ROAD NETWORK ANALYSIS FOR TRANSPORTATION INVESTMENT IN EGYPT

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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. 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. 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 road network in Egypt comprises over 26,000 kilometers of roads with approximately 12,000 km paved and 14,000 km unpaved, and highway intercity 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 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 upgradings 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, to road transport investment decisions in Egypt, and to develop the necessary procedures for its modification and and adaptation to the local Egyptian conditions. The scope of the research effort during the first phase was to evaluate 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 twenty-five links independently (1). 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:

1. Links which are in excellent present condition and for which the proposed investments may be postponed;
2. 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;
3. 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
4. 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. Thus, on all links studied, the heaviest construction and maintenance investments produced the greatest economic net present values. This and the above performance classification are being reviewed in light of assumptions made during data collection. A visual inspection was made of representative links in the study zone to verify these predictions.

The link analyses disclosed several key data items which had to be obtained before the ensuing network analysis could be undertaken. These data items were collected by the Transport Planning Authority (road user costs), the Road and Waterway Authority (traffic counts and axle load distributions), and Cairo University (road deterioration relations) personnel. These data collection efforts are documented in a companion report to this study (2). In addition, the need for rapid and accurate road condition evaluation equipment was emphasized.

This paper 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 our previous work (1). 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 paper.

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 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 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 were not analyzed in this investigation.

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?

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 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 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 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

Figure 1. Nortern Egypt and the study zone.

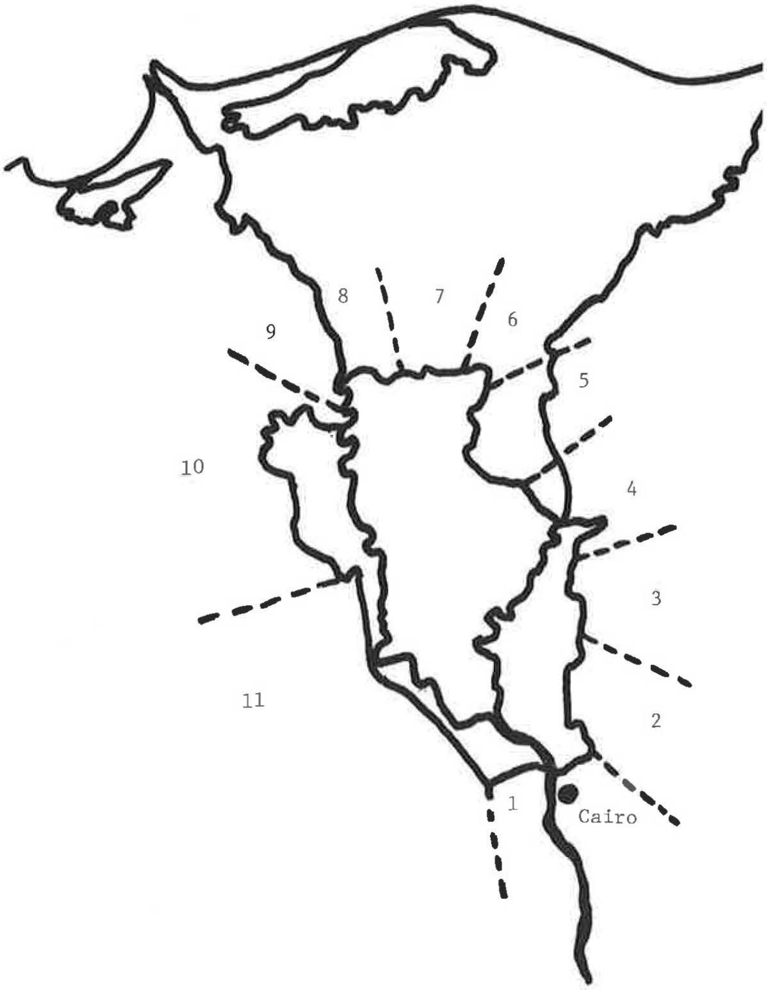
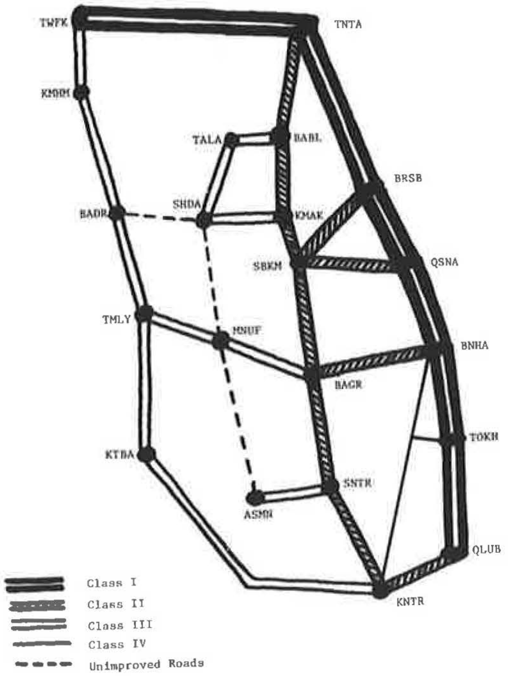


Figure 2. The Monofia and Qualubia Governorates road network.



Note: Class IV and unimproved roads were not analyzed due to lack of O-D data on these links.

Note: Node identifiers refer to village abbreviations.

Table 1. 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	--															
TOKH	609	--														
BNHA	12566	58	--													
QSNA	272	43	720	--												
BRSB	491	--	--	--	--											
TNTA	3165	--	472	201	238	--										
TWFK	11012	58	506	--	63	4590	--									
KMHM	723	--	--	--	--	291	--	--								
BADR	--	--	--	--	--	--	--	--	--							
TALA	145	--	40	--	--	450	--	--	--	--						
SHDA	109	--	--	44	--	71	--	--	--	--	--					
SBKM	969	--	626	508	416	900	291	--	--	76	663	--				
MNUF	628	--	69	68	--	--	691	180	656	--	--	128	--			
BAGR	806	66	--	--	--	--	--	--	--	--	--	67	181	--		
ASHM	1074	--	35	--	--	--	70	--	--	--	--	93	333	175	--	
KNTR	1043	54	37	--	--	--	--	--	--	--	--	88	--	--	117	--

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.

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 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.

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, meaning that one unit of actual cost difference between routes is perceived as one unit of cost difference by the road user. 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 1. 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:

1. The final assignment was reached with a diversion intensity parameter of 1.0.
2. 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 the predicted link volumes.
3. 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.
4. The average error between the actual traffic measurements and the predicted traffic flows on the network from the final assignment was 5.2%.

Economic 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 2. The road classes within the study zone were shown in Figure 2.

All policies were identical as regards the maintenance activities of patching, surface dressing, and miscellaneous maintenance. The patching standard was to repair 80 percent 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 surface whenever the total area of cracking and patching exceeded 10 percent of the total road surface area, but not more frequently than every two years or less frequently than every five 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.

The primary focus of this study was on the relative frequency and thickness of overalys 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 3 shows the effects of overlay frequency while holding the thickness of all overlays constant, presenting the discounted net present value (in this paper, net present value includes maintenance and user costs) 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 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 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 produced a highly skewed traffic distribution pattern which is viewed negatively by the road users, as will be discussed later in this report. Alternative 4 represents another non-uniform investment proposal, wherein links in Class I are not overlaid and those in 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 performance, as will be shown later.

Figure 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, 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 Classes II and III 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 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 3. (This is not surprising, since a review of Table 1 indicates that 73 percent 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 3 and the 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 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.

Consumer Surplus Criterion

The discounted maintenance costs, vehicle operating costs, total costs, and net present values for all alternatives are shown in Table 4. Also shown is the net consumer surplus of each alternative. The consumer surplus is a measure of the "user satisfaction" with the 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. 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 (3).

Using this new measure of system performance, which is included in Table 4, we can again rank the network performance of the various maintenance

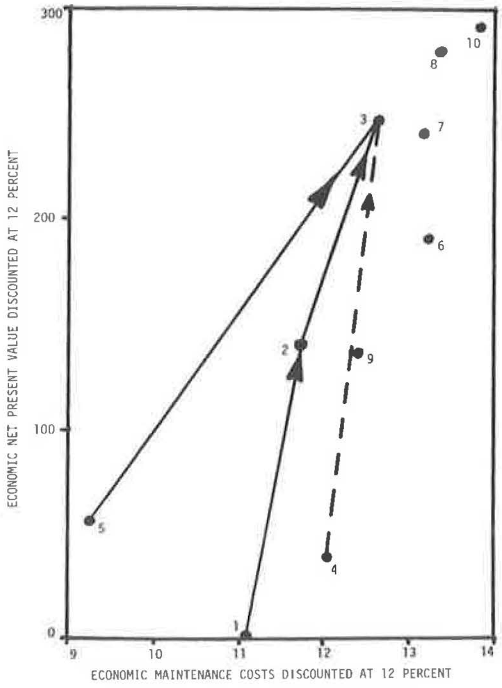
Table 2. Maintenance overlay policies.

Policy	Overlay Frequency		
	Class I	Class II	Class III
1	5000[a] (40)[b]	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)

[a] Overlay roughness threshold, mm/km.

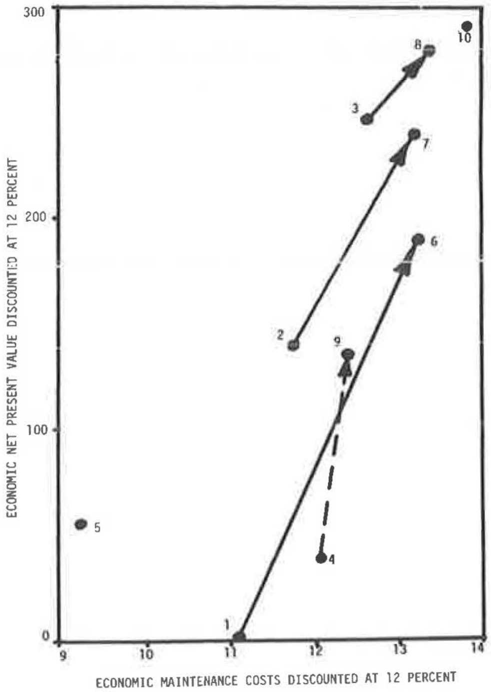
[b] Overlay thickness, mm.

Figure 3. Effects of overlay frequency on economic performance (million Egyptian pounds).



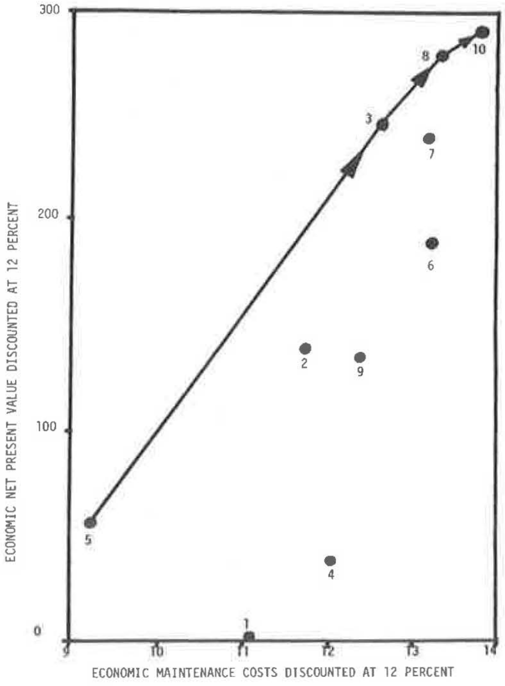
Note: Net present value is with respect to alternative 1, and includes road maintenance and road user costs.

Figure 4. Effects of overlay thickness on economic performance (million Egyptian pounds).



Note: Net present value is with respect to alternative 1, and includes road maintenance and road user costs.

Figure 5. Economically "efficient" maintenance alternatives (million Egyptian pounds).



Note: Net present value is with respect to alternative 1, and includes road maintenance and road user costs.

Table 3. Economically "efficient" maintenance policies.

Policy	Net Present Value[a]	Overlay Frequency Class I	Class II	Class III
5	56	3000[b] (40)[c]	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)

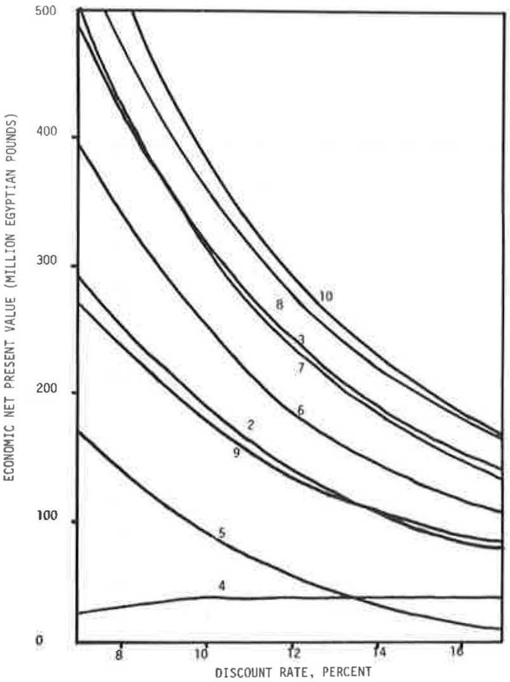
Note: 1 Egyptian pound = US $1.40.

[a] Million Egyptian pounds discounted at 12%; includes road maintenance and road user costs.

[b] Overlay roughness threshold, mm/km.

[c] Overlay thickness, mm.

Figure 6. Economic net present value as a function of discount rate.



Note: Net present value is with respect to alternative 1, and includes road maintenance and road user costs.

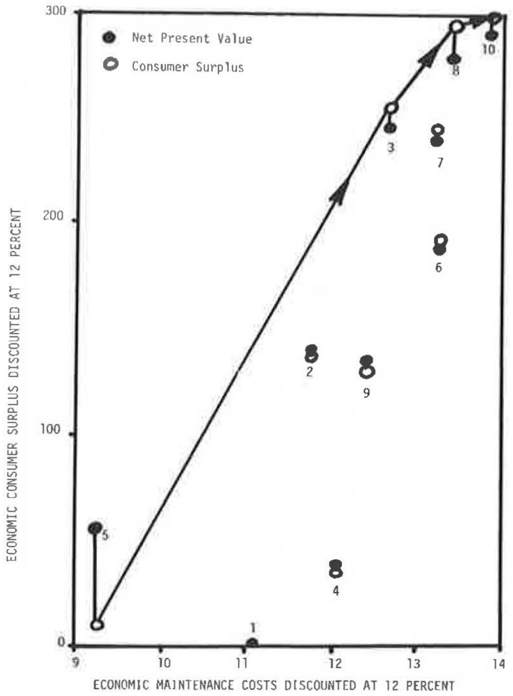
Table 4. Economic performance summary (million Egyptian pounds discounted at 12%).

Policy	Maintenance Costs	Vehicle Operating Costs	Total Costs	Net Present Value[a]	Net Consumer Surplus[b]
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

[a] Net present value is with respect to Policy 1.

[b] Net consumer surplus is with respect to Policy 1.

Figure 7. Economicall "efficient" maintenance alternatives from consumer surplus criterion.



Note: Net present value and net consumer surplus are with respect to alternative 1.

alternatives. Figure 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 percent 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 performance, as measured both by the economic efficiency and user satisfaction (consumer surplus) of the system.

Returns on Maintenance Investments

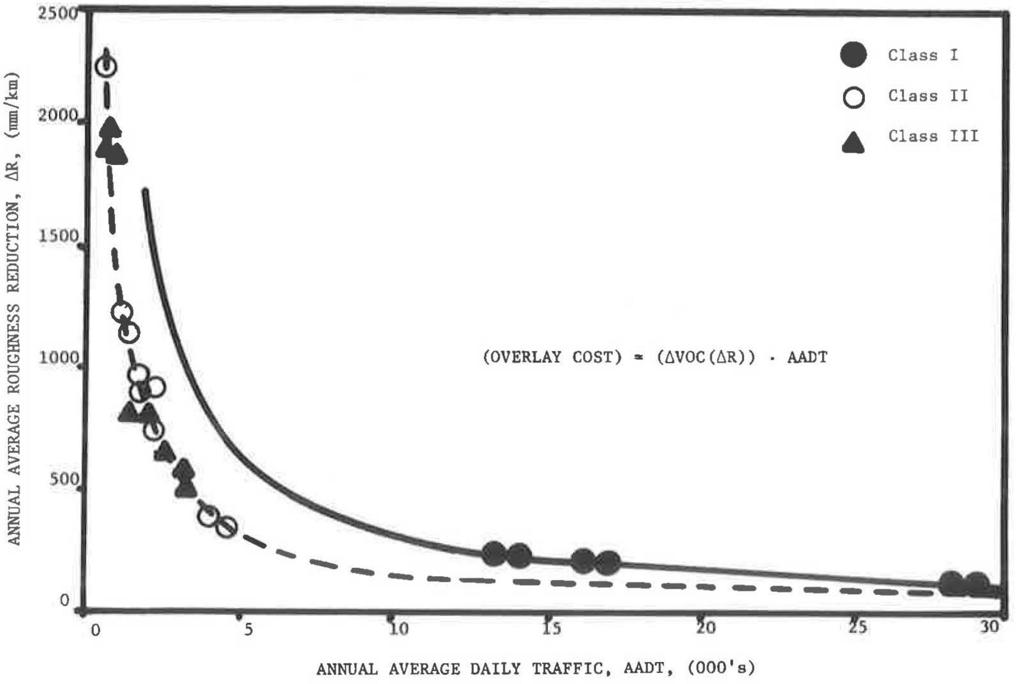
To explain the huge returns in the road network to the proposed maintenance investments, it is useful to study Figure 8. The figure shows the average roughness reduction in mm/km which must be maintained over a one year period such that the resulting vehicle operating cost savings equal the cost of a 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 8 was derived on an annual basis so that the results would not 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.

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.

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 deter-

Figure 8. Average roughness reductions as a function of average annual daily traffic such that the annual road user cost savings equal the cost of a 40 mm overlay.



ioration 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 percent 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.

References

1. Fred Moavenzadeh, Brian Brademeyer, et al. An Application of the Road Investment Model to the Evaluation of the Rehabilitation and Maintenance Program of the Egyptian Road Authority. International Road Federation Conference for the Middle East and North Africa, Cairo, Egypt, April, 1978.
2. Fred Moavenzadeh, et al. Conference on Transportation Planning Policy Proceedings, Technology Adaptation Program, Cairo, Egypt.
3. Fred Moavenzadeh, et al. The Road Investment Analysis Model: General Framework for Network Evaluation, Technology Adaptation Report 77-6, Winter, 1977.