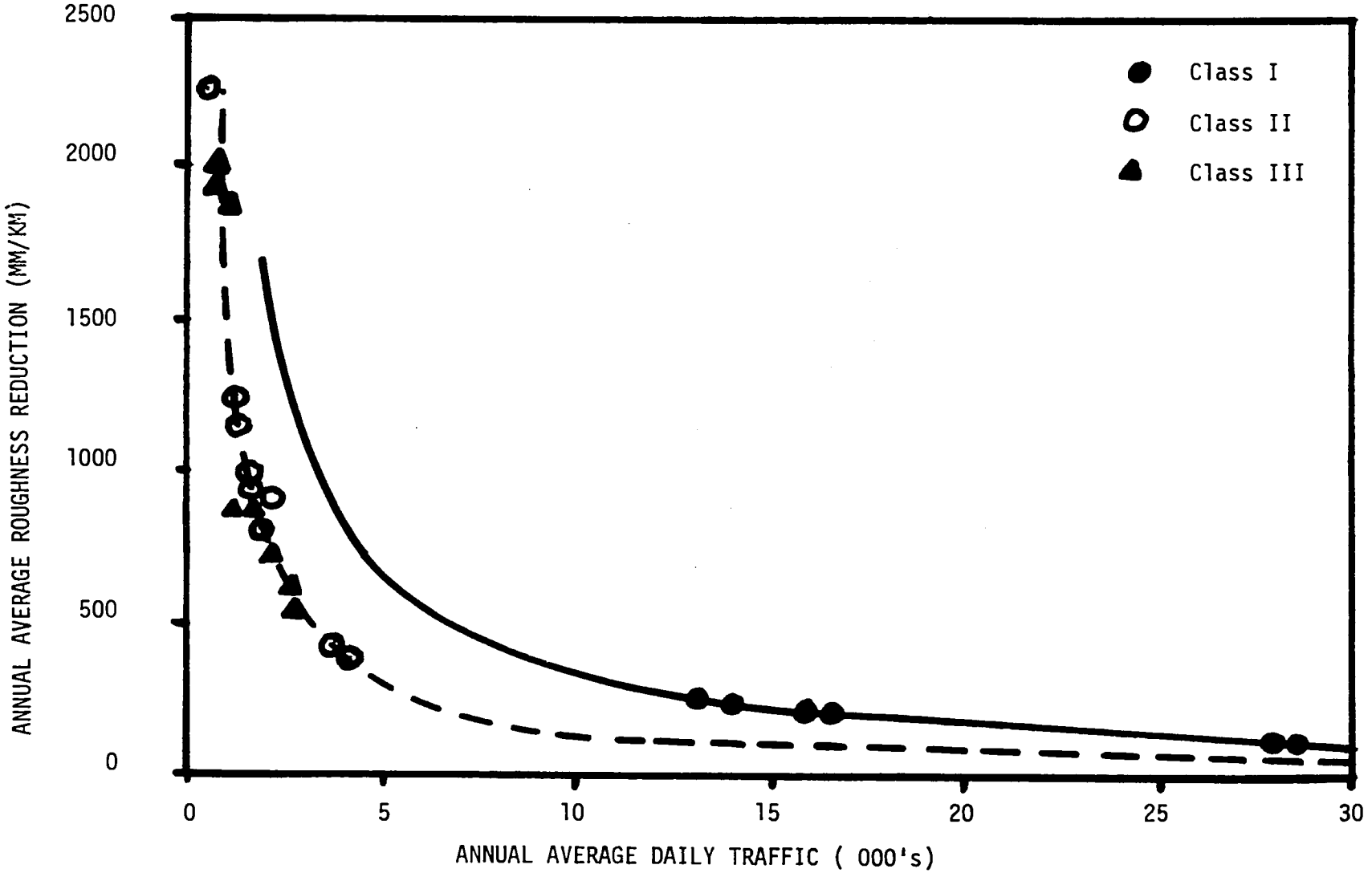


FIGURE 5-8
AVERAGE ROUGHNESS REDUCTIONS VERSUS AVERAGE ANNUAL DAILY TRAFFIC TO EQUATE ANNUAL USER SAVINGS WITH THE COST OF A 40 MM OVERLAY



be affected by the chosen discount rate. From the graph, we can see that the secondary and tertiary links require either a greater roughness reduction or a longer time period within which to accumulate benefits in order to achieve the same level of return as is available in the primary system, requiring either frequent, light overlays to maintain the riding quality or infrequent, heavy overlays to reduce the rate of road deterioration. The economic returns of both of these policies have been discussed previously.

5.4 CONCLUSIONS

From the above discussion, the following summary can be made. A highway transportation planning framework developed at M.I.T., the Road Investment Analysis Model, has been successfully applied to the analysis and planning of highway network investment decisions in Egypt. The disaggregate origin-destination survey data was used to calibrate the probabilistic traffic assignment diversion parameter to Egyptian conditions, yielding a value of 1.0.

Ten alternative maintenance policies were analyzed over the network study zone, reflecting three types of investment concerns important to the Egyptian Transport Planning Authority. First was the question of the relative frequency of the maintenance activities, in this case asphalt concrete overlays, which affect the mean road surface condition of each road class. Second was the relative magnitude of the investments as reflected in overlay thickness, which affects the rate of future deterioration of the riding surface in each road class. And third, was the question of the relative levels of investment among the three road classes - primary, secondary, and tertiary - to achieve the most effective overall investment strategy in the network.

The economic analysis indicated that the more uniform the investment levels among the road classes, the higher the economic performance of the network. Additionally, the heavier the level of investment, the greater was the economic return from that investment, given that the investment was distributed fairly evenly among the various road classes. The best alternative analyzed was found to consist of frequent, light

overlays on the primary links, which as a corridor represent at least 73% of the total traffic demand, and infrequent, heavy overlays on the secondary and tertiary links. However, since this alternative was only marginally better (considering all alternatives) than a policy of frequent, light overlays throughout the system, we conclude that the optimum maintenance overlay policy would consist of frequent, light overlays on the primary system (where additional structural strength is not required) and initial heavy overlays followed by frequent, light overlays on the secondary and tertiary systems (where additional structural strength is needed to meet future traffic demands). These conclusions held true whether the system was judged on strict economic efficiency or on user satisfaction, as measured by the consumer surplus criterion.

In considering the above conclusions, one must bear in mind the limitations of the model, which does not include the effects of congestion, roadway occupancy during maintenance and rehabilitation operations, motorized/non-motorized vehicle interaction, or maintenance resource or capacity constraints. However, the predicted economic returns seemed so large that these considerations would probably not alter the general findings of the analysis.

CHAPTER 6. IMPLICATIONS OF ANALYSIS RESULTS FOR ROAD INVESTMENTS IN EGYPT

The results presented in the previous two chapters summarized the performance of links which represent only slightly more than three percent of the Egyptian paved road network. In this section we wish to synthesize the link and network results, and extrapolate the findings to the entire Egyptian road network, which contains 12319 kilometers of paved roads.

This may be most easily done by examining the per kilometer performances of the links and network under the various alternatives analyzed. Since the link results are inherently more disaggregate than the network results, they may be more readily extended to other similar roads not analyzed in the present study. For establishing the total levels of investments required, however, the network results are more suitable, as will be discussed below.

6.1 Implications of Link Results

Table 6-1 presents the pertinent link results, taken from Table 4-1, normalized by link length to obtain unit construction costs, maintenance costs, and net present values in economic terms. The net present values are with respect to alternative EXIS, the discount rate is 12%, and the analysis period is 1977 through 1995. Inspection of this table indicates that, within a given road class, per kilometer investment costs (construction and maintenance) are nearly constant, while per kilometer returns (net present values) show a considerable degree of variation, reflecting the effects of different traffic volumes and compositions on the various links.

To illustrate this more clearly, Table 6-2 presents the mean and standard deviation of the investment costs and returns by road class for the various alternatives. The links were classified in the following manner (see Figure 5-2):

Class I - Links 1, 2, 3, 4, 5, 6
Class II - Links 7, 9, 16, 17, 18, 19, 20, 21, 22, 23
Class III- Links 8, 10, 11, 12, 13, 14, 15, 24, 25

As can be seen from the table, the per kilometer construction costs are constant, as would be expected since we are dealing with structural overlays,

TABLE 6-1

PER KILOMETER LINK INVESTMENTS AND RETURNS (MILLION EGYPTIAN POUNDS DISCOUNTED AT 12%)

No.	Link	Alt.	Construction Costs	Maintenance Costs	Net Present* Value
1	QBTK	EXIS	0.000	0.016	--
		PMXS	0.042	0.024	-0.882
	(20)**	HACS	0.059	0.017	0.790
		PMXR	0.042	0.022	-0.804
		HACR	0.059	0.020	0.947
2	TKBN	EXIS	0.000	0.016	--
		PMXS	0.042	0.024	0.960
	(15)	HACS	0.059	0.017	2.825
		PMXR	0.042	0.025	1.384
		HACR	0.059	0.020	3.063
3	TNTW	EXIS	0.000	0.016	--
		PMXS	0.042	0.024	0.726
	(26)	HACS	0.059	0.017	1.897
		PMXR	0.042	0.025	1.013
		HACR	0.059	0.020	2.044
4	BNQS	EXIS	0.000	0.016	--
		PMXS	0.042	0.024	0.800
	(12)	HACS	0.059	0.017	1.656
		PMXR	0.042	0.025	0.989
		HACR	0.059	0.020	1.760
5	QSBS	EXIS	0.000	0.016	--
		PMXS	0.042	0.024	0.982
	(12)	HACS	0.059	0.017	1.987
		PMXR	0.042	0.025	1.206
		HACR	0.059	0.020	2.111
6	BSTN	EXIS	0.000	0.016	--
		PMXS	0.042	0.024	0.914
	(20)	HACS	0.059	0.017	1.869
		PMXR	0.042	0.025	1.126
		HACR	0.059	0.020	1.986
7	QSSH	EXIS	0.000	0.015	--
		PMXS	0.017	0.019	-0.019
	(12)	HACS	0.024	0.015	0.110
		PMXR	0.017	0.017	-0.018
		HACR	0.024	0.017	0.122

No.	Link	Alt	Construction Costs	Maintenance Costs	Net Present* Value
8	BGTM	EXIS	0.000	0.015	--
		PMXS	0.017	0.019	0.392
	(23)	HACS	0.023	0.015	0.515
		PMXR	0.017	0.021	0.500
		HACR	0.023	0.017	0.535
9	QBKN	EXIS	0.000	0.015	--
		PMXS	0.017	0.019	0.426
	(9.6)	HACS	0.023	0.016	0.448
		PMXR	0.017	0.019	0.456
		HACR	0.023	0.017	0.458
10	KNTM	EXIS	0.000	0.015	--
		PMXS	0.017	0.018	0.231
	(56)	HACS	0.023	0.015	0.431
		PMXR	0.017	0.023	0.402
		HACR	0.023	0.017	0.407
11	KNBL	EXIS	0.000	0.015	--
		PMXS	0.017	0.018	0.343
	(21.9)	HACS	0.023	0.015	0.586
		PMXR	0.017	0.022	0.575
		HACR	0.023	0.017	0.638
12	BLTK	EXIS	0.000	0.015	--
		PMXS	0.017	0.019	0.253
	(4)	HACS	0.024	0.015	0.367
		PMXR	0.017	0.022	0.372
		HACR	0.024	0.017	0.385
13	BLBN	EXIS	0.000	0.015	--
		PMXS	0.017	0.018	0.345
	(9.1)	HACS	0.024	0.015	0.589
		PMXR	0.017	0.022	0.578
		HACR	0.024	0.017	0.642
14	ASSN	EXIS	0.000	0.015	--
		PMXS	0.017	0.018	0.258
	(9)	HACS	0.023	0.015	0.455
		PMXR	0.017	0.022	0.437
		HACR	0.023	0.017	0.485
15	SDBB	EXIS	0.000	0.015	--
		PMXS	0.017	0.018	0.140
	(17)	HACS	0.023	0.015	0.171
		PMXR	0.017	0.019	0.164
		HACR	0.023	0.017	0.175

No.	Link	Alt	Construction Costs	Maintenance Costs	Net Present* Value
16	BSSH	EXIS	0.000	0.015	--
		PMXS	0.018	0.018	0.315
	(12)	HACS	0.025	0.015	0.634
		PMXR	0.018	0.023	0.573
		HACR	0.025	0.017	0.703
17	BBTN	EXIS	0.000	0.015	--
		PMXS	0.017	0.018	0.286
	(11)	HACS	0.023	0.015	0.487
		PMXR	0.017	0.022	0.467
		HACR	0.023	0.017	0.514
18	KNSN	EXIS	0.000	0.015	--
		PMXS	0.017	0.018	0.230
	(18)	HACS	0.024	0.015	0.650
		PMXR	0.017	0.023	0.533
		HACR	0.024	0.019	0.849
19	SNBG	EXIS	0.000	0.015	--
		PMXS	0.017	0.018	0.266
	(14)	HACS	0.024	0.015	0.748
		PMXR	0.017	0.023	0.615
		HACR	0.024	0.019	0.978
20	BGSH	EXIS	0.000	0.015	--
		PMXS	0.017	0.018	0.277
	(13)	HACS	0.023	0.015	0.570
		PMXR	0.017	0.022	0.512
		HACR	0.023	0.017	0.630
21	SHKM	EXIS	0.000	0.015	--
		PMXS	0.017	0.018	0.286
	(5)	HACS	0.023	0.015	0.487
		PMXR	0.017	0.022	0.467
		HACR	0.023	0.017	0.514
22	KMBB	EXIS	0.000	0.015	--
		PMXS	0.017	0.018	0.286
	(9)	HACS	0.023	0.015	0.487
		PMXR	0.017	0.022	0.467
		HACR	0.023	0.017	0.514
23	BNBG	EXIS	0.000	0.015	--
		PMXS	0.017	0.018	0.151
	(18)	HACS	0.024	0.015	0.256
		PMXR	0.017	0.021	0.248
		HACR	0.024	0.017	0.270

No.	Link	Alt	Construction Costs	Maintenance Costs	Net Present* Value
24	KMSD	EXIS	0.000	0.015	--
		PMXS	0.017	0.018	0.128
	(19)	HACS	0.023	0.015	0.176
		PMXR	0.017	0.019	0.178
		HACR	0.023	0.017	0.182
25	TMTW	EXIS	0.000	0.015	--
		PMXS	0.017	0.018	0.056
	(36)	HACS	0.023	0.015	0.210
		PMXR	0.017	0.022	0.211
		HACR	0.023	0.022	0.592

* Net Present Value is with respect to alternative EXIS

** Link Length in kilometers

TABLE 6-2

MEAN INVESTMENTS AND RETURNS BY ROAD CLASS
(THOUSAND EGYPTIAN POUNDS DISCOUNTED AT 12%)

Road Class	Alt.	Per Kilometer: Construction Costs	Maintenance Costs	Net Present Value[a]
I[b]	EXIS	0 (0)[c]	16 (0)	---
	PMXS	42 (0)	24 (0)	876 (110)
(238)[d]	HACS	59 (0)	17 (0)	2047 (452)
	PMXR	42 (0)	25 (1)	1144 (160)
	HACR	59 (0)	20 (0)	2193 (504)
II	EXIS	0 (0)	15 (0)	---
	PMXS	17 (0)	18 (0)	250 (117)
(10,282)	HACS	24 (1)	15 (0)	488 (189)
	PMXR	17 (0)	21 (2)	432 (186)
	HACR	24 (1)	17 (1)	555 (253)
III	EXIS	0 (0)	15 (0)	---
	PMXS	17 (0)	18 (0)	238 (113)
(1,799)	HACS	23 (0)	15 (0)	389 (168)
	PMXR	17 (0)	21 (1)	380 (163)
	HACR	23 (0)	18 (2)	449 (178)

a) Net Present Value is with respect to alternative EXIS

b) Does not include link QBTK, which had an extremely high structural number

c) Numbers in parentheses are standard deviations

d) Total national kilometrage of the road class

except within Class II, where a slight variation exists due to the difference in widths (6 and 6.5m) within this class. The maintenance costs are also constant, except for small variations in the responsive policies (HACR and PMXR), which is also to be expected, since in those policies the maintenance performed is a function of road condition. However, the smallness of the variation is interesting, indicating a fairly uniform structural performance of the roads within each class, for a given investment alternative. The per kilometer returns, the net present values of the alternatives, are, however, far from constant, with the variations in the secondary and tertiary roads being considerably higher than the variation within the primary class. This reflects the greater variations in traffic volumes and compositions within these classes as compared with the primary class.

According to a recent report (1), the Egyptian paved road network comprises the following:

Class I - 238 Km
Class II- 10,282 Km
Class III- 1,799 Km

for a total of 12,319 kilometers. Table 6-3 presents the discounted capital (construction and maintenance) costs extrapolated to this larger Egyptian network for the various link alternatives. Since the variation in investment costs were so small, they were ignored, and only the mean values were used. The table indicates that the present economic worth of capital investments through 1995, discounted at 12%, would range from a low of LE185 million in the do-nothing case (alternative EXIS) to approximately LE500 million for the overlay options analyzed. These massive investment levels will be discussed at the end of this section.

One cannot meaningfully talk of investment levels without also describing the returns on those investments. Table 6-4 presents the range of net present values (plus and minus one standard deviation) produced by the various overlay options as compared to the do-nothing case. These were produced by taking the per kilometer performance values in each road class and multiplying by the total national kilometrage within that road class, to arrive at the national benefits associated with each alternative. Although the unit benefits were substantially greater in the primary road network (see Table 6-2), the national

TABLE 6-3

CAPITAL COSTS ON TOTAL EGYPTIAN ROAD NETWORK
(MILLION EGYPTIAN POUNDS DISCOUNTED AT 12%)

	Road Class			
Alternative	I	II	III	Total
EXIS	4	154	27	185
PMXS	16	360	63	439
HACS	18	401	68	487
PMXR	16	391	68	475
HACR	19	422	74	515

TABLE 6-4

RANGE OF RETURNS ON TOTAL EGYPTIAN ROAD NETWORK
(MILLION EGYPTIAN POUNDS DISCOUNTED AT 12%)

		Net Present Value*		
Class	Alt.	Minus Sigma	Mean	Plus Sigma
I	PMXS	182	208	234
	HACS	379	487	595
(238)**	PMXR	234	272	310
	HACR	402	522	642
II	PMXS	1368	2571	3774
	HACS	3075	5018	6961
(10,282)	PMXR	2530	4442	6354
	HACR	3106	5707	8308
III	PMXS	225	428	631
	HACS	398	700	1002
(1,799)	PMXR	391	684	977
	HACR	488	808	1128
ALL	PMXS	1775	3207	4639
	HACS	3852	6205	8558
(12,319)	PMXR	3155	5398	7641
	HACR	3996	7037	10078

* Net Present Value is with respect to alternative EXIS

** Total national kilometrage of the road class

benefits accrue primarily from the investments in the secondary class. This road class comprises 83% of the total Egyptian paved network, and accounts for from 80 to 82% of the total benefits. The national net benefits are truly massive, ranging in a mean value sense of from 3 to 7 thousand million Egyptian pounds, or, expressed in another way, from 7 to 14 times the levels of investment discussed earlier. The total benefits accruing from the primary and tertiary networks are roughly comparable, despite the large difference in total kilometrage within the two classes, reflecting the difference in traffic levels.

6.2 Implications of Network Results

The results of the network analysis are not so readily extendable to the entire road network, since they aggregate and interrelate the performance of the various links in a systems fashion. Additionally, the network study zone had a relatively uniform kilometrage distribution within the three classes, which is not representative of the greater Egyptian network. However, it presented in close proximity links of wide-ranging quality and standard, and thus might be quite representative of the performance of the entire system as the proposed investments are programmed and implemented within the larger system. Also, in the network analysis the investments were performed as they were needed (demand responsive), whereas the link analysis, in effect, reconstructed the entire system of links in the same year (1980).

From the above considerations, it was considered appropriate to expand the per kilometer network investment and performance measures to the entire Egyptian paved road network by multiplying by the total national paved kilometrage. The results of this are presented in Table 6-5 for the ten network alternatives described in Chapter 5. The net present values were obtained as the difference in total economic costs through 1995, discounted at 12%, of each alternative and the total link costs under alternative EXIS. Again we see that the per kilometer investment costs (maintenance costs, since construction was not performed in the network analysis due to the difficulty of scheduling projects) are quite constant, while the net present values show considerable variation. The national net present values ranged from 0 to 6 thousand million Egyptian pounds.

TABLE 6-5

NETWORK INVESTMENT AND RETURNS[a]

(MILLION EGYPTIAN POUNDS DISCOUNTED AT 12%)

Alternative	Per Kilometer Maintenance Costs	Per Kilometer Net Present Value[b]	Total Road Network[c] Net Present Value
1	0.028	0.008	99
2	0.029	0.217	2673
3	0.032	0.428	5273
4	0.030	0.131	1614
5	0.023	-0.011	-136
6	0.033	0.278	3425
7	0.033	0.346	4262
8	0.034	0.501	6172
9	0.031	0.174	2144
10	0.035	0.480	5913
Mean	0.031	0.255	3144
Standard Deviation	0.004	0.184	2268

a) Analysis period of 1977 to 1995

b) Net Present Value is with respect to link alternative EXIS

c) Total road network of 12,319 kilometers

To visualize the implications of the above results, it is useful to study Figure 6-1, which presents the total Egyptian road network net present value versus the average per kilometer investment costs. All net present values are with respect to alternative EXIS, discounted at 12%. For the link alternatives, the figure shows the range of returns (mean plus and minus one standard deviation), while for the network results each alternative is shown as a point and the resulting range (mean plus and minus one standard deviation) is shown by the dashed bar. All labels are as given in Chapters and 5.

The range of returns predicted by the link and network results are similar. However, the magnitude of the net benefits predicted by the network extrapolation is smaller than those predicted by the superior link extrapolations, as are the incremental investment costs over alternative EXIS. Both are smaller by 35 to 40%. This is intuitive if one recollects the manner in which the two sets of analyses were performed: the link analysis performed the same investments on all links independently and with the same scheduling; while the network analysis performed ten specific investment policies encompassing all links simultaneously. Thus, at the network level, traffic could respond to each investment made in the system, reducing the demand for additional investments; at the link level, where traffic was "captive,"only investments in the link being analyzed could produce benefits, increasing the total investment demand of the system.

6.3 Implications for National Investment Requirements

Given the magnitude of the above investment levels and returns when discussing the entire Egyptian network, some mention must be made of the physical and fiscal requirements of these investments. For this it is convenient to investigate the predictions of the network analysis, since the total resources are predicted by the Road Investment Analysis Model. Also, the network predictions were more conservative of investment requirements, for the reasons discussed above. Table 6-6 presents the resource requirements derived by extrapolating the network results to the entire paved network. Given are the patching, surface dressing, overlay, and financial quantities consumed in the first five years of the analysis, 1977 through 1981. As

FIGURE 6-1
TOTAL EGYPTIAN ROAD NETWORK NET PRESENT VALUE
(THOUSAND MILLION EGYPTIAN POUNDS DISCOUNTED AT 12%)

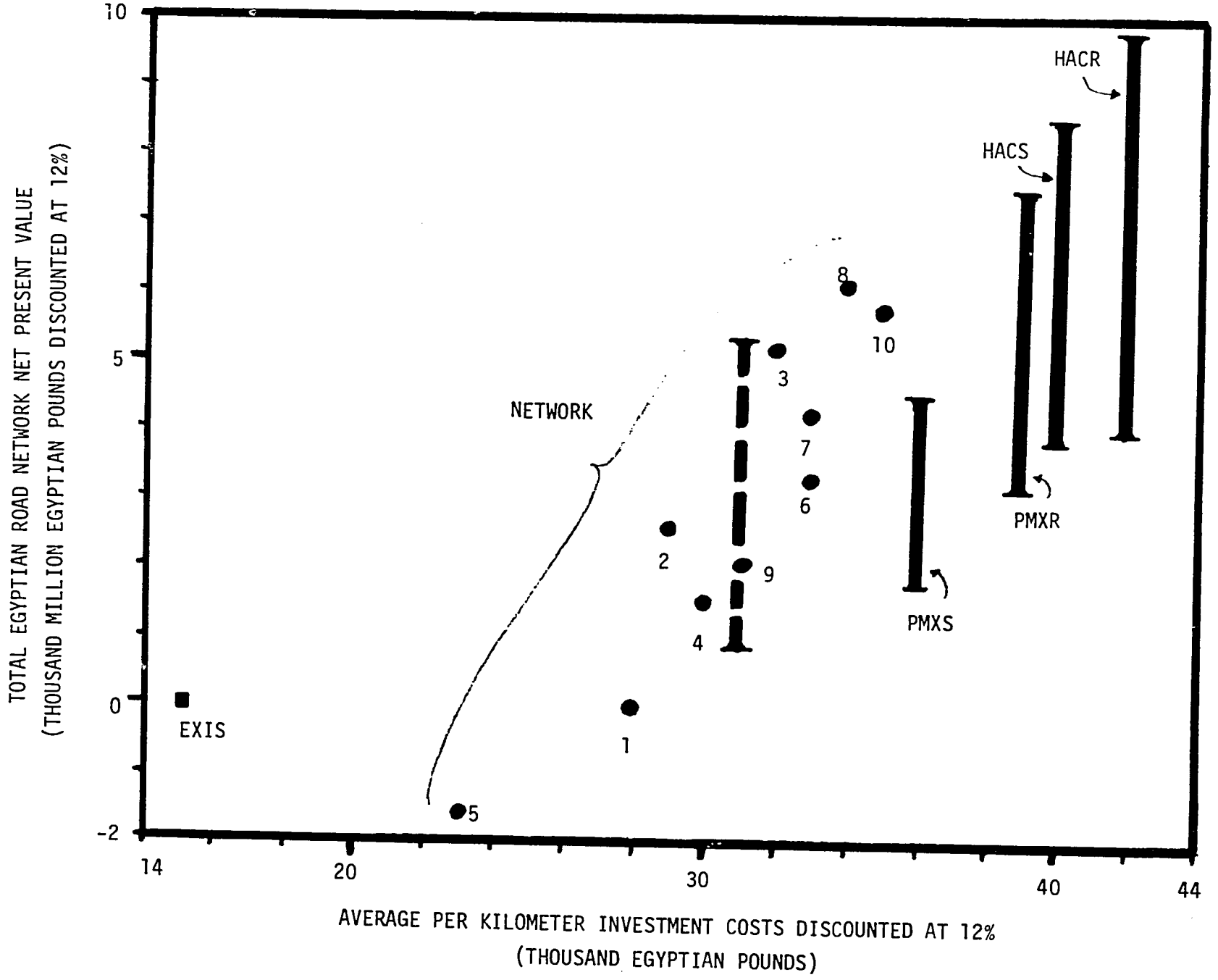


TABLE 6-6

MAINTENANCE QUANTITY SUMMARY: 1977-1981*

Alternative	Patching (Million Sq. M)	Surface Dressing (Million Sq. M)	Overlay (Million Cu. M)	Undiscounted Financial Cost (Million Egyptian Pounds)
1	2.99	145	2.27	126
2	2.88	132	2.66	139
3	2.82	98	3.97	184
4	2.76	86	3.53	164
5	2.43	148	1.19	82
6	2.84	118	5.41	246
7	2.78	101	4.44	203
8	2.75	100	4.75	216
9	2.75	100	4.17	192
10	2.84	118	6.37	284
Mean	2.78	115	3.88	184
Standard Deviation	0.14	21	1.53	59

*Maintenance quantities are for the entire Egyptian road network (12,319 Km)

would be expected given the nature of the analysis, the patching and surface dressing operations, which were constant over all policies but responsive to road conditions, show little variation in resource requirements, with mean values of 2.78 and 115 million square meters, respectively. Assuming constant annual investments in the first five years, this translates into 0.56 and 23 million sq. m/year, or an annual financial expenditure of 1.1 and 4.6 million Egyptian pounds for patching and surface dressing, respectively. The variation in financial cost reflects, to a large extent, the variation in overlay quantities produced by the different overlay policies analyzed. Again assuming constant annual investments in this period, overlay requirements would be .78 million cubic meters per year, at a financial cost of 31.1 million Egyptian pounds. The average annual financial maintenance budget for the above operations would be LE 36.8 million, or over 5 times the entire 1977 expenditure of the Roads and Bridges Organization of LE 6.9 million for non-city investments(2).

Table 6-7 shows the maintenance resource quantity summary for the 24 year period 1977 through 2000. From this we can see that the long-term quantities and financial requirements show much less variation than the short-term requirements. Also, the average annual investments decrease, indicating the proposed heavy initial investments are adequate for a considerable period of time. The average annual financial maintenance cost reduces to LE 22.6 million, which is still over 3 times the 1977 Roads and Bridges Organization expenditure level. The maintenance resource requirements likewise reduce to 0.55, 19.2, and 0.44 million units annually for patching, surface dressing, and overlaying, respectively.

6.4 Conclusions

In this chapter we have looked at the national implications of the link and network results for the Egyptian paved road network, and the resources required to produce these results. It was argued that, while not as adequate as an analysis of the network in its entirety, which is beyond the scope of this research, the extrapolations of average per kilometer investments and returns was sufficient to gauge the magnitude of national investment requirements and benefits. In addition, the extrapolations of the link and network results each provided valuable insights into the predictions of the other.

TABLE 6-7

MAINTENANCE QUANTITY SUMMARY: 1977-2000*

Alternative	Patching (Million Sq. M)	Surface Dressing (Million Sq. M)	Overlay (Million Cu. M)	Undiscounted Financial Cost (Million Egyptian Pounds)
1	14.28	551	8.42	476
2	14.16	460	10.52	541
3	14.10	397	12.61	612
4	13.49	472	9.86	516
5	6.45	464	6.06	348
6	13.78	473	11.53	583
7	13.92	438	11.97	594
8	14.07	387	12.33	599
9	13.60	536	9.42	511
10	13.83	426	13.38	648
Mean	13.17	460	10.61	543
Standard Deviation	2.37	53	2.23	87

*Maintenance quantities are for the entire Egyptian road network (12,319 Km)

The link extrapolations, which were the easier to perform due to the disaggregate and uncoupled results of the link evaluations, tend to overestimate both potential investment requirements and returns. This is due to the "captive" nature of the traffic and the fact that each link was analyzed independently. These extrapolations predicted national economic benefits of from 3 to 7 billion (thousand million) Egyptian pounds on investments of less than one-half billion, in a mean value sense. The returns ranged from 2 to 10 billion at the one standard deviation level.

The network extrapolations, which were compounded by the "non-representativeness" of the study zone when compared with the total network (which was actually one of the primary initial reasons for its selection), predicted significantly lower investment requirements and returns than the link extrapolations, typically by 30 to 40%. However, the "range of uncertainty" in both predictions seemed consistent, and indicated that returns of from 7 to 14 times the levels of investment may be anticipated.

The network extrapolations were used to project national maintenance resource and budgetary requirements, both in the first five years and through the end of this century. The average annual expenditures in each of the first five years was seen to be more than 5 times the 1977 level of expenditure, while the average annual expenditure through the year 2000 was smaller, but still more than 3 times the 1977 level. In addition, the total investment requirements in the national network were seen to stabilize over time.

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CHAPTER 7. SUMMARY AND RECOMMENDATIONS

7.1 Summary

A highway transportation planning framework developed at M.I.T., the Road Investment Analysis Model (RIAM), has been applied to the analysis and planning of highway investment decisions in Egypt at both the link, network and national levels. During the link evaluation phase, five reconstruction and subsequent maintenance policy alternatives were analyzed on each of twenty-five links independently, in a zone comprising roughly one-fourth of the paved road network of the Nile Delta. For each alternative and on each link, economic analyses of net present value, first year benefits, and internal rate of return were performed against the do-nothing alternative. Where data were lacking or unreliable, surveys were undertaken or engineering judgments were used.

The results of the twenty-five link-evaluation applications of the Road Investment Analysis Model indicated that there were four classes of link performance in the study zone under the proposed structural overlays and subsequent maintenance standards. These classes were:

(i) links which are in excellent present condition and for which the proposed investments may be postponed;

(ii) links which are in poor present condition and for which the proposed investments produce acceptable results. This means that the heavier structural overlay performs satisfactorily for the entire analysis period thus requiring no major subsequent maintenance investments;

(iii) links which are in poor present condition and which performed marginally under the proposed investments, in that the heavier structural overlay failed in from 5-14 years requiring major subsequent maintenance investments, and for which heavier initial investments should be considered; and

(iv) links which are of weak structural strength and poor present condition and which would have performed poorly under the proposed investments, in that both of the proposed structural overlays failed in less than 5 years and where all of the net benefits accrued from major subsequent maintenance investments, and for which heavier initial investments or reconstruction must be considered.

A tentative general finding which held true on all links analyzed was that, of the four post-construction maintenance policies studied, the one with the heaviest overlay dominated the economic analysis, independent of the effectiveness of the original double (asphalt over premix) overlay, which was the more extensive of the two construction options analyzed.

During the network evaluation phase the links in the study zone were analyzed simultaneously and as interdependent, being coupled through a stochastic traffic assignment procedure. Ten alternative maintenance policies were analyzed over the network study zone, reflecting three types of investment concerns important to the Egyptian Transport Planning Authority. Among the questions addressed were: (1) the relative frequency of the maintenance activities; (2) the relative magnitude of the investments as reflected in the overlay thickness; and (3) the relative levels of investment among the three road classes - primary, secondary, and tertiary - to achieve the most effective overall investment strategy in the network. The analysis indicated that the more uniform the investment levels among the road classes, the higher the economic performance of the network. Additionally, the heavier the level of investment, the greater was the economic return from that investment, given that the investment was distributed fairly evenly among the various road classes. The optimum alternative identified was found to consist of frequent, light overlays on the primary system (where additional structural strength is not required) and initial heavy overlays followed by frequent, light overlays on the secondary and tertiary systems (where additional structural strength is needed to meet future traffic demands). These results held true whether the performance was judged on economic efficiency or user satisfaction (consumer surplus).

The implications of the link and network analyses were then determined for the entire Egyptian paved road network. Returns on investment were found to range between 7 and 14 times the level of investment, while in turn these levels of investment were from 3 to 5 times greater than present levels of expenditure. The range of returns was consistent between the link and network extrapolations, although the network predictions were for investments and returns typically smaller than those of the link predictions by 30-40%. The returns on the proposed investments ranged from 3 to 7 billion (thousand million) Egyptian pounds.

7.2 Recommendations

The conclusions drawn from the analysis of the links within the study zone concern the areas of appropriate construction standards, as regards both structural capacity and riding quality; appropriate maintenance standards, both qualitative and quantitative; and data availability and reliability. The implications of these conclusions leads to the recommendations made below.

Construction Standards

The results of these applications of the Road Investment Analysis Model indicated that there were four classes of link performance under the proposed structural overlays. These classes were the following:

(a) Links in excellent present condition for which the proposed investments may be postponed:

1) QBTK Qalub--Touck
2) TKBN Touck--Banha
3) TNTW Tanta-Tawfikieh
4) BNQS Banha-Quesna
5) QSBS Quesna--Berket-el-Saab
6) BSTN Berket-el-Saab--Tanta
7) QSSH Quesna--Shibean-el-Koam

(b) Links in poor present condition for which the proposed investments produce good results:

8) BGTM Bagour--Tamaly
9) QBKN Qalub--Kanater
10) KNTM Kanater--Tamaly
11) KNBL Kanater--Biltan
12) BLTK Biltan--Touck
13) BLBN Biltan--Banha

14) ASSN Ashmoon--Santriss
15) SDBB Shohda--Babel
24) KMSD Kom-el-Akder--Shohda

(c) Links in poor present condition which respond marginally to the proposed investments and which require heavy subsequent maintenance investments, for which heavier initial investments should be considered.
16) BSSH Berket-el-Saab--Shibean-el-Koam
17) BBTN Babel--Tanta
18) KNSN Kanater--Santriss
19) SNBG Santriss-Bagour
20) BGSH Bagour-Shibean-el-Koam
21) SHKM Shibean-el-Koam--Kom-el-Akder
22) KMBB Kom-el-Akder--Babel
23) BNBG Banha--Bagour

(d) Links of weak structural strength and poor present condition which respond poorly to the proposed investments and where all of the net benefits accrue from subsequent maintenance investments, for which initial investments or reconstruction must be considered:
25) TMTW Tamaly--Tawfikieh

The precise construction standard which should be applied to each link is dependent upon three major factors: the cost of the overlay, the improvement in surface condition achieved, and the reduction in the rate of future deterioration or increment in structural strength. For the two construction overlays studied, the costs were determined by the volume of material placed; the resulting surface conditions were given; and the structural numbers of the pavements were increased by a specific amount.

The large net present values produced on those links in group a) above resulted not from the construction projects significantly reducing the rate of future deterioration, but rather through an improvement in the road surface condition produced by subsequent maintenance overlays which are assumed by the model to be of high quality. In reality, the majority of these overlays would have been postponed until these links had reached a more deteriorated condition. However, the results indicate that extremely

large benefits may be obtained by minimizing the roughness on these links, so that higher quality overlays should be considered in the future.

For the links in group b) above, the selection of proper construction standard is dominated by the large improvement in surface condition and reduction in the rate of future deterioration, in that the structural strengths of the overlaid payments seem well suited to the traffic volumes carried. The uncertainty in the investment decision, then, is in the reliability of the existing road conditions and structural capacities.

For the links in group c) above, which performed marginally under the proposed investments, the choice of design standards should consider higher initial investments than those analyzed here. If, however, the existing structural strengths have been underestimated, the proposed investments may indeed be appropriate. For these links, an accurate measure of structural capacity is of greater importance than are measures of existing surface conditions, since even the overlaid pavements subsequently require substantial maintenance investments.

For the links in group d) above, which responded poorly to the proposed investments, a choice of upgrading standards cannot be properly made without verification of the accuracy of the data on their existing structural strengths. Although some of these links are in an existing failed state, others are not. However, given the structural strengths and traffic volumes on these links, the existing conditions are almost irrelevant, as the model predictions are that these links, even if upgraded through the proposed investments, will almost immediately fail.

Maintenance Standards

Four maintenance policies were proposed for the links after the overlays, the significant differences between which were in the performing of asphaltic concrete overlays of 40 mm thickness. These policies were dependent on the type of construction overlay performed, as follows:

a) Premix overlay

-- a scheduled overlay in 1990 (PMXS)

--responsive overlays whenever the roughness exceeds 3500 mm/km, but not more frequently than every 5 years nor less frequently than every 10 years (PMXR)

b) Double (asphalt concrete over premix) overlay
--no scheduled overlays (HACS)
--responsive overlays whenever the roughness exceeds 3000 mm/km, but not more frequently than every 5 years nor less frequently than every 10 years (HACR)

In addition, the policies varied as to patching and surface dressing standards, but these did not contribute significantly to the outcomes of the analysis.*

Of these maintenance policies, the one most overlay-intensive, HACR, dominated the economic analysis on all links, independently of the effectiveness of the original double overlay, which was the more extensive of the two construction options analyzed. Thus, on all links studied, the heaviest construction and maintenance investments provided the greatest economic benefits. In almost all cases, the net present values increase as the investments increase, the exceptions being the ranking of alternatives HACS and PMXR, the merits of which are dependent on the quality assumed for the construction and maintenance overlays.

Since this trend of greater returns to greater investments held across all links, which varied tremendously in their conditions, traffic volumes, and structural capacities as well as in the reliability of these data items, we can conclude that maintenance and upgrading investments will be economically justifiable at considerably higher levels than we have analyzed in the link-evaluation phase of this study.

At the network level, ten alternative maintenance policies were analyzed over the network study zone, reflecting three types of investment concerns important to the Egyptian Transport Planning Authority. First was the

*The Road Investment Analysis Model does not relate the level of cracking to vehicle operating costs, so these items contributed only to maintenance costs.

question of the relative frequency of the maintenance activities, in this case asphalt concrete overlays, which affect the mean road surface condition of each road class. Second was the relative magnitude of the investments as reflected in overlay thickness, which affects the rate of future deterioration of the riding surface in each road class. And third, was the question of the relative levels of investment among the three road classes - primary, secondary, and tertiary - to achieve the most effective overall investment strategy in the network.

The economic analysis indicated that the more uniform the investment levels among the road classes, the higher the economic performance of the network. Additionally, the heavier the level of investment, the greater was the economic return from that investment, given that the investment was distributed fairly evenly among the various road classes. The best alternative analyzed was found to consist of frequent, light overlays on the primary links, which as a corridor represent at least 73% of the total traffic demand, and infrequent, heavy overlays on the secondary and tertiary links. However, since this alternative was only marginally better (considering all alternatives) than a policy of frequent, light overlays throughout the system, we conclude that the optimum maintenance overlay policy would consist of frequent, light overlays on the primary system (where additional structural strength is not required) and initial heavy overlays followed by frequent, light overlays on the secondary and tertiary systems (where additional structural strength is needed to meet future traffic demands). These conclusions held true whether the system was judged on strict economic efficiency or on user satisfaction, as measured by the consumer surplus criterion.

In considering the above conclusions, one must bear in mind the limitations of the model, which does not include the effects of congestion, roadway occupancy during maintenance and rehabilitation operations, motorized/non-motorized vehicle interaction, or maintenance resource or capacity constraints. Additionally, the reliability of the data used should be enhanced through further surveys and mechanical testing procedures, and additional testing equipment should be obtained. However, the predicted economic returns seemed so large that these considerations would probably not alter the general findings of the analysis.

At the national level, the projected investments and returns are enormous, with the required investments exceeding the present expenditure levels by a factor of 5 in the short term and 3 in the long term. While we do not doubt that extremely large benefits may accrue from the suggested investments, their very magnitude indicates that a further investigation of the proper investment level and scheduling for each link of the system should be undertaken. This scheduling and programming investigation would indicate the relative priorities of various link investments, and would provide a sound economic basis for approaching the international lending institutions whose support is essential for generating the very large levels of investments being proposed.