THE HIGHWAY COST MODEL
EVALUATION OF THE
DAR-ES-SALAAM - MOROGORO SECTION
OF THE
TANZANIA-ZAMBIA HIGHWAY

BY

ANIL BHANDARI
FREDRIC BERGER

PREPARED FOR

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SUMMARY

This report presents an analysis of alternative design and maintenance strategies for the recently completed Dar-es-Salaam--Morogoro section of the Tanzania-Zambia Highway. The analysis is undertaken using an analytic model--the Highway Cost Model--which estimates construction, maintenance and road user costs as a function of the initial design standards, level of maintenance, and traffic volume and loading. The road, which is showing signs of early failure, is evaluated from two perspectives--a review of the design assumptions which were made prior to construction; and a review of the alternatives which are available to the Tanzanian government now that the road has been completed. Specific issues which are addressed include the adequacy of the original design, the possible effects of vehicle overloading, and the effects of applying a low standard of maintenance.

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. The purpose of the Technology Adaptation Program is to work with institutions in selected developing countries in adapting technologies and problem-solving techniques to the needs of those countries.

This report describes the use of the Highway Cost Model to evaluate a section of the Tan-Zam Highway. Initiated in 1969, the Highway Cost Model project evolved from a need to rationally analyze the economic consequences of alternative design, construction and maintenance policies for low volume roads. Work on the model has been sponsored by organizations with a strong practical interest in this area--first the World Bank and subsequently the Agency for International Development--and has paralleled research elsewhere--most notably at the Transportation and Road Research Laboratory in England.

Initial development of the Highway Cost Model was conducted at MIT starting in 1969, under the aegis of the World Bank's Highway Design Standards Study. This program, which was completed in 1971, resulted in an integrated framework for relating construction, maintenance and road user costs to proposed design and maintenance standards. The approach was distinguished from the then current practice in that it included realistic models of road deterioration and related this phenomenon to the costs and benefits of a road, and to specific policy alternatives available to the decision maker. However, a major conclusion of the study was that there was very little empirical data available confirming either the hypothesized patterns of deterioration for different types of road surfaces, or the hypothesized relationships between design standards, surface condition and road user costs.

Subsequently, the Transportation and Road Research Laboratory--in conjunction with the World Bank Program--sought to develop these relationships through extensive field studies in Kenya. The specific objectives of the TRRL project were to measure the deterioration characteristics of low design standard roads and the costs incurred in using these roads. These studies included (1) the measurement of speed and fuel consumption for different types of vehicles on roads designed to different standards and with different surface conditions (2) a survey of fleet owners to obtain estimates of tire consumption, and maintenance, and depreciation costs; and (3) measurements of road deterioration for gravel and surface treated roads under different maintenance policies and traffic conditions. This work was completed in 1974.

The current MIT study, sponsored by the Agency for International Development, has three objectives: (1) updating the model from its hypothetical foundations of 1971 by incorporating the results of extensive field work which has been conducted in the intervening period; (2) demonstration of the model by using it to evaluate, on an after-the-face basis, investment decisions on recently completed projects and (3) implementation of the model in operational setting of the highway department of a less-developed country.

This report is one of several dealing with the background and application of the Highway Cost Model. The first in this series--The Highway Cost Model: General Framework--describes the results of the completed first phase of study--modification of the Highway Cost Model. It describes the scope of the model, its technical content, assumptions and capabilities and its use as a tool in evaluating the economic consequences of alternative design, construction and maintenance standards.

The current report describes the results obtained in using the model to evaluate a recently constructed section of the Tanzania-Zambia Highway. This section, which runs from Dar-es-Salaam to Morogoro, is an extremely interesting one in that it is showing signs of early failure--some possible causes of which are at least inferentially touched upon in this report. Accordingly, it must be emphasized that this study was undertaken in the context of a research program using methods which have yet to stand the hard test of experience; and that MIT did not conduct any on-site review of the road. The results should therefore not be construed as recommending a particular course of action over any which may actually have been taken on the project, but are for illustrative purposes only.

Subsequent reports in this series will describe the results obtained in using the Highway Cost Model on road construction projects elsewhere.

Fred Moavenzadeh
Program Director

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I. INTRODUCTION

This report presents a case-study demonstrating the application of the Highway Cost Model (HCM) as a tool for evaluating alternative design and maintenance standards on a selected road project in Tanzania. The project selected is the Dar-es-Salaam--Morogoro section of the Tanzania-Zambia Highway (Tan-Zam Highway). This particular project was selected for two reasons. One, because it gave the opportunity of evaluating a large number of alternatives in terms of several pavement designs and maintenance policies for each of four different possible cases of traffic projections that were analysed by an earlier study of the Tan-Zam Highway. Second, the newly constructed road has shown signs of an early failure on several sections. Using the HCM, it was possible to evaluate several post construction investment strategies in terms of different maintenance policies, taking into account the effects of possible overloading of medium and heavy truck traffic, so that recommendations could be made for an optimum maintenance policy.

The application of the Highway Cost Model is presented in three distinct experiments. In each case the Model is used primarily to generate the time stream of construction, maintenance and vehicle operating costs during a specified analysis period for specific pavement designs and maintenance policies.

First, the Highway Cost Model is used to evaluate the pavement design and maintenance policy proposed for the case-study section by an earlier study. The total construction, maintenance and vehicle operating costs computed by the model are analysed and discussed in comparison with those of the study.

Second, the model is used in a feasibility level experiment to evaluate a wider range of alternative strategies. The strategies are defined as combinations of different pavement designs and maintenance policies, under four different cases of traffic projections. The least cost alternative (sum of the present values of construction, maintenance and vehicle operating costs) is identified for each case of traffic projection, followed by a discussion of tradeoffs between maintenance and vehicle operating costs, pavement deterioration characteristics, and the advantages of constructing a stronger pavement initially.

Third, the Highway Cost Model is used in a post construction investment tradeoff experiment to develop recommendations for an optimum maintenance strategy for the newly built road. Three maintenance policies are evaluated assuming first no overloading of traffic, and second, a 30% overload on all medium and heavy truck traffic. The analysis includes a discussion of the tradeoffs between maintenance expenditure and user savings, and a possible early reconstruction of the newly built road.

Summary of the HCM - Analytic Framework*

The basic function of the Highway Cost Model is to estimate construction, maintenance, and user costs for a road which has been designed and maintained to specific standards. This is done by simulating the life of the road from initial construction through periodic upgrading, and the yearly cycle of use, deterioration and maintenance.

The simulation of the life of the road is accomplished by estimating construction and maintenance activities, road conditions, traffic volumes, and all associated costs on a year by year basis through the analysis period. The specific operations undertaken in each year are as follows:

A construction submodel schedules projects, estimates construction quantities and costs, allocates a percentage of these costs to the current year, and updates the status of the road's segments as projects are completed.

A preliminary estimate of the current year's traffic is made based on the previous year's traffic and anticipated growth.

The road deterioration and maintenance submodel estimates average road surface conditions for the year as a function of the initial design standard, traffic volume and composition, age of the road, environment and the specified maintenance policy. Surface deterioration is estimated for unpaved and paved roads using empirical relations developed by the Transportation and Road Research Laboratory in Kenya (gravel roads and bituminous treated roads on cement stabilized base) and results from the AASHO road tests (asphalt concrete roads on granular bases).

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*In order to avoid unnecessary duplication, detailed descriptions of the functional form of the various routines and submodels of the Highway Cost Model are omitted from the present report. However, where necessary, the reader is referred to particular sections of the HCM text for details "The Highway Cost Model: General Framework," MIT June 1975 .

Maintenance activity may be specified for each surface type on either a scheduled or demand responsive basis, and are priced according to the maintenance actually performed. The condition of the road is expressed in terms of roughness, rut depth, cracking and patching (all roads) and looseness and moisture content (unpaved roads).

The user cost submodel estimates the cost of operating vehicles over the road as a function of surface type and condition, and design geometries (grade, horizontal curvature and road width). The components of vehicle operating costs include both running costs (fuel, oil, tires, maintenance parts and labor) and time costs (depreciation financing, wages, overhead, and time value of cargo). Estimates are based primarily on the results of the TRRL study in Kenya, and are generally applicable to free flowing traffic conditions on two lane roads.

The results of the simulation include a record of expenditures incurred by road users; and a detailed history of the status and deterioration of the road. Construction and maintenance costs are broken down into labor, equipment, material, overhead and profit components by line item. Vehicle operating costs are estimated for each type of vehicle using the road.

All estimates are made in terms of physical quantities, from which costs are obtained by applying the appropriate unit rates. The model can therefore be used within any monetary system, and is not affected by changes in relative prices.

The model estimates costs, both in financial and economic terms. Financial costs represent actual monetary expenditures for vehicle operations, and for road construction, and maintenance activities. Economic costs represent the costs to the economy in terms of the resources consumed. In most cases taxes, duties, subsidies and other government transfer payments do not constitute a real social cost, so the economic costs of resources must be expressed net of all such transfer payments.

Data Problems

Given the time and resource constraints of the present case-study, it was not possible to gather first hand data from Tanzania. Resort was therefore made to whatever data was available from various feasibility and engineering studies performed on other road related projects in Tanzania. Inevitably there were historical inconsistancies among different studies, and in some cases, data was not available at the level of detail required by the HCM. Maximum use was made of whatever data was available and engineering judgements made where necessary.

In reviewing the comparative results presented in this report one therefore must be cognizant of these shortcomings, and the differences observed should not be extrapolated.

The rest of this report is divided into three sections. SECTION II gives a statement of the problem describing the case-study project and the analysis and recommendations of earlier feasibility and engineering design studies. SECTION III contains the results and analysis of the three experiments in the application of the HCM. SECTION IV contains a summary of major conclusions. Two appendices are attached to the report. Appendix A gives a complete bibliography of the data sources used for the entire case-study, and Appendix B gives a detailed documentation of the Data inputs to the HCM not included in the text.

II. THE PROBLEM STATEMENT

A. Choice of Project for the Case Study

The project selected for the present case study is the Dar-es-Salaam--Morogoro section of the Tanzania--Zambia (Tan-Zam) Highway, shown circled in FIGURE 1. The 1920 km Tan-Zam Highway connects Ndola, the center of Zambia's copper belt, with Dar-es-Salaam, the chief port of Tanzania. Large sections of the highway, including the Dar-es-Salaam--Morogoro section, required upgrading and realignment in order to provide an all-weather road that would handle both present and projected traffic through the two countries. The highway became more important after the United Nations imposed an embargo on traffic with Rhodesia, an act which led Zambia to seek alternate routes for its sea-going import-export traffic.

The old road between Dar-es-Salaam and Morogoro was a two lane bituminous surface treated road 192.9 kms long and built in the mid-fifties. The road was 8.5 m (28 ft) wide with a pavement 6.1 m (20 ft) wide, and some very winding, undulating sections. The pavement was in poor condition (PSI below 2.5) due to heavy traffic and lack of adequate maintenance.

In 1966, Stanford Research Institute (SRI), under a contract financed by USAID, conducted a feasibility study of the entire Tan-Zam Highway. On the Dar-es-Salaam--Morogoro section, SRI proposed to replace the old road with an asphalt concrete road along a new alignment that would shorten the total length by 8.3 kms. Subsequent to the SRI study, final engineering designs were prepared by DeLeuw Cather International Inc. (DCI). The construction, financed by USAID and constructed by Nello L. Teer, started in 1970 and was completed in 1973.

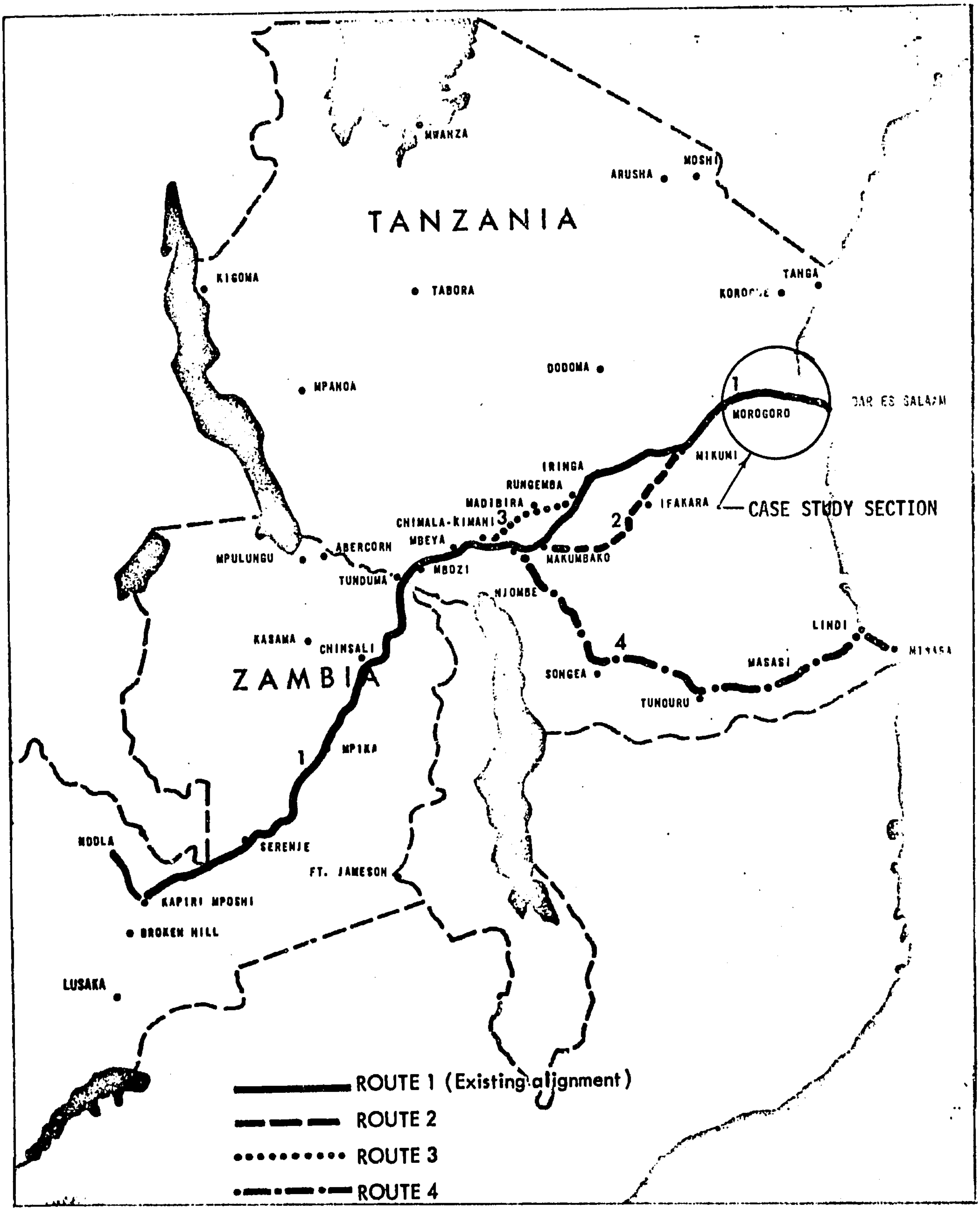

FIGURE 1

TAN-ZAM HIGHWAY --- ALTERNATIVE ROUTES AND THE CASE STUDY SECTION

B. The SRI Study of the Tan-Zam Highway and Recommendations for the Dar-Morogoro Section

The primary objective of the SRI study was "the determination of the optimum route, engineering features, and costs of a highway link between Zambia and Tanzania, and the appraisal of the economic development potential made possible by the construction of the highway and appropriate feeder roads." SRI evaluated four alternative routes through Tanzania using four possible cases of traffic loading. The four alternative routes considered by SRI are also shown in FIGURE 1. The four cases were:

Case 1. Present and projected traffic assuming normal growth but no copper or developmental traffic.

Case 2. Case 1 plus developmental traffic due to complementary investments in development schemes along the highway.

Case 3. Case 2 plus transportation of Zambian copper in excess of the 1966 level of production.

Case 4. Case 2 plus transportation of all Zambian copper.

The period of analysis used by SRI was 13 years from 1967 to 1980. The average daily traffic projections by vehicle type and their annual growth rates for each of the four loading cases are summarized in TABLE 1. Copper traffic is included in a separate category of 22 ton copper trucks to facilitate the application of different growth rates.

SRI concluded that for Traffic Cases 1 and 2, Route 1 was economically superior; for Case 4, Routes 1 and 3 were equally desirable. For Traffic Case 3, however, SRI concluded that transportation of the expected growth in copper production was not economically favorable over any of the routes

TABLE 1. TRAFFIC VOLUMES BY VEHICLE TYPE (ADT)

VEHICLE TYPE / LOADING CONDITION	CARS	BUSES	7TON TRUCK	10 TON TRUCK	22 TON TRUCK	22 TON COPPER TRUCKS
Case 1						
1967	79	22	58	39	13	0
1980	239	54	98	66	22	0
Annual Growth Rate %	8.9	7.2	4.1	4.1	4.1	0
Case 2						
1967	79	22	60	40	14	0
1980	239	54	101	91	32	0
Annual Growth Rate %	8.9	7.2	4.1	6.5	6.5	0
Case 3						
1967	79	22	60	40	14	8
1980	239	54	101	91	32	100
Annual Growth Rate %	8.9	7.2	4.1	6.5	6.5	21.4
Case 4						
1967	79	22	60	40	14	200
1980	239	54	101	91	32	300
Annual Growth Rate %	8.9	7.2	4.1	6.5	6.5	3.2

considered. The reason given was that the large outlay required for added highway construction and maintenance costs to handle the limited addition of heavy copper trucks more than offset any savings in vehicle operating costs due to shipping the growth copper over the Tan-Zam Highway rather than by rail through Rhodesia and other neighboring countries.

Routes 1 and 3 were divided into a total of 13 segments and the highway requirements in terms of pavement design and maintenance costs, of each segment under each case of traffic loading identified. Segment 13, the section between Dar-es-Salaam and Morogoro, was common to both routes.

For Segment 13, SRI's recommendation was a new asphalt concrete road to replace the existing double bituminous surface treated road along a new alignment.

1. ALIGNMENT

The old road was 192.9 kilometers. On the new road, the first 10 kilometers from Dar-es-Salaam follows the same alignment due to the concentration of urban activity along the right of way. For the balance of the new route, only 3.4 kms follows the old alignment. The total length of the new route is 184.6 kms providing not only an 8.3 km distance savings, but a higher standard of geometric and safety design.

2. PAVEMENT DESIGN

SRI recommended an asphalt concrete pavement design with the following materials and thicknesses:

asphalt concrete surface	- 5.08 cms (2 ins)
crushed stone base	- 15.24 cms (6 ins)
gravel sub-base	- 12.7 cms (5 ins)

The above thicknesses were proposed for the Traffic Case 4 but the design was not based on any site investigations. Hence, no compensation was made for the different subgrade strengths along the new alignments. A typical section of the SRI pavement design is shown in FIGURE 2.

3. MAINTENANCE POLICIES

SRI derived the following equations for computation of annual maintenance expenditure on bituminous surface treated (DBST) roads (20 ft wide) and asphalt concrete (AC) roads (24 ft wide) as a function of average daily traffic (ADT):

DBST MAINTENANCE = 2750 + 1.44 (ADT) shs/km [1]

AC MAINTENANCE = 8000 + 0.16 (ADT) shs/km

Although no specific maintenance activities were given for the old (DBST) road, major activities on the new (AC) road were specified as follows:

shoulder grading	- 4 bladings per year
culvert/ditch clearing	- 2 times per year
seal coat	- once every five years
major overlay	- once every 15 years

Because an overlay was specified for once in 15 years, none was included in the present analysis which extended only 13 years, including construction in the first 3 years.

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(1) Approximately 7 Tanzanian Shillings (shs) = $1 US at the time of the study.

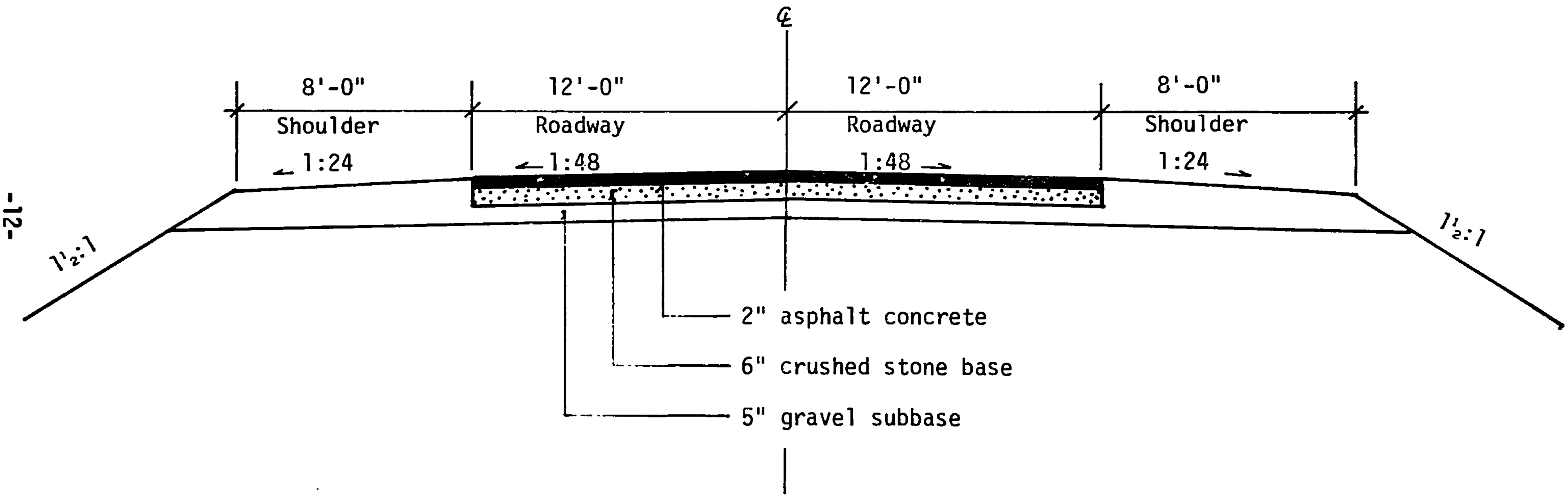

FIGURE 2

TYPICAL SECTION - SRI DESIGN

4. VEHICLE OPERATING COSTS

The unit vehicle operating costs used by SRI on DBST surfaced roads in Tanzania are summarized in TABLE 2. On the new alignment, SRI implied an average reduction of 20% in vehicle operating costs. The vehicle operating costs used by SRI did not include vehicle finance, insurance, administration, or cargo finance costs. Detailed derivation of the unit costs was not given in their report.

TABLE 2

UNIT VEHICLE OPERATING COSTS (SRI)
(Shs/Veh/Km)

	MED CAR	BUS	7 TON TRUCK	10 TON TRUCK	22 TON TRUCK
Fuel	.055	.160	.079	.153	.216
Oil	.004	.020	.011	.018	.031
Maintenance	.043	.126	.101	.261	.372
Tires	.027	.055	.044	.100	.138
Wages	----	.101	.258	.275	.275
Depreciation	.138	.206	.103	.204	.250
Total	.267	.668	.596	1.011	1.282
Veh. Speed (km/hr)	80	72	72	72	72

5. COST SUMMARY

The construction period was specified as 3 years, from 1967 to 1970, and the analysis made for a total of 13 years, 1967 tO 1980.

A summary of the construction costs estimated by SRI is presented in TABLE 3, while the Present Value of Total Maintenance and Vehicle Operating Costs, using the maintenance equations and vehicle operating costs specified by SRI and a discount rate of 10%, is presented in TABLE 4.

TABLE 3

SUMMARY OF CONSTRUCTION COSTS (SRI)

(Thousands of Tanzania Shillings)

Excavation Plus Clearing	6,132
Pavement	33,500
Drainage	9,438
Total	49,070

TABLE 4

PRESENT VALUE OF MAINTENANCE AND VEHICLE OPERATING COSTS (SRI)

(Thousands of Tanzania Shillings)

	MAINTENANCE	VEHICLE OPERATING
Old Road	26,009	247,300
New Road	16,100	206,548

C. DeLeuw Cather Pavement Designs

Subsequent to the SRI study, DeLeuw Cather International, Inc. (DCI) was retained by USAID to make a final engineering and design study of the Dar-es-Salaam--Morogoro segment. DCI used more current and updated information on existing traffic and growth patterns, and recommended, at first, an asphalt concrete paved surface with a trench type section for base-course and sub-base. The typical section is shown in FIGURE 3. From difficulties encountered in the earlier stages of construction, it became apparent that this design was not adequate to meet the conditions encountered. The major factor involved was the poor drainage characteristic of the trench section.

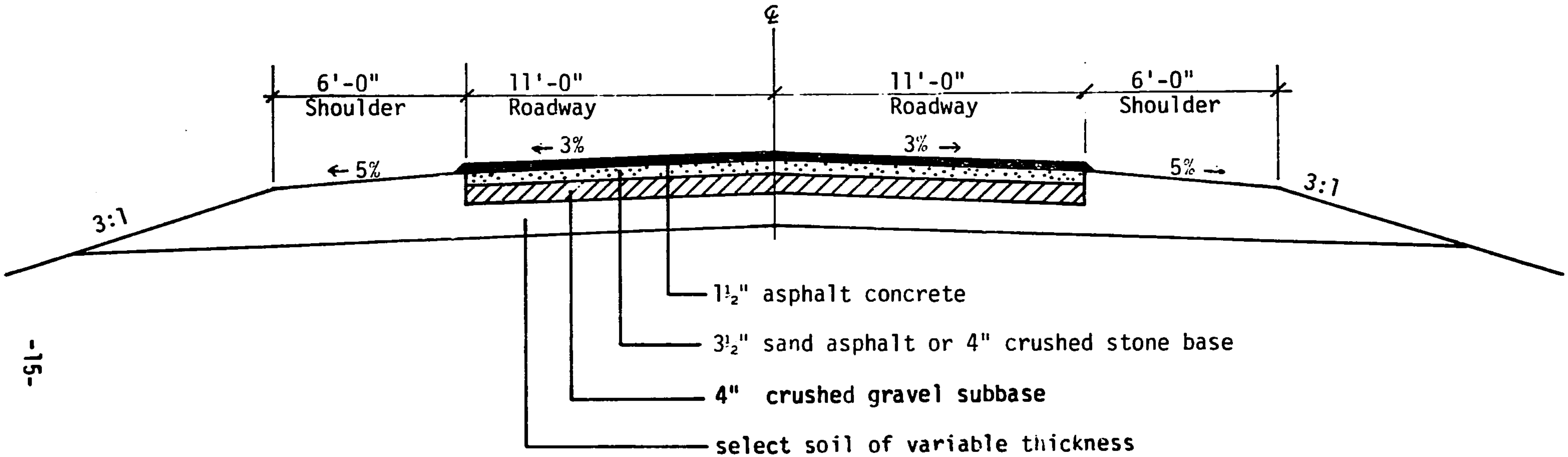

FIGURE 3

TYPICAL SECTION - DCI TRENCH DESIGN

The design was subsequently modified by DCI with an extension of the base and sub-base across the entire cross-section, as shown in FIGURE 4. The pavement was designed for a total of 675,000 applications of an 18 kip equivalent axle load and the thicknesses recommended were 3.8 cms (1.5 ins) of asphalt concrete over 10 cm (4 ins) of crushed stone (or 8.9 cms (3.5 ins) of sand asphalt) base over 10.2 cms (4 ins) of gravel sub-base on top of select soil of variable thickness depending upon the CBR value of the underlying subgrade. At the contractor's option, the first half of the road from Dar-es-Salaam was built with a sand asphalt base while the rest was built with crushed stone. The total sub-base thicknesses were specified as follows.

Average Subgrade CBR(%)	Sub-base Thickness
7	36.8 cms (14.5 ins)
8	25.4 cms (10 ins)
10	21.6 cms (8.5 ins)
30	no sub-base

The traffic projections used by DCI are given in TABLE 5.

In SECTION III-A, the SRI pavement design (FIGURE 2) is evaluated using the HCM, under Traffic Case 4 and the results compared with those of SRI, (summarized in TABLES 2, 3, and 4). In SECTION III-B, the HCM is used to evaluate a number of alternatives in terms of pavement design and maintenance policies for each of the four traffic loading cases summarized in TABLE 11. The pavement designs evaluated include the SRI pavement, the DCI trench design, and the DCI modified design. Another pavement, designed according to the AASHO Design Criteria, is also evaluated under Traffic Case 4, and its performance compared with those of the SRI and DCI designs. The "as-built", DCI modified pavement design, and the DCI traffic projections (given in TABLE 5) are used in SECTION III-C, which deals with the evaluation of post-construction investment tradeoffs and the impact of overloading.

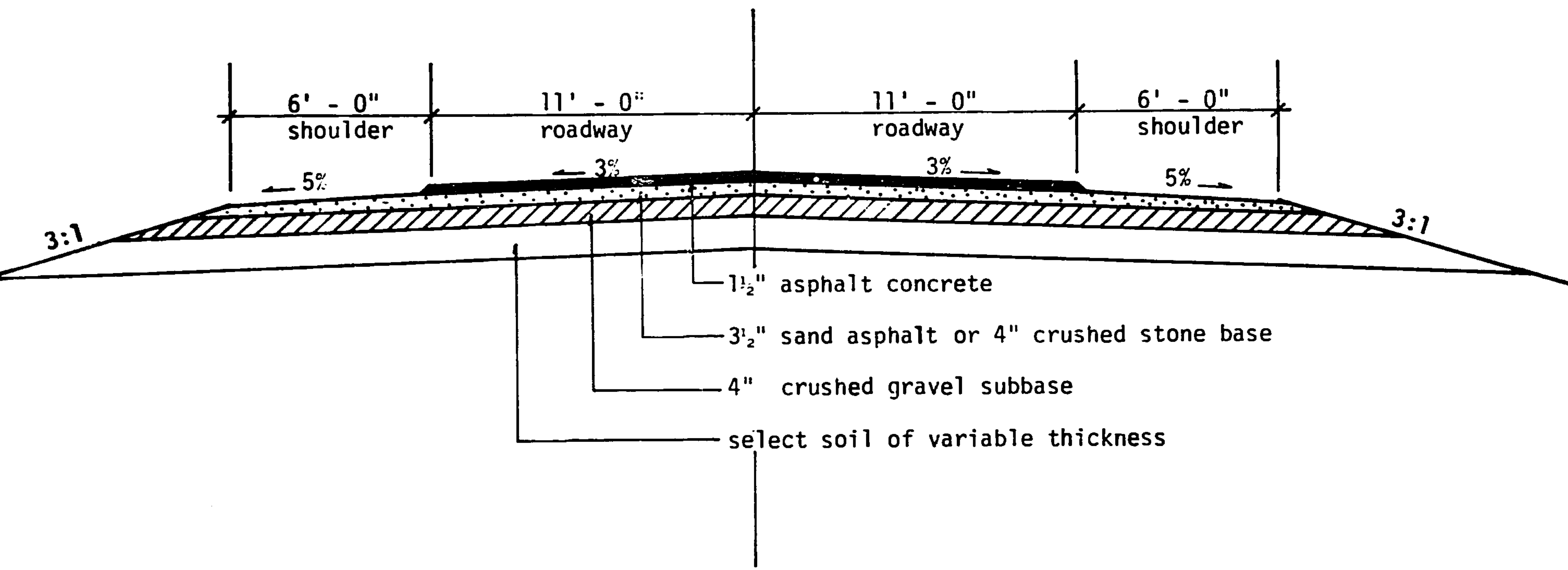

FIGURE 4

TYPICAL SECTION - DCI MODIFIED DESIGN

TABLE 5. TRAFFIC PROJECTIONS USED BY DCI (ADT)

YEAR	MED. CAR	BUS	7 TON/10TON	22 TON
1967	122	47	166	22
1970	158	58	189	25
1971 *	192	69	221	27
1978	351	111	301	37
1979 *	382	119	255	23
1991	1075	267	434	39

*DCI assumed an impulse jump of 12.5% in 1971 when the new road was expected to open, and a shift of 14.5% of the medium (7 Ton and 10 Ton) and 35.5% of the heavy (22 Ton) truck traffic to the Tan-Zam Railroad scheduled to open in 1979.

III. DESIGN AND EVALUATION OF EXPERIMENTS WITH THE HIGHWAY COST MODEL

A. Evaluation of the SRI Proposal on Dar-es-Salaam--Morogoro Segment

The HCM was used to compute construction, maintenance and vehicle operating costs on the old and new roads using the SRI pavement design, alignment characteristics, and maintenance policy, and Traffic Case 4. The results obtained with the model are analysed and discussed in comparison with the SRI results.

1. INPUTS TO THE HIGHWAY COST MODEL

Since the Dar-Morogoro Segment was only a small part of the entire Tan-Zam feasibility study, the SRI report lacked data at the level of detail required by the HCM. Where necessary the additional data were obtained from other similar studies conducted in Tanzania. In particular, this applied to the design and operating characteristics of the 5 vehicle types, maintenance practice and unit costs on the existing road, CBR values of the underlying subgrades, and the pavement design, age and condition of the old road.

A complete bibliography of the data sources used for this case study is given in Appendix A; a detailed documentation of the inputs to the HCM, in Appendix B. A brief description of the various input categories is outlined below.

Segment Description and Alignment Characteristics

The old road was divided into four segments: two segments, totaling 179.5 kms., that were to be realigned; one segment, 3.4 kms. long, to be reconstructed along the existing alignment; and a final segment, 10 km. long, that remained unchanged, as specified by SRI.

The new road was divided into seven segments reflecting primarily changes in the subgrade CBR values. All segments were coded and described by their lengths, average curvature, subgrade CBR values, average rise and fall, and intensity of rainfall. (see FIGURE B-1 and TABLES B-1a and B-1b in Appendix B). The number of 25 foot contour lines crossed per kilometer was also input for all segments along new alignments, for computation of earthwork quantities.

Road Cross-Section and Pavement Design

The cross-section and pavement designs for the new road input to the Highway Cost Model were as specified by SRI. TABLE B-2b, summarizes the cross-section standard, while FIGURE 2 in SECTION II shows the pavement materials and thicknesses proposed by SRI.

TABLES B-2a and B-2c show the data used to describe the cross-section and pavement design on the old road.

Traffic

The SRI Traffic Case 4 was used, with the volumes and projections as shown in TABLE 1 in SECTION II.

Vehicle Operating Costs

Normal traffic was divided into five basic categories: cars, buses, and 7-ton, 10-ton, and 22-ton trucks. A detail description of each category, and their respective financial and economic cost components, used as inputs to the HCM, are shown in TABLES B-3a and B-3b.

Maintenance Policies

The maintenance policy on the new asphalt road was specified as follows

surface patching	140 sq.m./km per year
seal coat	every 5 years
shoulder grading	4 bladings per year
culvert/ditch cleaning	2 times per year

A maintenance policy obtained from Lyon Associates[(1)] for the old double bituminous surface treated road was defined as follows:

surface patching	900 sq.m./km. per year
seal coat	every 5 years
regravelling of shoulders	400 cu.m./km. per year
brush control	2 times per year
culvert/ditch cleaning	once per year

The unit maintenance and construction costs used in the model are summarized in TABLES B-4 and B-5.

2. COMPARISON OF THE HCM RESULTS WITH SRI

Construction Costs

TABLE 6 shows the construction costs obtained with the HCM, the SRI estimates and the percentage difference.

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(1)"Tanzania-Maintenance and Organization" Vol. II, Aug. 1972--reference [2] in Appendix A.

TABLE 6

COMPARISON OF CONSTRUCTION COSTS
(Thousands of Tanzania Shillings)

	(HCM)	(SRI)	(% diff)
Excavation plus Clearing	7,102	6 132	+16%
Pavement	32,543	33 500	- 3%
Drainage	1,890	9 438	-80%
Total	41,535	49 070	-15%
Total (with SRI drainage)	49,083		

Excavation costs as calculated by the HCM are 16% higher, pavement cost 3% lower than those estimated by SRI. At the feasibility level these differences are within reason.

The volume of excavation required is computed by the construction submodel(1) of the HCM based on a relationship between earthwork quantity and the contour density (number of contour lines crossed per unit length) along the alignment and the maximum allowable grade. Clearing costs are for clearing of the entire Right of Way prior to excavation. The volumes of materials required in the pavement are computed from the geometry of the pavement section (including shoulders) and multiplied by their respective unit costs, in place, to obtain total pavement-cost.

The major difference is in the drainage estimate. SRI provided a lump sum for drainage, based on "on-site inspection" including the cost of building reinforced concrete box culverts, 10 ft. by 7 ft., and major

(1) for a detailed description, the reader is refered to Chapter 2 in "The Highway Cost Model: General Framework, MIT, June 1975.

structures spanning 30 ft. or greater. No data was available regarding the exact number of these structures. The HCM estimate, on the other hand, is based on the minimum drainage required in terms of reinforced concrete pipes ranging in diameter from 24" to 48" depending upon rainfall and topography in the area.

In that the HCM methodology is based on a statistical distribution analysis and SRI's estimate on "on-site inspection", it is expected that the latter estimate is more nearly correct.

The total construction cost as calculated by the HCM is 15% below the SRI estimate. Excluding the drainage (or correcting for the differential) brings the difference to less than one-tenth of one percent.

Maintenance Costs

TABLE 7 summarizes the Present Value of the maintenance costs to 1967 at 10%, obtained with the HCM, those estimated by SRI, and the percent difference.

TABLE 7
PRESENT VALUE OF MAINTENANCE COSTS
(Thousands of Tanzania Shillings)

	HCM	SRI	% diff
Old Road	10,449	26,009	-60%
New Road	7,724	16,100	-52%

Compared with the SRI estimates of maintenance costs, the HCM estimate is 60% less on the old road and 52% less on the new road. The main reason for this difference is in the assumptions underlying the estimation of maintenance costs.

The Road Deterioration and Maintenance Submodel[1] of the HCM computes the amount of surface cracking as a function of traffic and the pavement's structural strength. If this amount exceeds the maximum amount of surface patching specified in the scheduled maintenance policy, the full specified amount is done--otherwise only that amount of cracking, as computed by the model, is patched. Maintenance costs due to other scheduled activities such as seal coating, brush control, shoulder grading and regraveling, and culvert/ditch cleaning, are computed as fixed costs in the year in which they occur.

The SRI estimates on the other hand, are a function of the ADT in each year, and are computed using the formulas given in SECTION II-B. SRI assumed that the structural quality of the road, and hence its PSI,[2] was maintained at the initial quality throughout the analysis period.

In order to test the SRI assumption, the HCM was used to compute the maintenance costs required to maintain the roads at various PSI values. This was done by specifying demand responsive overlays (5 cms) in the maintenance policies, such that the road was overlayed each time its PSI value reached the minimum value specified. By varying the minimum allowable PSI value before the road is overlayed, and comparing the associated maintenance costs, it was hoped to determine the level of quality (PSI) at which the old and the new roads could be maintained with the SRI estimates of maintenance expenditure. However, it was found that

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(1) Chapter 3, "The Highway Cost Model--General Framework, MIT, June 1975.

(2) PSI is the Present Serviceability Index developed during the AASHO Road Test, reflecting the subjective quality of the pavement. The PSI has been co-related to the structural number of the pavement, equivalent axle loads, environment, subgrade strength and other parameters such that a PSI of about 4.2 represents a pavement in excellent, newly built condition while a PSI below 2.0 denotes a pavement in poor condition.

maintaining the old road at a PSI above 2.0 would cost approximately 43 million shs, and at a PSI above 1.0, 37 million shs. This is respectively, 17 and 11 million shillings more than the 26 million shs. specified by SRI for maintaining the road to its initial quality (PSI = 2.5).

Similarly, on the new road, it was found that it would cost 36 million shillings to maintain the road at a PSI of 1.0 and 25 million shillings at a PSI of 0.5. These costs are respectively 20 and 9 million shillings more than the SRI estimate of 16 million shillings to maintain the newly built road to its initial quality (PSI = 4.2).

In other words, it was evident that the SRI estimates of maintenance costs are not only insufficient to maintain the roads at their initial qualities, but in fact seriously underestimate the costs to maintain the roads even at a minimum PSI of one.

Vehicle Operating Costs

Per kilometer vehicle operating costs (economic) by vehicle type obtained with the HCM on the old road in the first year are shown in TABLE 8.

Compared with the unit costs used by SRI (shown in TABLE 2) the HCM estimates of vehicle maintenance costs for the 7 ton, 10 ton, and 22 ton trucks are much higher, while the depreciation costs much lower. The wage costs are lower for all vehicle categories, and the tire cost significantly higher for the 22 ton truck. Since the SRI report did not include a detailed description of its derivation of vehicle operating costs, it is not possible to explain the differences. It should als be noted that SRI did not include administrative, insurance, and cargo finance costs in their estimates.

TABLE 8

UNIT VEHICLE OPERATING COSTS ON OLD ROAD (HCM)
(Initial year, economic, shs/veh/km)

ITEM/VEHICLE	Med. Car	Bus	7 Ton Truck	10 Ton Truck	22 Ton Truck
Fuel	.059	.139	.068	.072	.247
Oil	.004	.012	.012	.012	.012
Maintenance	.117	.057	.219	.627	.918
Tires	.019	.099	.115	.199	.494
Wages	____	.093	.082	.103	.094
Depreciation	.090	.061	.057	.100	.119
Administration		.088	.073	.076	.191
Insurance	.020	.028	.014	.018	.017
Cargo	0	0	.001	.001	.001
Total	.309	.597	.641	1.203	2.093
Vehicle Speed (km/hr)	80	52	55	55	55

The HCM estimates[1] were based primarily on recent research done in Kenya by the Transportation and Road Research Laboratory[2] of the U.K., and the input data used in deriving these costs is summarized in TABLES B-3a and B-3b.

A summary of vehicle operating costs on the old and new roads used by SRI and those estimated with the HCM excluding administrative, insurance and cargo finance costs, is presented in TABLE 9.

TABLE 9

SUMMARY AND COMPARISON OF VEHICLE OPERATING COSTS
(Initial year, economic, shs/veh/km)

Vehicle Type	Old Road			New Road		
	SRI	HCM	% Diff.	SRI	HCM	% Diff.
Cars	.267	.289	+8%	.214	.223	+4%
Buses	.668	.481	-23%	.534	.413	-23%
7 ton truck	.596	.552	-7%	.477	.462	-3%
10 ton truck	1.011	1.112	+10%	.809	.887	+10%
22 ton truck	1.282	1.883	+47%	1.026	1.538	+50%

(1) A detailed description of the Vehicle Operating Cost Methodology is given in Chapter 4 in the "Highway Cost Model--General Framework," MIT, June 1975.

(2) U.K. Transportation and Road Research Laboratory, Kenya Road Transport Cost Study, Vol.: Research on Vehicle Operating Costs.

While the HCM estimates for cars, and 7 ton and 10 ton trucks are within 10% of the SRI estimates, the operating cost for buses is 23% lower and for 22 ton trucks 50% higher than the SRI estimate. In the case of buses, the lower cost is due mainly to lower maintenance and depreciation costs while in the case of the 22 Ton Truck category, the difference is due mainly to higher maintenance and tire costs. These differences, as pointed out earlier, are primarily due to insufficient detailed data in the SRI report, though some of the difference may be due to differences in the methodology used.

The HCM estimates of vehicle operating costs on the old road shown in TABLE 9 are derived for the traffic in the first year of the analysis period, while those for the new road are for the traffic in the fourth year, when the new road is scheduled to open.

As the road deteriorates in the subsequent years, the vehicle operating costs increase due to the increase in surface roughness, cracking and patching, and the change in the vehicle operating speeds. This increase in the vehicle operating costs with the change in PSI as the road deteriorates, is discussed in the following section.

Vehicle Operating Costs Versus PSI

FIGURE 5a shows the change in per kilometer operating costs of the five vehicle types on the old road during the entire analysis period. FIGURE 5b shows the change in the PSI value during the same time. FIGURES 6a and 6b show the same relationships on the new road. On the old road the unit operating costs increase significantly in the first year, when the PSI drops from 2.5 to 1.0, and thereafter, the costs remain constant as the PSI is held constant at one. On the new road the costs increase rapidly in the first three years as 77% of the road, with subgrade CBR of 10% and less, deteriorates to PSI of 1.0 and thereafter the increase is more gradual as the remainder of the road with CBR

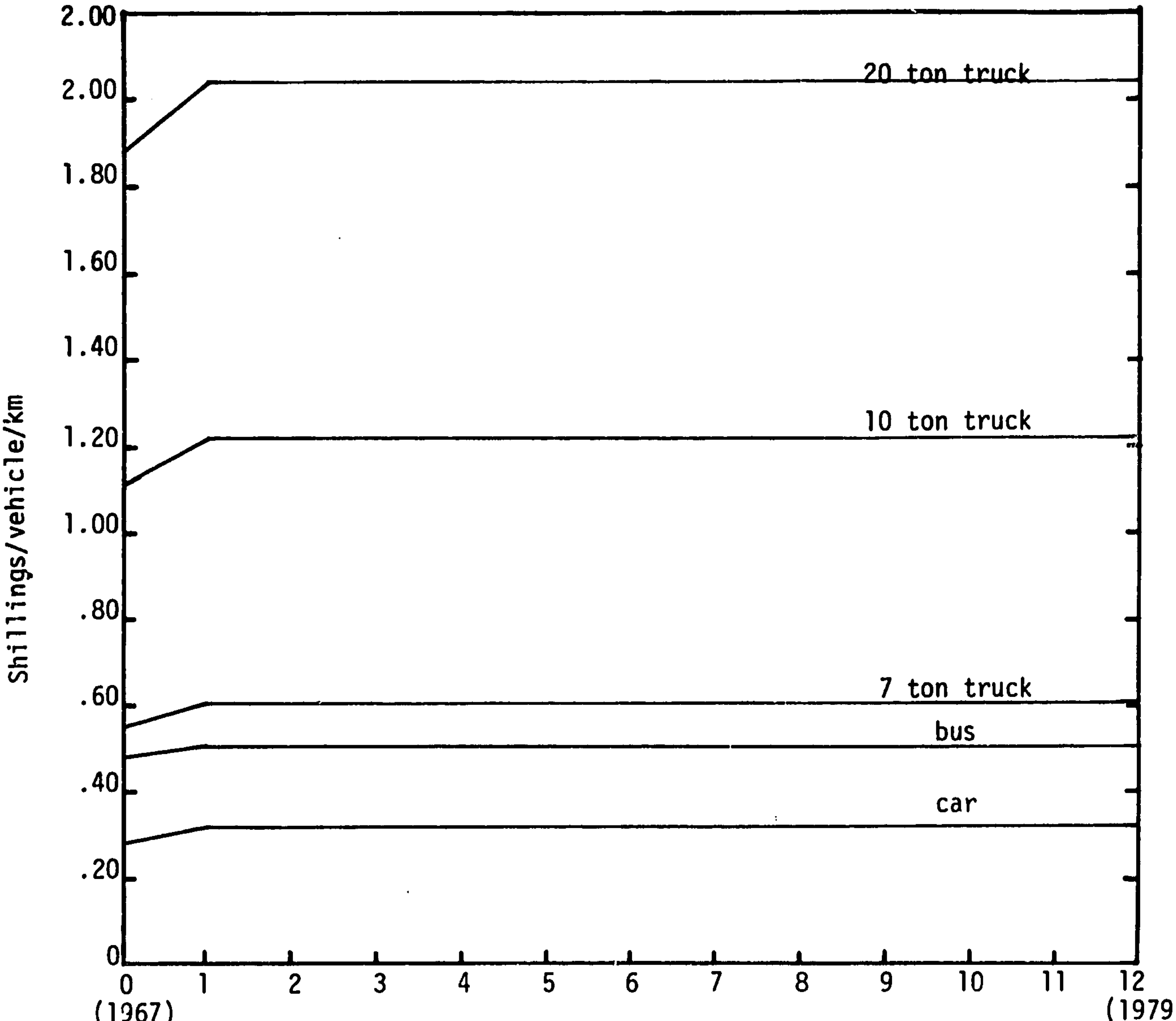

FIGURE 5a

VEHICLE OPERATING COST VERSUS TIME - OLD ROAD

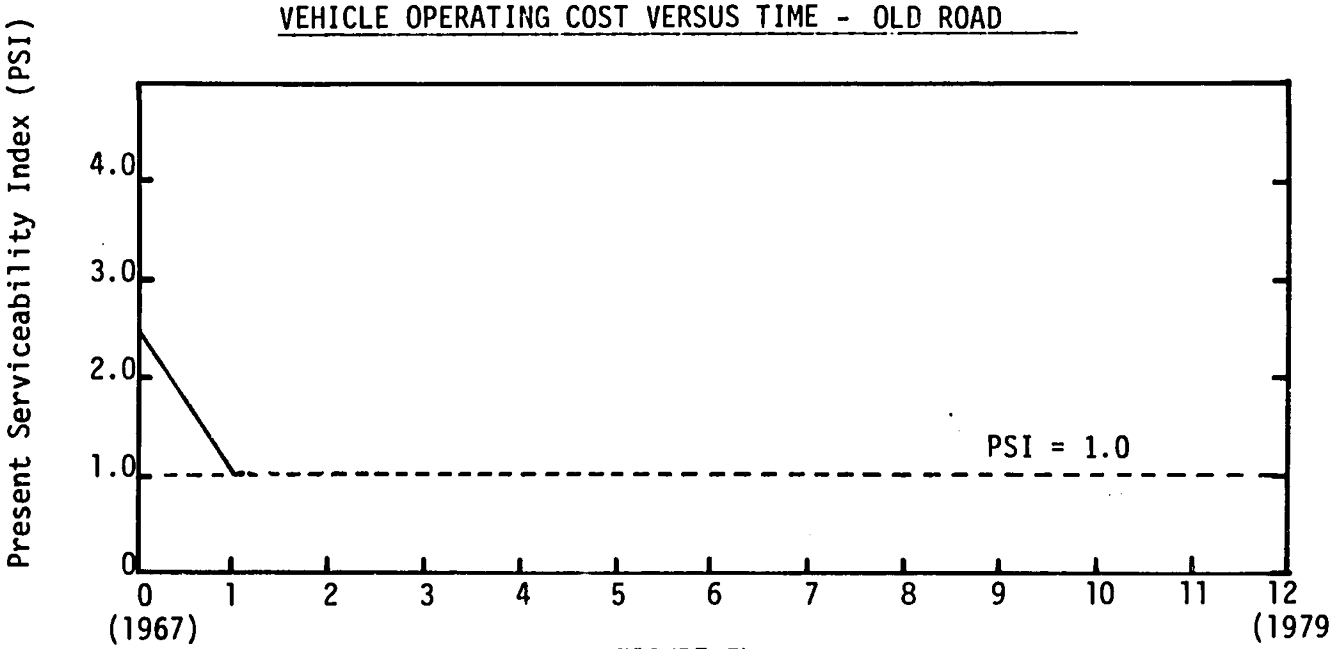

FIGURE 5b

PSI VERSUS TIME - OLD ROAD

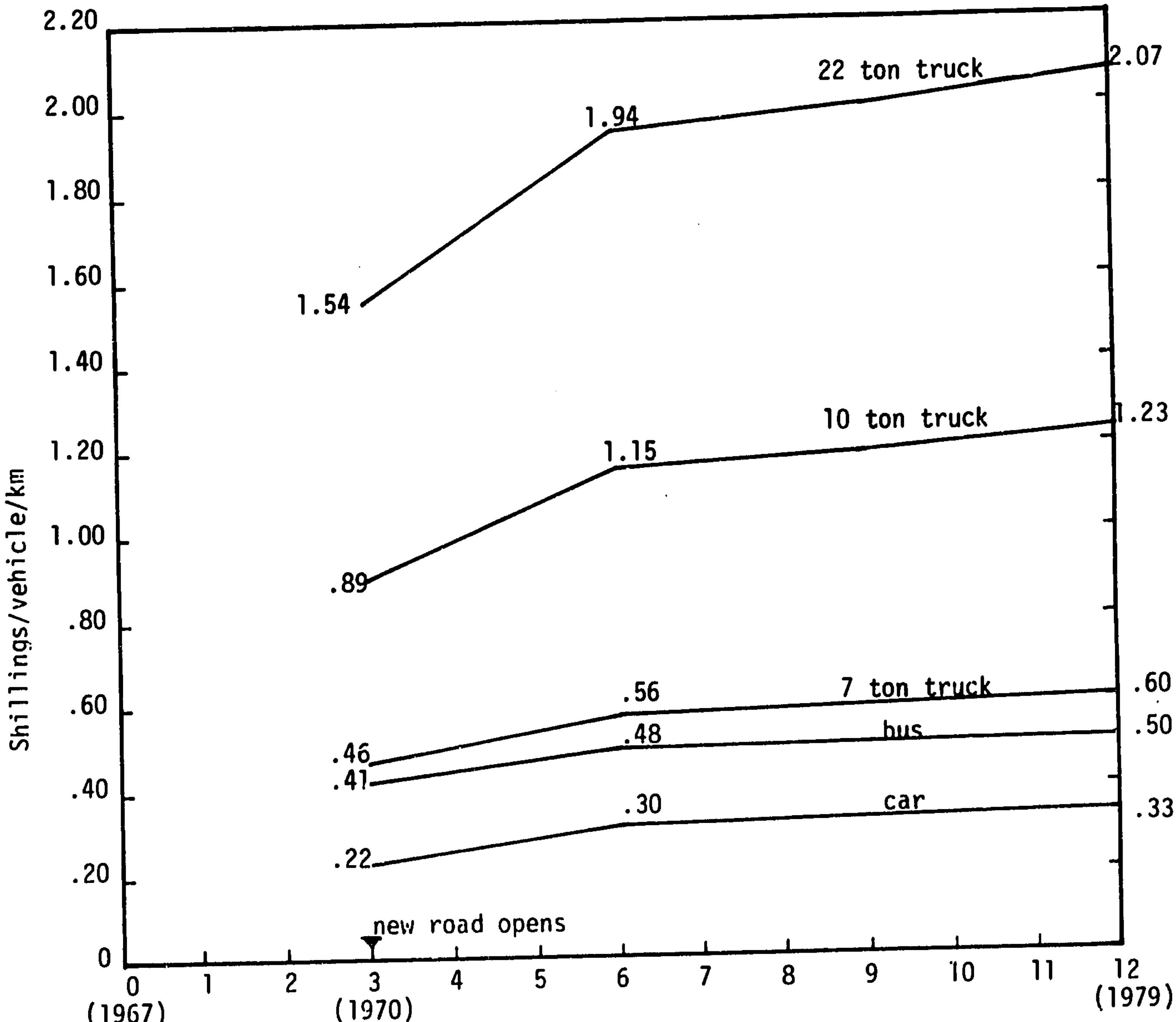

FIGURE 6a

VEHICLE OPERATING COST VERSUS TIME - NEW ROAD

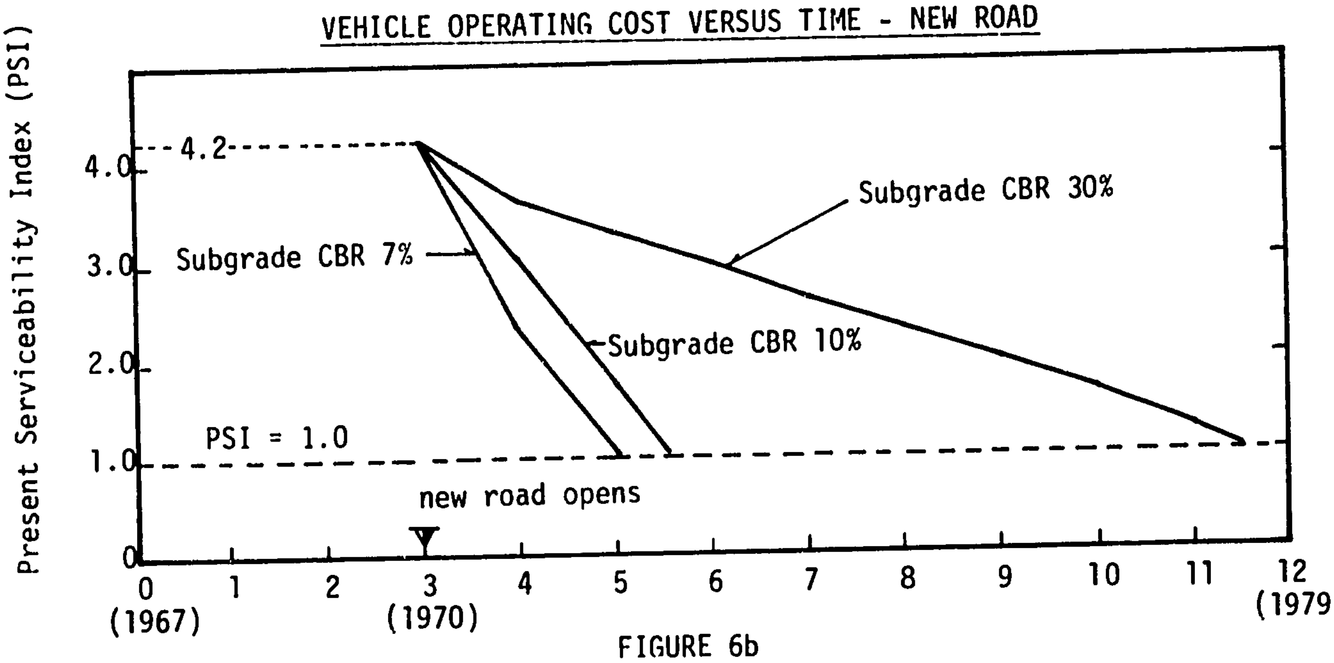

FIGURE 6b

PSI VERSUS TIME - NEW ROAD

of 30% continues to deteriorate to PSI of 1.0 in the next five years. Since the maintenance policy for neither the old nor the new road provided for an overlay in the analysis period, the roads would, theoretically, be expected to continue to deteriorate beyond a PSI of 1.0 and the vehicle operating costs to increase exponentially. (See SECTION III-C for further discussion.) However, for the purposes of this experiment and the feasibility level experiment discussed in SECTION III-B, the roads were allowed to deteriorate only to a PSI of one, and then were artificially held constant at that value. The total vehicle operating costs computed by the model are therefore underestimated, especially on the old road.

The present value of the vehicle operating costs obtained with the HCM, the SRI estimates, and the percent differences are presented in TABLE 10.

TABLE 10

PRESENT VALUE OF VEHICLE OPERATING COSTS
(Thousands of Tanzania Shillings)

	HCM	SRI	% diff
Old Road	390,188	247,300	+58%
New Road	360,277	206,548	+75%

Compared to the SRI estimates of vehicle operating costs, the HCM estimate is 58% higher on the old road, 75% higher on the new road. The estimates with the HCM would be even higher if the road were allowed to deteriorate below a PSI of one, instead of being artificially held at that value. SRI's costs assume that the PSI of both roads is preserved by their specified maintenance policies, an assumption which does not appear warranted as shown in the Maintenance Costs discussion above.

Pavement Performance

The old road was found to deteriorate from its initial PSI value of 2.5 to 1.0 in the first year of the analysis period after less than 95,000 18-kip Equivalent Single Axle Load (ESAL) applications on segments with a modified structural number of 1.73, and less than 30,000 applications on segments with modified structural number 1.55. This was due to the poor structural quaility of the old road and the fact that it was already 13 years old.

On the new road, segments with subgrade CBR value of 7% (modified structural number 2.84), deteriorated to PSI of 1.0 in less than 2 years after 200,000 18-kip ESAL applications, and segments with CBR value of 10% (modified structural number 3.05), in 2 and 1/2 years, after a total of 300,000 18-kip ESAL applications. Segments with a subgrade CBR of 30% (modified structural number of 3.76), lasted 8 and 1/2 years before reaching a PSI of 1.0 after over one million 18-kip ESAL applications. It appears therefore, that the SRI pavement proposal is under designed on subgrades with CBR values of 10% or less, but sufficient for subgrades with a CBR of 30%

3. CONCLUSION

Several conclusions can be made based on the preceeding analysis and the assumptions underlying the HCM's operation:

1) The maintenance expenditure specified by SRI is not sufficient to maintain the old or the new roads at their initial qualities, as assumed by SRI, and it would require considerable additional expenditure (in the form of overlays) to maintain either road at a minimum PSI of one.

2) The new pavement proposed by SRI is underdesigned for subgrades with CBR 10% or less, and therefore over 75% of the road drops to a PSI of one within three years of the road's opening.

3) As a result of the above two observations, the vehicle operating costs as estimated by SRI are much lower than might be expected.

In the next section, which deals with evaluating different pavement designs using different maintenance policies under varying cases of traffic loading, it will be shown that a pavement, costing almost the same as the SRI proposal (but designed using the AASHO design criteria) remains at a PSI above 1.0 throughout the analysis period, requires minimal maintenance, and causes considerably lower vehicle operating costs.

B. Design and Evaluation of Feasibility Level Experiment.

The primary objective of the feasibility level experiment is to generate and evaluate a number of alternative strategies in terms of different pavement designs and maintenance policies under each of four different traffic loading cases.

The four traffic loading cases used in this section are defined as follows:

Case 1 Present and projected traffic assuming normal growth but no copper or developmental traffic.

Case 2 Case 1 plus transportation of Zambian copper in excess of the 1966 level of production.

Case 3 Case 1 plus transportation of all Zambian copper.

Case 4 Case 3 plus developmental traffic due to complementary investments in development schemes along the highway.

Traffic case 1 and case 4 are the same as those discussed earlier, in SECTION II-B. Case 2 and case 3 were redefined in order to analyse the effect of the incremental growth in copper traffic without developmental traffic. The volumes and projections for each of the four traffic cases defined above are summarized in TABLE 11.

Four pavement types and five maintenance policies were defined as follows:

Pavement Type 1 (PAVE 1) This was the old pavement with the cross-section characteristics and pavement thicknesses given in TABLES B.2a and B.2e respectively in Appendix B.

TABLE 11

TRAFFIC VOLUMES USED IN FEASIBILITY LEVEL EXPERIMENT

VEHICLE TYPE / LOADING CONDITION	CARS	BUSES	7 TON TRUCK	10 TON TRUCK	22 TON TRUCK	22 TON COPPER TRUCK
CASE 1						
1967	79	22	58	39	13	0
1980	239	54	98	66	22	0
Annual Growth Rate %	8.9	7.2	4.1	4.1	4.1	0
CASE 2						
1967	79	22	58	39	13	8
1980	239	54	98	66	22	100
Annual Growth Rate %	8.9	7.2	4.1	4.1	4.1	21.4
CASE 3						
1967	79	22	58	39	13	200
1980	239	54	98	66	22	300
Annual Growth Rate %	8.9	7.2	4.1	4.1	4.1	3.2
CASE 4						
1967	79	22	60	40	14	200
1980	239	54	101	91	32	300
Annual Growth Rate %	8.9	7.2	4.1	6.5	6.5	3.2

Pavement Type 2 (PAVE 2) and Pavement Type 3 (PAVE 3) were the DCI trench design and the DCI modified design respectively, shown in FIGURES 3 and 4 and described earlier under SECTION II-C.

Pavement Type 4 (PAVE 4) was the SRI design shown in FIGURE 2 and evaluated earlier under SECTION III-A.

Maintenance Policy 1 (MAINT-1) No maintenance at all.

Maintenance Policy 2 (MAINT-2) Moderate maintenance on the DBST road with no overlays (same as that used in evaluating the SRI proposals in SECTION III-A).

Surface Patching	900 sq.m/km per year
Major Seal Coat	every 5 years
Regravelling of Shoulders	2 times per year
Brush Control	2 times per year
Culvert/Ditch Cleaning	once a year

Maintenance Policy 3 (MAINT 3) Increased maintenance on the old road with a major overlay every 6 years, and increased frequency of seal coating.

Surface Patching	900 sq.m/km per year
Major Seal Coat	every two years
Overlay (5 cms.)	every 6 years
Resurfacing Gravel Shoulders	400 cu.m./km per year
Brush Control	2 times per year
Culvert/Ditch Clearing	once a year

Maintenance Policy 4 (MAINT-4) Moderate maintenance on the new asphalt concrete road with no overlay during the analysis period. (Same policy used in evaluating the SRI proposals in SECTION III-A).

Surface Patching	140 sq. m/km per year
Major Seal Coat	every 5 years
Grading of Gravel Shoulders	4 bladings per year
Culvert/Ditch Clearing	2 times per year

Maintenance Policy 5 (MAINT-5) Intensive maintenance on asphalt concrete road, with twice the amount of surface patching, increased frequency of seal coating, and an overlay every 6 years.

Surface Patching	280 sm/km per year
Major Seal Coat	every 2 years
Overlay (5 cms.)	every 6 years
Grading of Gravel Shoulders	4 bladings per year
Culvert/Ditch Clearing	2 times per year

1. DESIGN OF ALTERNATIVES TO BE EVALUATED

TABLE 12 gives the alternatives that were specified and evaluated for each traffic loading case and FIGURES 7a, 7b, and 7c give the same alternatives for the four traffic cases in the form of decision trees.

TABLE 12

ALTERNATIVES FOR EVALUATION

TRAFFIC LOADING CONDITION	ALTERNATIVE	PAVEMENT TYPE	MAINTENANCE POLICY
CASE 1	0	PAVE 1	MAINT 2
	1	PAVE 1	MAINT 3
	2	PAVE 2	MAINT 1
	3	PAVE 2	MAINT 4
CASE 2 and	0	PAVE 1	MAINT 2
	1	PAVE 1	MAINT 3
CASE 3	2	PAVE 2	MAINT 4
	3	PAVE 2	MAINT 5
	4	PAVE 3	MAINT 4
	5	PAVE 3	MAINT 5
	6	PAVE 4	MAINT 1
	7	PAVE 4	MAINT 4
CASE 4	0	PAVE 1	MAINT 2
	1	PAVE 1	MAINT 3
	2	PAVE 3	MAINT 4
	3	PAVE 3	MAINT 5
	4	PAVE 4	MAINT 4
	5	PAVE 4	MAINT 5

In all cases, the do nothing alternative was assumed to be the old pavement (PAVE 1) with moderate maintenance (MAINT 2). Specification of no-maintenance (MAINT 1) was not considered a realistic alternative for all cases, it was specified only with Pavement 2 in Traffic Case 1, and with Pavement 4 in Traffic Cases 2 and 3. For the lightest-traffic, (Case 1), only the cheapest pavement (PAVE 2) with maintenance

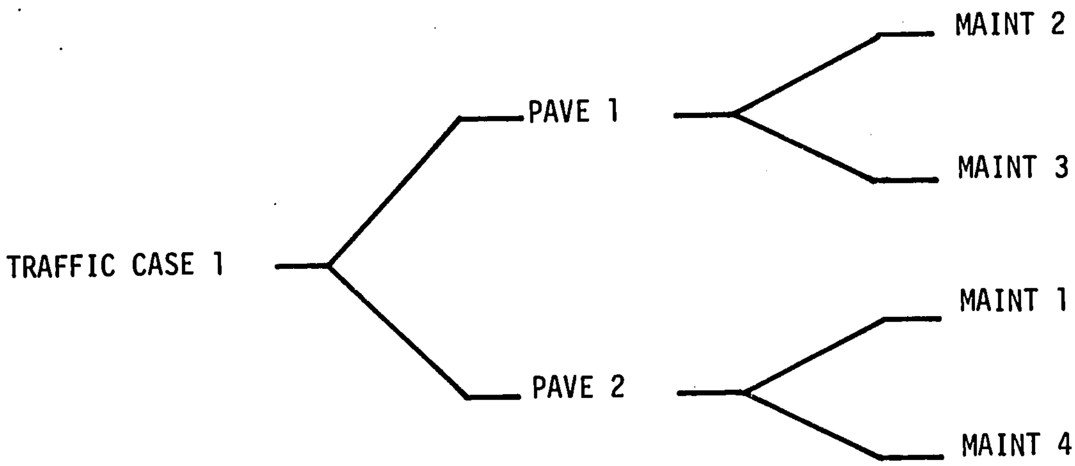

FIGURE 7a

DECISION TREE FOR ALTERNATIVES IN TRAFFIC CASE 1

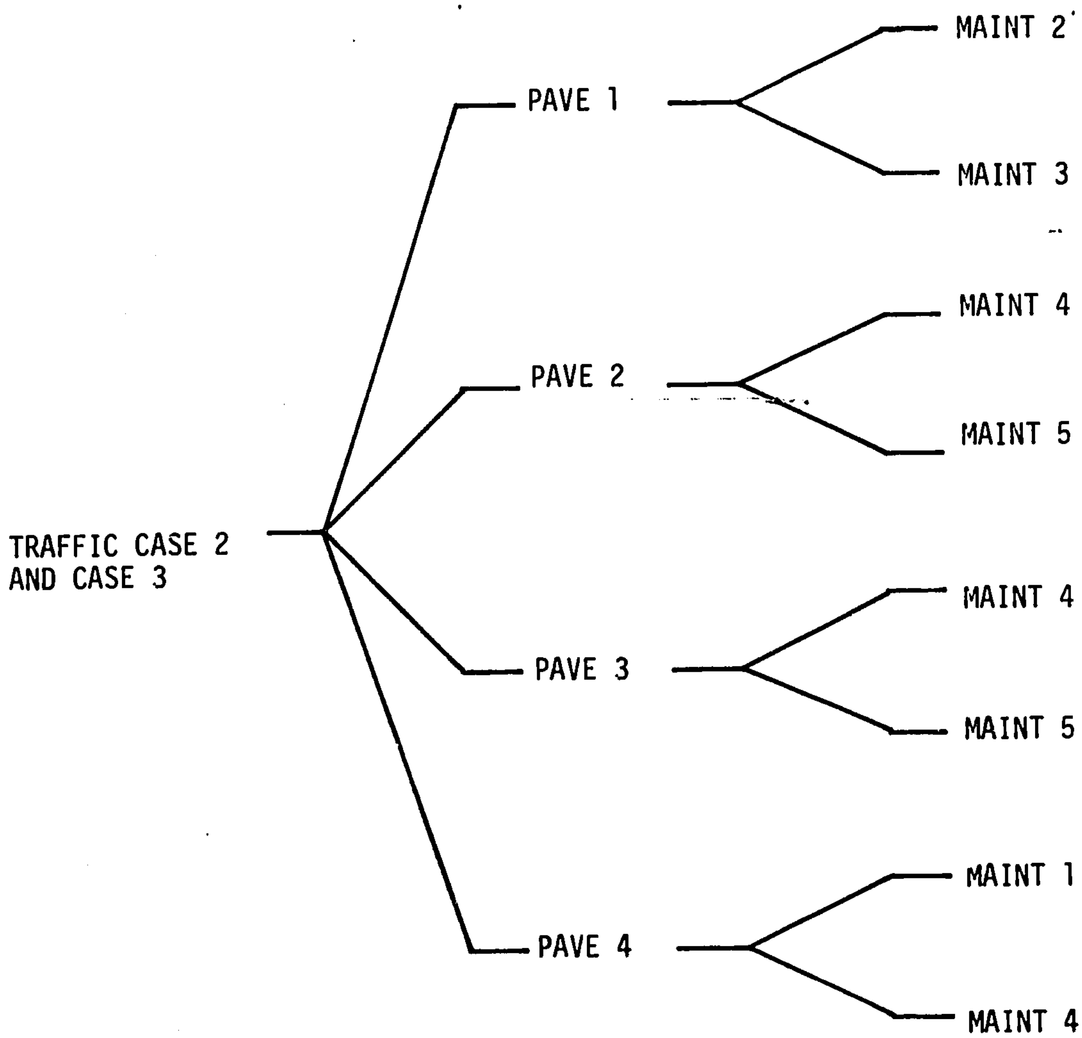

FIGURE 7b

DECISION TREE FOR ALTERNATIVES IN TRAFFIC CASES 2 AND 3

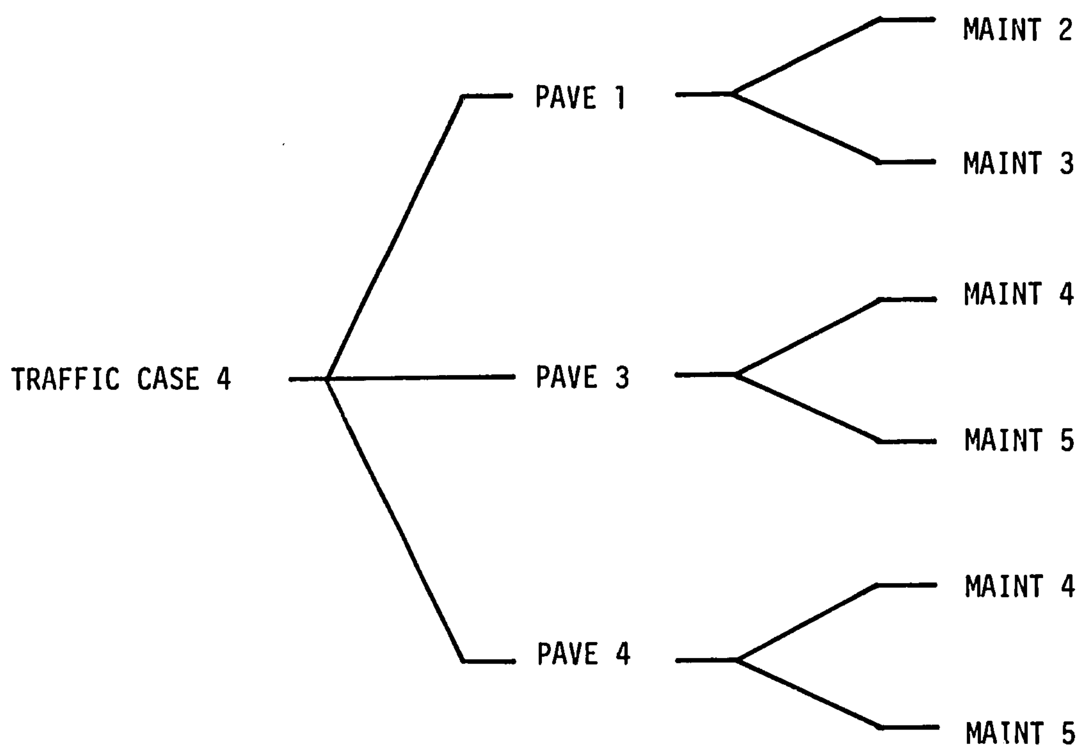

FIGURE 7c

DECISION TREE FOR ALTERNATIVES IN TRAFFIC CASE 4 policies 4 and 5, and the existing pavement (PAVE 1) with maintenance policy 3 were considered to be reasonable alternatives to the do-nothing case. Pavement 2, which was the weakest of the three pavement designs for the new road, was not considered a reasonable option for the heaviest traffic (Case 4).

A construction period of three years was specified with 50% of the construction costs in the first year, 30% in the second, and 20% in the third year. Since 98% of the construction is along a new alignment, traffic was continued over the old road during the three years of construction. Maintenance policy 2 was specified for the old road during the construction period. Therefore, maintenance costs obtained for alternatives specified with the no-maintenance policy refer to the maintenance costs on the old pavement (PAVE 1) during the first three years, when the new road is under construction. As before, an analysis period of 13 years was used, from 1967 to 1980. (This includes three years of construction and ten years of service). However, ten years of service is rather short for realizing the full value of the construction costs, therfore, a salvage value of 60% of the initial investment, discounted over the analysis period, is used in the present experiment. 60% of the initial investment amounts of all of the excavation, base, sub-base, and drainage costs, plus part of the surface cost components of the total construction costs.
Once again the PSI value of the road was not allowed to go below one. This again understates the vehicle operating costs especially on the old road which deteriorates to a PSI of one in less than one year even with the lightest traffic (Case 1).

2. EVALUATION OF ALTERNATIVES AND DISCUSSION OF RESULTS

The HCM was used to compute construction, maintenance and vehicle operating costs for each of the alternatives. A summary of the Present Value of these costs, with the salvage values, where applicable, and the total costs is presented in TABLES 13 through 16.

TABLE 13

SUMMARY OF TOTAL COSTS -- TRAFFIC CASE 1
(P.V. in Thousands of Shillings)

ALTERNATIVE	CONSTRUCTION	MAINTENANCE	VEHICLE OPERATING	SALVAGE VALUE	TOTAL COSTS	RANKING
(0) PAVE 1 - MAINT 2	0	10449	109084	0	119533	1
(1) PAVE 1 - MAINT 3	0	34675	85942	0	120617	*
(2) PAVE 2 - MAINT 1	28984	4017	97010	<5907>	124104	*
(3) PAVE 3 - MAINT 4	28984	7099	96590	<5907>	126766	*

* Total costs higher than for the do-nothing alternative

TABLE 14

SUMMARY OF TOTAL COSTS -- TRAFFIC CASE 2
(P.V. in Thousands of Shillings)

ALTERNATIVE	CONSTRUCTION	MAINTENANCE	VEHICLE OPERATING	SALVAGE VALUE	TOTAL COSTS	RANKING
(0) PAVE 1 - MAINT 2	0	10449	144210	0	154659	2
(1) PAVE 1 - MAINT 3	0	34968	116623	0	151591	1
(2) PAVE 2 - MAINT 4	28984	7105	129412	<5907>	159594	*
(3) PAVE 2 - MAINT 5	28984	20170	118888	<5907>	162135	*
(4) PAVE 3 - MAINT 4	30414	7101	128392	<6199>	159708	*
(5) PAVE 3 - MAINT 5	30414	20153	118103	<6199>	162471	*
(6) PAVE 4 - MAINT 1	35418	4485	127066	<7219>	159750	*
(7) PAVE 4 - MAINT 4	35418	7704	126583	<7219>	162486	*

* Total costs higher than for the do-nothing alternative.

TABLE 15

SUMMARY OF TOTAL COSTS-TRAFFIC CASE 3

(P.V. in Thousands of Shillings)

ALTERNATIVE	CONSTRUCTION	MAINTENANCE	VEHICLE OPERATING	SALVAGE VALUE	TOTAL COSTS	RANKING
(0) PAVE 1 - MAINT-2	0	10 449	378 695	0	389 144	
(1) PAVE 1 - MAINT-3	0	35 689	339 399	0	375 088	2
(2) PAVE 2 - MAINT-4	28 984	7 124	355 230	<5907>	385 431	
(3) PAVE 2 - MAINT-5	28 984	20 337	332 305	<5907>	375 719	3
(4) PAVE 3 - MAINT-4	30 414	7 122	353 719	<6199>	385 056	
(5) PAVE 3 - MAINT-5	30 414	20 322	330 178	<6199>	374 716	1
(6) PAVE 4 - MAINT-1	35 418	4 485	350 265	<7219>	382 949	
(7) PAVE 4 - MAINT-4	35 418	7 727	349 373	<7219>	385 299	

TABLE 16

SUMMARY OF TOTAL COSTS -- TRAFFIC CASE 4

(P.V. in Thousands of Shillings)

ALTERNATIVE	CONSTRUCTION	MAINTENANCE	VEHICLE OPERATING	SALVAGE VALUE	TOTAL COSTS	RANKING
(0) PAVE 1 - MAINT- 2	0	10449	390188	0	400637	
(1) PAVE 1 - MAINT- 3	0	35699	350465	0	386164	2
(2) PAVE 3 - MAINT- 4	30414	7123	364677	<6199>	396015	
(3) PAVE 3 - MAINT- 5	30414	20327	340222	<6199>	384764	1
(4) PAVE 4 - MAINT- 4	35418	7727	360277	<7219>	396203	
(5) PAVE 4 - MAINT- 5	35418	22008	336655	<7219>	386862	3

2.1 CONSTRUCTION COSTS

Pavement Type 3 (DCI modified design) costs approximately 1.4 million shillings more than Pavement Type 2 which is the DCI trench design. This additional cost is due to the extension of the crushed stone (or sand asphalt) base and the gravel subbase across the entire cross-section of the road, including the shoulders, as specified in the DCI modified design. The SRI design costs 5 million shillings more than the DCI modified design, mainly due to the additional 1.27 cms (½") of asphalt concrete surface and 5.08 (2") of crushed stone base, and to the increased width of the total cross-section.

2.2 MAINTENANCE COSTS

The maintenance costs for the moderate maintenance policy (MAINT-4) on the new road increase slightly with increases in the intensity of traffic loading, from 7.099 million on Pavement 2 in Traffic Case 1 to 7.124 on the same pavement in Traffic Case 3. This slight increase is due to the increase in surface cracking, and hence, surface patching, as a result of increased traffic in the initial years when the full 140 sq.m/km of surface patching is not yet required as specified in the maintenance policy. The amount of surface patching performed (when less than 140 sq. m/km) also varies with the type of pavement. For example, in Traffic Case 3 the maintenance cost on Pavement 3 for Maintenance Policy 4 is 7.122 million and increases to 7.124 million on Pavement 2 and 7.72 on Pavement 4. However, part of the increase on Pavement 4 is due also to the wider section. The same argument holds for Maintenance Policy 5 which includes an overlay after 6 years; the cost differences are due to the differences in the amount of surface patching in the initial years and the years immediately following the overlays.

On the old road, the maintenance cost for Maintenance Policy 2 is the same (10.499 million) for all traffic cases. This is because the road deteriorates to a PSI of 1.0 in less than a year in all cases and the full amount of 900 sq.m/km of surface patching is done each year throughout the analysis period. However, the cost for

Maintenance Policy 3, which includes an overlay after six years, increases from 34.675 million for Traffic Case 1 to 35.699 million for Traffic Case 4 due to the differences in the amount of surface patching in the years following the overlay.

2.3 VEHICLE OPERATING COSTS

Vehicle operating costs are primarily a function of traffic and pavement deterioration. The increase in vehicle operating costs due solely to the increase in traffic is apparent from the vehicle operatings costs on the existing pavement (PAVE 1) with Maintenance Policy 2: the cost in Traffic Case 1 is 109.1 million increasing to 144.2 million for Traffic Case 2 and 378.7 million for Case 3 and 390.2 for Case 4. Similarly the vehicle operating costs on Pavement 2 with Maintenance Policy 4 are 96.6 million in Case 1, 129.4 million in Case 2 and 355.2 million in Case 3.

The differences in the vehicle operating costs within a particular traffic case are due to the different deterioration characteristics of the various pavements and different maintenance policies.

For example in Traffic Case 4, TABLE 16, the vehicle operating costs on Pavement 4 are 360.277 million shillings with Maintenance Policy 4, but on Pavement 3 they are 364.677 million shillings with the same Maintenance Policy; an increase of 4.4 million shillings. This is primarily due to the fact that Pavement 3 with Maintenance Policy 4 is at or below a PSI of one for a longer duration of time on most segments than Pavement 4. This difference in the deterioration characteristics is seen more clearly in FIGURE 8, and discussed under Pavement Deterioration.

Similarly the effect of maintenance policy on the vehicle operating cost is apparent from the same traffic case 4 in TABLE 16, where going from Maintenance Policy 4 to Maintenance Policy 5 on Pavement 3 reduces vehicle operating costs from 364.677 million shillings to 340.222 million shillings. This reduction is due to the improvement made in the pavement strength by the overlay after 6 years, resulting in a slower rate of deterioration thereafter. A further discussion of the tradeoffs between different maintenance expenditures and the incremental savings in vehicle operating costs is presented under Maintenance Trade-offs.

2.4 ALTERNATIVE RANKING

Judging from the total costs involved in terms of construction, maintenance and vehicle operating costs (net of any salvage value), it is apparent that building a new road for Traffic Cases 1 and 2 is not a cheaper alternative to the do-nothing case of using the old road with moderate maintenance. However, for Traffic Case 2, a cheaper alternative is to use the old road with increased maintenance (including an overlay every six years) in which case an additional 24.5 million shillings in maintenance costs reduces vehicle operating costs by 27.6 million shillings, a net saving of approaximately 3 million shillings.

For Traffic Cases 3 and 4, the alternative with the least total cost is Pavement 3 (the DCI modified design) with an intensive maintenance policy which includes an overlay after six years, seal coating every 2 years, and 280 sq.m/km of surface patching each year. The difference in the present value of total costs for this alternative and the do-nothing alternative is 14.4 million shillings in Traffic Case 3 and 15.8 million in Traffic Case 4.

It is interesting to note that, in Traffic Case 2 (which included normal traffic plus transportation of the expected growth in copper production above the 1966 level) savings in terms of reduced vehicle operating costs are not sufficient to offset the capital costs involved in building and maintaining a new road required to transport the expected growth in copper production. However, these reductions in operating expenses are significant for the traffic cases involving transportation of all copper (Case 3) and all copper plus developmental traffic (Case 4).

2.5 MAINTENANCE TRADEOFFS

Comparing the alternative of a moderate maintenance policy (MAINT-4) to an intensive maintenance policy (MAINT-5) on Pavement 3 for Traffic Cases 2, 3, and 4, it is seen that the tradeoff ratio between maintenance expenditure and user savings is 1:0.79 for Traffic Case 2, increasing to 1:1.78 and 1:1.85 for heavier traffic (Cases 3 and 4). In other words, at higher traffic levels such as Case 3 and Case 4, the savings in user costs more than offset increased maintenance costs due to overlays and the increased frequency of seal coating and surface patching. On the other hand, it would appear, by observing the difference in vehicle operating costs on pavements with the options of no-maintenance (MAINT-1) and moderate maintenance (MAINT-4) policies, such as Pavement 2 in Traffic Case 1 (TABLE 13), and Pavement 4 in Traffic Case 2 and 3 (TABLES 14 and 15) that moderate maintenance which includes surface patching and seal coating, but no overlays, has no significant effect on vehicle operating costs. For example, on Pavement 2 in Traffic Case 1 (TABLE 13), the additional cost of approximately 3 million shillings due to moderate maintenance reduces vehicle operating costs by less than one half million shillings.* Similarly, on Pavement 4 for Traffic Cases 2 and 3, the additional cost of about 3.3 million shillings due to moderate maintenance reduces vehicle operating costs by only one half million shillings in Traffic Case 2 and about 1 million in Traffic Case 3. The reason for this apparent insensitivity of vehicle operating costs to a moderate maintenance effort is primarily the rapid deterioration characteristics of the pavements in question.

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*The reader is reminded that the maintenance costs shown for the policy of no maintenance (MAINT-1) refer to the maintenance costs on the old road during the 3 year construction period.

Analysis with the HCM showed that less than 4 years after opening, over 60% of the road with Pavement 2 deteriorated to a PSI value of 1.0 under Traffic Case 1, and over 75% of the road with Pavement 4 deteriorated to the same value under Traffic Cases 2 and 3. Therefore, any patching and sealing of surface cracks on pavements that are structurally weak and have a high rate of deterioration causes no lasting improvement in the Present Serviceability Index of the road, hence little change in the vehicle operating costs.

In such a situation, an overlay would be justified only if the volume of traffic were high enough to give a ratio between incremental user savings and the overlay cost greater than one, such as for Traffic Case 3 shown earlier. Otherwise maintenance efforts, short of adequate initial reconstruction, simply waste resources.

2.6 PAVEMENT DETERIORATION

The pavement deterioration relationships used in the HCM for paved roads with granualar bases are derived primarily from the AASHO Road Test, and the deterioration is predicted in terms of the drop in the Present Serviceability Index (PSI).

The drop in the PSI in each year of the analysis period is computed as a function of the volume of equivalent standard axles, and the effective (or modified) structural number of the pavements. The annual deterioration is modified by adding an annual deterioration factor which incorporates time dependent deterioration due solely to aging of the pavement.

The structural number of a pavement is defined by an empirical relationship in which the thickness and strength of the pavement layers are combined together as follows:

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

where, SN is the structural number,

a_i is the strength coefficient of the i^{th} layer,

D_i is the thickness of the i^{th} layer, in inches

and the summation is over all pavement layers.

The strength coefficients (a_i) used in the HCM for various pavement layer materials were as follows:

ashpalt concrete	0.44
bituminous surface	0.20
crushed stone base	0.14
sand asphalt base	0.20
gravel subbase	0.11
sand subbase	0.08

The structural number is then modified ($\overline{SN}$) to take into account the strength of the subgrade, environmental impact, and the drainage characteristics of the base and subbase. The CBR value is used to denote the subgrade strength, while a regional factor, RG, is used as a proxy for the environmental impact, and a drainage factor DF = 1.0 is used to denote reasonably well drained base and subbase conditions. Higher drainage and regional factors indicate weaker effective pavement strength.[(1)]

For Pavements 3 and 4 a drainage factor of 1.0 was used while, in the absence of better information, a drainage factor of 1.2 was used for the trench design (Pavement 2), denoting a 20% poorer drainage characteristic compared with Pavement 3.

[(1)] For a detailed description of the pavement deterioration submodel see Chapter 3 in "The Highway Cost Model: General Framework, MIT, June 1975.

TABLE 17 summarizes the total number of 18 kip Equivalent Single Axle Load (ESAL) applications that the SRI and the DCI modified designs can withstand before reaching a PSI value of 2.0 on segments with CBR values of 7%, 10% and 30%, as computed with the HCM.

TABLE 17

COMPARISON OF THE DCI AND SRI PAVEMENT PERFORMANCE TO PSI OF 2.0

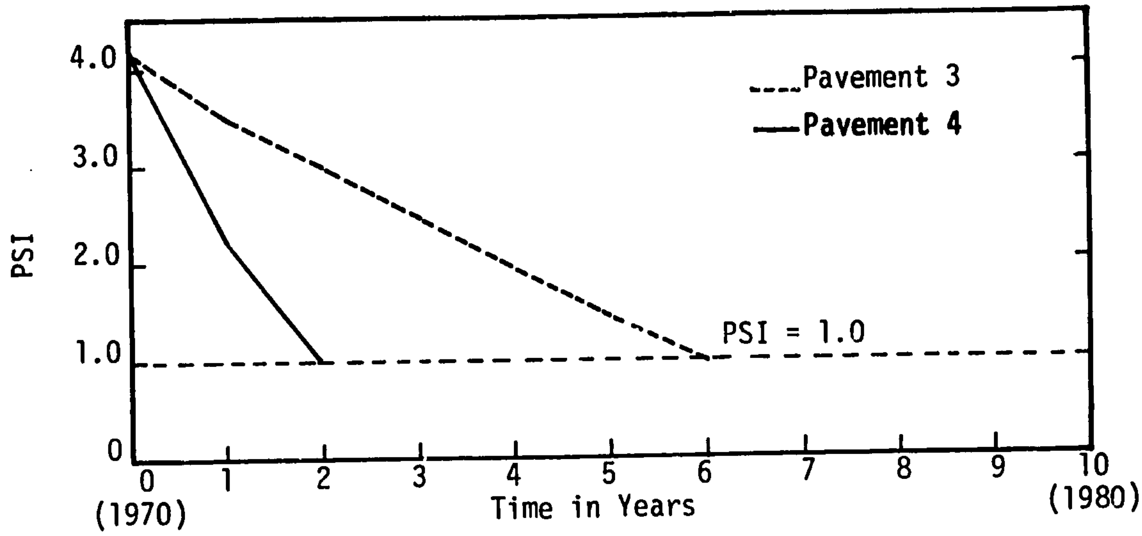
SUBGRADE CBR VALUE %	STRUCTURAL NUMBER (SN)		MODIFIED STRUCUTURAL NUMBER ($\overline{SN}$)		TOTAL 18 kip EQUIVALENT SINGLE AXLE LOADS (in thousands)	
	DCI DESIGN	SRI DESIGN	DCI DESIGN	SRI DESIGN	DCI DESIGN	SRI DESIGN
7	2.81	2.27	3.48	2.84	550	150
10	2.12	2.27	2.86	3.05	180	230
30	1.36	2.27	2.41	3.76	<60	970

It is seen that the DCI modified design reaches a PSI value of 2.0 after 550,000 18 kip ESAL applications on segments with subgrade CBR value of 7% (modified structural number of 3.48); after 180,000 applications on subgrades with CBR value of 10% (modified structural number of 2.86) and less than 60,000 applications on subgrades with CBR value of 30% (modified structural number of 2.41). Hence the DCI pavement (1) is apparently underdesigned on subgrades with CBR values of 10% and 30% but close to its expected performance on subgrades with CBR value of 7%,

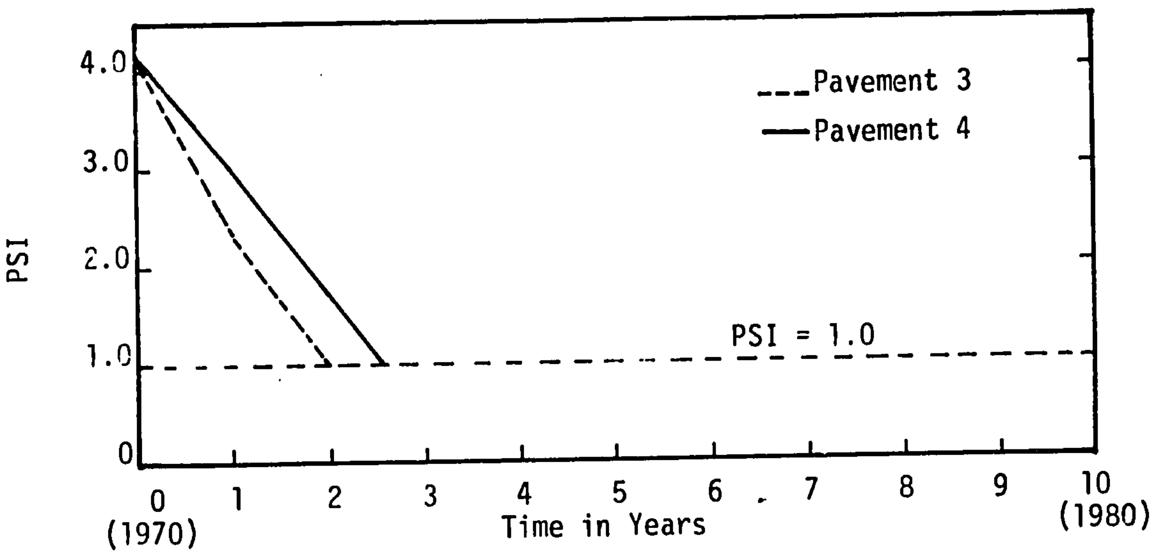
(1) This pavement was designed for 675,000 applications of 18 kip equivalent single axles and a terminal PSI of 2.0, with variable subbase thicknesses in recognition of the underlying subgrade strength (described in SECTION II-C).

The SRI pavement, on the other hand, which was not designed in recognition of the underlying subgrade strength, is capable of taking nearly a million applications of 18 kip ESAL's on subgrades with CBR of 30% (modified structural number 3.76), but only 150,000 applications on a CBR of 7% before reaching a PSI value of 2.0.

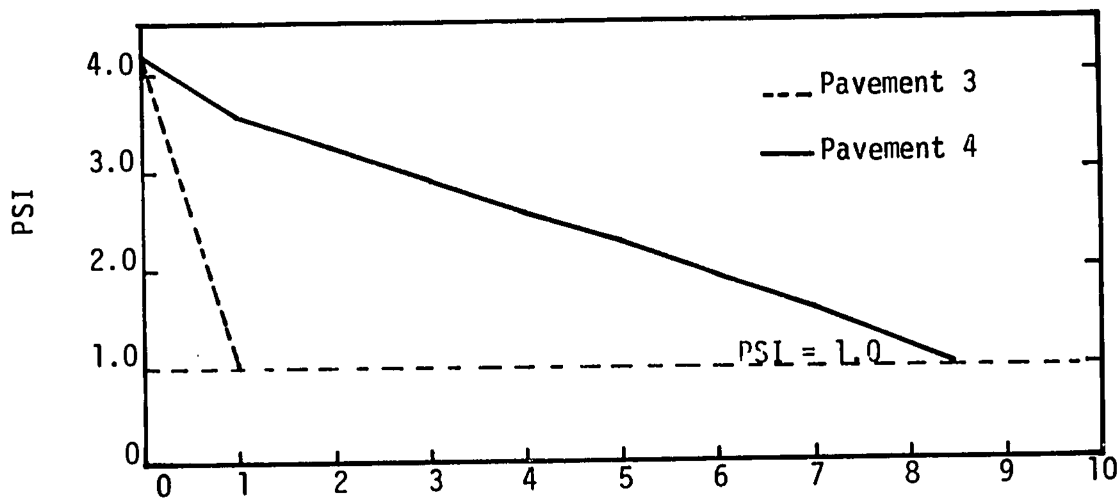
Figures 8a, 8b, and 8c compare the PSI versus time characteristics of Pavements 3 and 4 (the DCI modified design and the SRI design) on subgrades with CBR values of 7%, 10% and 30% respectively under the heaviest traffic (Case 4). As was noted earlier, in SECTION III-A under Evaluation of the SRI Proposal, the SRI pavement is underdesigned on segments with CBR values of 10% and 7%. The DCI modified design, (Pavement 3) on the other hand, deteriorates to a PSI of 1.0 on segments with subgrade CBR values of 10% and 30% in less than 2 years, while on segments with a CBR of 7% in 6 years, so that it is clearly underdesigned on segments with CBR values of 10% and 30%.



(a) SUBGRADE CBR 7%



(b) SUBGRADE CBR 10%



(c) SUBGRADE CBR 30%

FIGURE 8

PSI VERSUS TIME - MAINTENANCE POLICY 4

2.7 EVALUATION OF A PAVEMENT DESIGNED ACCORDING TO AASHO DESIGN CRITERIA

A new pavement, defined as Pavement Type 5, was designed using the AASHO design criteria and evaluated under the heaviest traffic loading (Case 4), and Maintenance Policies 4 and 5. The pavement was designed to have a modified structural number of 4.4 (compared to the highest value of 3.48 in the DCI design, and 3.76 in the SRI design). The required structural numbers (SN) were 3.55 for a CBR of 7%, 3.25 for a CBR of 10% and 2.45 for a CBR of 30%. Using Equation 1 and the material coefficients given on page 51, the various pavement layer thicknesses were computed as summarized in TABLE 18.

TABLE 18

PAVEMENT THICKNESSES - PAVEMENT TYPE 5

SURFACE (ASHPALT CONCRETE)	5.08 cms (2 ins)
BASE COURSE (CRUSHED STONE)	12.70 cms (5 ins)
SUBBASE (GRAVEL)	
on a subgrade with a CBR of 7%	46.41 cms (18.27 ins)
on a subgrade with a CBR of 10%	41.17 cms (15.42 ins)
on a subgrade with a CBR of 30%	25.95 cms (10.22 ins)

Since Pavement 5 was designed to have the same modified structural number on all subgrades, the deterioration pattern did not vary significantly on different segments. FIGURE 9 shows the deterioration of Pavement 5 with Maintenance Policy 4 during the analysis period. Due to the higher initial strength, Pavement 5 deteriorates at a much slower rate than the SRI and DCI pavements, reaching a PSI of 2.0 nine years after the opening of the road, and after a total of just over 2 million

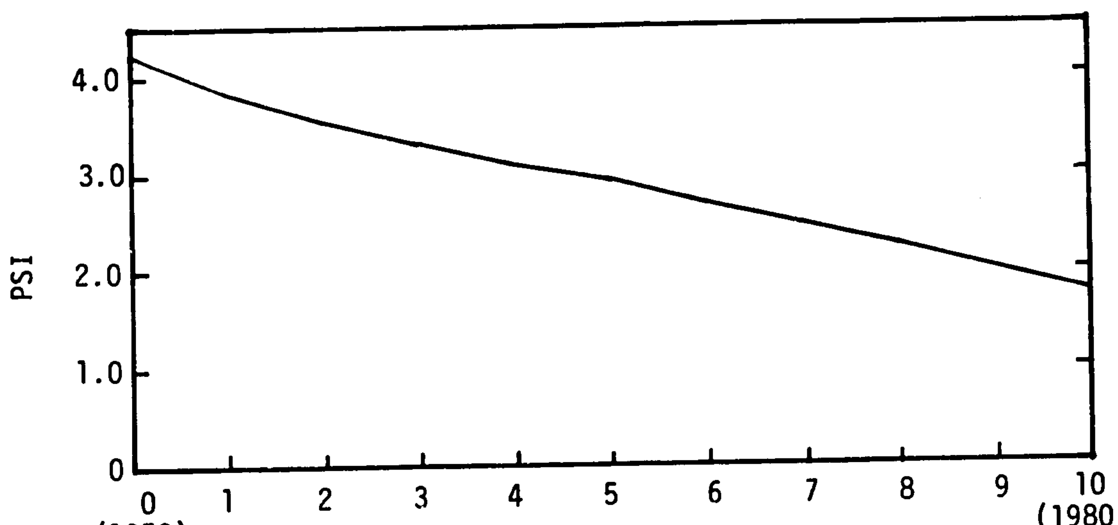


FIGURE 9

PSI VERSUS TIME - PAVEMENT 5-MAINTENANCE POLICY 4

18 kip ESAL applications. It reaches a PSI of 1.7 at the end of the analysis period.

A summary of the present value (P.V.) of maintenance, construction, vehicle operating and total costs, net of salvage value, for Pavement 5 with Maintenance Policy 4 and 5 under Traffic Case 4 is presented in TABLE 19.

TABLE 19

SUMMARY OF TOTAL COSTS - TRAFFIC CASE 4 - PAVEMENT 5
(P.V. in Thousands of Shillings)

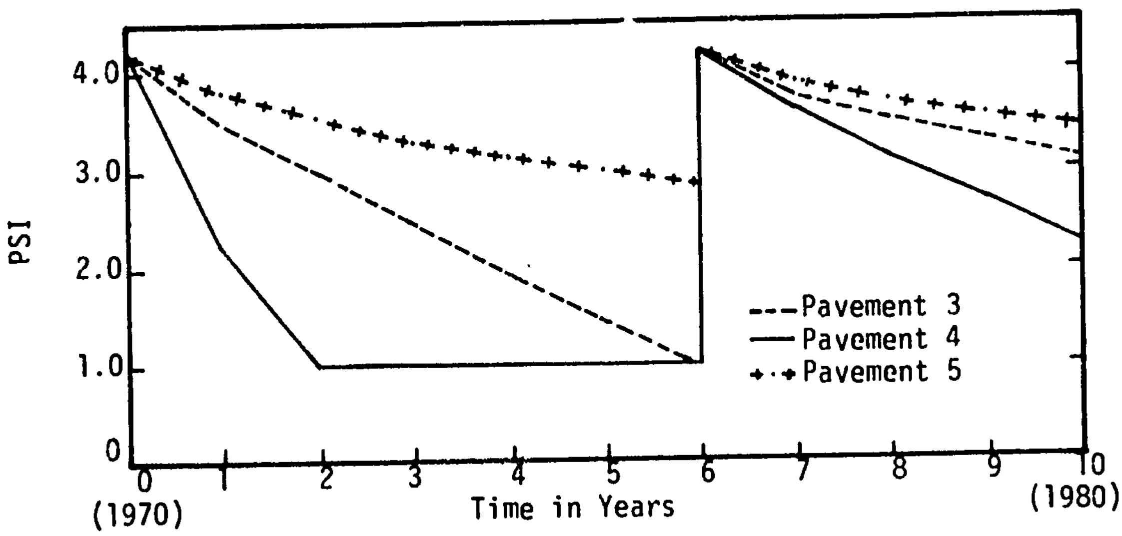
ALTERNATIVE	CONSTRUCTION	MAINTENANCE	VEHICLE OPERATING	SALVAGE VALUE	TOTAL COSTS
PAVE 5-MAINT 4	35761	7556	298075	<7289>	334103
PAVE 5-MAINT 5	35761	20491	293594	<7289>	342557

Comparing the results for Pavement 5 in TABLE 19 with the previous alternatives for the same traffic (Case 4) in TABLE 16, it can be noted that Pavement 5 costs about 5 million more to construct than Pavement 3 (DCI modified design) and only 0.34 million more than Pavement 4 (SRI design). The greater cost difference with the DCI pavement is due to the greater depths of the surface, base and subbase. The vehicle operating costs are considerably lower on Pavement 5 because during a major portion of the analysis period the PSI value is well above 2.0, the point after which the vehicle operating costs begin to increase exponentially with further drop in PSI.

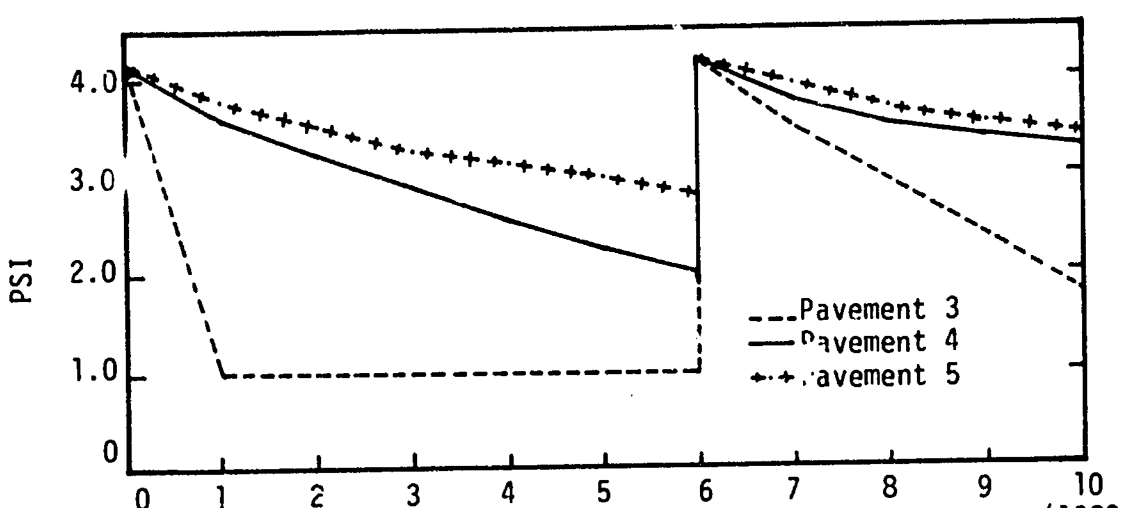
In comparing Maintenance Policy 5 with Policy 4 on Pavement 5, we note that the additional maintenance cost of about 13 million shillings reduces vehicle operating costs by only about 4.5 million. This is due to the fact that the pavement is in relatively good condition (PSI = 2.7) in the sixth year when the overlay is scheduled. Therefore, the relative improvement in the road condition is small and the corresponding savings in vehicle operating costs would also be small. This is contrary to what one observes in the case of Pavements 3 and 4 in TABLE 16, where change from the moderate to the intensive maintenance policy on Pavement 3 costs about 13 million shillings more, but reduces vehicle operating costs by 23.6 million. This is made clearer by observing the deterioration patterns of Pavements 3, 4, and 5 as shown in FIGURES 10a and 10b for subgrade CBR values of 7% and 30% respectively. FIGURE 10a, shows that 6 years after the opening of the road, when the overlay is scheduled, Pavements 3 and 4 are already at a PSI of 1.0, but Pavement 5 is at 2.7. In FIGURE 10b, Pavement 5 is at a PSI of 2.7 in Year 6, Pavement 3 at a PSI of 1.0 and Pavement 4 at 2.0, so that the overlay has a greater impact of Pavements 3 and 4 compared to Pavement 5 in restoring their PSI values to 4.2, and decreasing vehicle operating costs.

In terms of least total costs, therefore, the cheapest alternative in Traffic Case 4 is to use the new pavement (PAVE 5) with only moderate maintenance. Compared to the previous best alternative (Pavement 3, the DCI modified design, with intensive maintenance) the new pavement costs 5 million shillings more to construct, but reduces maintenance costs by 12.8 million shillings and vehicle operating costs by 42.1 million shillings. Compared to the SRI proposal (Pavement 4 and Maintenance Policy 4) we see that, although there is not a significant difference in the initial construction and subsequent maintenance costs, the vehicle operating costs on Pavement 5 are 62.2 million shillings less than on Pavement 4. In both cases the savings in vehicle operating costs result primarily form the slower rate of deterioration of Pavement 5.

This has interesting implications for government decisions on initial investments for road building, especially whan a large portion of the investment is funded by international agencies and other aid programs. In this situation, it would be appropriate for the government to consider building a heavier pavement initially which would require only moderate maintenance, thus making available for investment elsewhere,



(a) SUBGRADE CBR 7%



(b) SUBGRADE CBR 30%

FIGURE 10

PSI VERSUS TIME - MAINTENANCE POLICY 5

the resources normally allocated to an intensive maintenance policy.

2.8 CONCLUSIONS

The following conclusions may be drawn from the above analysis.

For Traffic Cases 1 and 2, the alternative of building a new road involves greater discounted total costs than the alternative of using the old road. For Traffic Case 1, only moderate maintenance is recommended on the old road, while for Traffic Case 2 an increased maintenance policy, which includes an overlay after six years and seal coating every two years, is recommended.

For the heavier traffic (Cases 3 and 4), the DCI modified design (PAVE 3) is cheaper in terms of total discounted costs than the SRI design (PAVE 4). The DCI design, however, reguires an intensive maintenance policy of overlays every six years and seal coatings every two years. The DCI design with this intensive maintenance will have a PSI below 2.0 for most of the time before the overlay. This is due to the initially weak design, which will result in relatively high vehicle operating costs.

If a pavement is built weak initially, and hence, has a rapid rate of deterioration, any increase in the frequency of seal coats or surface patching does not reduce the vehicle operating costs significantly.

A pavement built stronger initially would keep the new road above a PSI of 2.0 for most of the time, requiring only moderate maintenance (no overlays) and hence, resulting in substantially reduced vehicle operating costs. Hence, a better alternative for Traffic Cases 3 and 4 would have been to build a stronger pavement, such as Pavement 5, initially and do only moderate maintenance in the future.

Governments confronted with uncertainties over future maintenance allocations or organizational inefficiencies in the execution of planned maintenance programs should seriously consider making higher initial investments in constructing a stronger pavement. Such pavements would require only moderate maintenance in the future, be less sensitive to variations in maintenance budgets or practice, and result in considerably lower vehicle operating costs.

Furthermore, this is of particular interest when a large portion of the initial investment will be met by international funding agencies through aid programs, while the entire maintenance expenditure must be met from local resources.

C. Post Construction Investment Tradeoffs

1. INTRODUCTION

The third phase of this case study covers the deterioration aspects of the Dar-Morogoro segment of the Tan-Zam Highway after its construction. In this phase an attempt is made to predict the rates of deterioration for different maintenance policies and the efficiencies of these policies under different traffic loading (and overloading) assumptions.

The analysis begins in 1970 with the start of construction of the new Dar-Morogoro segment, and ends in 1993. The traffic at the start of 1970 is shown in TABLE 20. These volumes are based on the projections developed by DCI (TABLE 5) with the 7 and 10 ton truck category split in the ratio 3:1.

TABLE 20

AVERAGE DAILY TRAFFIC ON DAR-MOROGORO SEGMENT IN 1970

Pass. Cars	50 Pass Bus	7 Ton Truck	10 Ton Truck	22 Ton Truck
158	58	142	47	25

The new road was built during 1970-1973, according to the Modified DeLeuw Cather (DCI) pavement design described in SECTION II-C and shown in FIGURE 4. During this period passenger car ADT grew at 8.9% per year, buses at 7.2%, and all trucks at 4.5%[1]. When the road opened in 1973

(1) Source: USAID [7], in Appendix A.

(year 4 of our analysis) an impulse traffic jump of 12.5% above the nominal growth rates was predicted by DCI. We have not been able to verify this assumption from the literature or more current traffic counts. Thereafter, the rates of growth of traffic continued as before for the duration of the analysis period (to 1993) with one possible exception, a mode shift of part of the medium and heavy truck traffic to the railroad.

The original schedule for the railroad link from Zambia to Dar-es-Salaam called for completion of the railroad in 1979, at which time DCI posited a one-time loss of 14.5% of the 7 and 10 ton and 35.5% of the 22 ton truck traffic. Current projections place the opening, and therefore the shift, around 1976. The overall growth pattern is summarized in TABLE 21.

TABLE 21

TRAFFIC GROWTH RATES (%)

	1970-1973 during con.	1973-1974 opening year	1974-1993 nominal growth	1976 loss when RR opens
PASSENGER CARS	8.9	21.4	8.9	—
BUSES	7.2	19.7	7.2	—
7 & 10 TON TRUCKS	4.5	17.0	4.5	-14.5
22 TON TRUCKS	4.5	17.0	4.5	-35.5

2. MAINTENANCE POLICIES

The first issue to be analyzed concerns the effect of various maintenance policies on the deterioration of the road. The concern here is primarily with the trade-off which exists between the maintenance cost and vehicle operating costs. The vehicle operating cost is affected by the deterioration of the road, and using the HCM one is able to generate the time stream of maintenance costs and vehicle operating costs for a selected number of maintenance policies.

Three policies are specified for this analysis. These policies are shown in TABLE 22. In order to represent more accurately the costs of vehicle operation on failed roads, the PSI was allowed to drop to zero, rather than one as used earlier.

TABLE 22

ASPHALT MAINTENANCE POLICIES

	Moderate	Intensive	Responsive
SURFACE PATCHING (m^2/km/yr)	140	280	280
SEAL COATS (Frequency)	every 5 years	every 2 years	every 2 years
OVERLAYS OF 5 cm.	none	every 6 years	when PSI on segment drops below 2.5
SHOULDER GRADING (Bladings per year)	4	4	4
CULVERT CLEANING (Times per year)	2	2	2

The first is a scheduled policy and includes surface patching each year, seal coats applied every five years, shoulder grading, and culvert cleaning. No overlays are performed over the life of the road in this first policy. It is referred to as the moderate policy, and is the same as MAINT 4 specified earlier.

The second policy is a more intensive scheduled policy than the first. Twice as much patching is done each year, and seal coats are applied every two years. Shoulder grading and culvert cleaning are as before. In addition, this policy provides for overlays of 5 cm every six years. This is the intensive policy, and is identical to MAINT 5.

The third policy is identical to the second, except the overlays are not scheduled, but rather are set to occur whenever the PSI of the section drops below 2.5. This is referred to as the demand-responsive, or responsive, policy.

The moderate policy is substituted for both the intensive policy and the responsive policy in year 20 to prevent overlaying near the end of the analysis horizon.

FIGURE 11 shows the present worth of the 1970 to 1993 stream of maintenance and vehicle operating costs (economic) for the three miantenance policies. The cost streams are discounted at 10% to a present value in 1970. The three columns of costs have been labeled A, C, and E to simplify reference in the text.

The additional maintenance expenditure to go from the moderate policy (Column A) to the intensive policy (Column C) is about 18.7 million shillings. The return to this expenditure, in terms of vehicle operating cost savings, is about 61 million shillings. In other words for each additional shilling of maintenance expenditure, over three shillings in operating costs are saved.

If the government seeks a minimum total cost solution, then the intensive maintenance policy would be recommended over the moderate. On the other hand, if the government wishes to transfer more of the cost of the infrastructure to the local transport industry and road users or if there are budgetary constraints, it may choose the moderate policy. It should be noted, however, that adoption of the moderate policy will not only cause the public to bear the additional cost, but will also result in a net loss (extra cost) to the nation as a whole of 42.3 million shillings. The intensive policy would have an incremental benefit to cost ratio of 3.0 at 10% discount rate and a life span of 23 years, and since few investment opportunities yield such a high return, it is unlikely that the government would choose the moderate policy solution over the intensive.

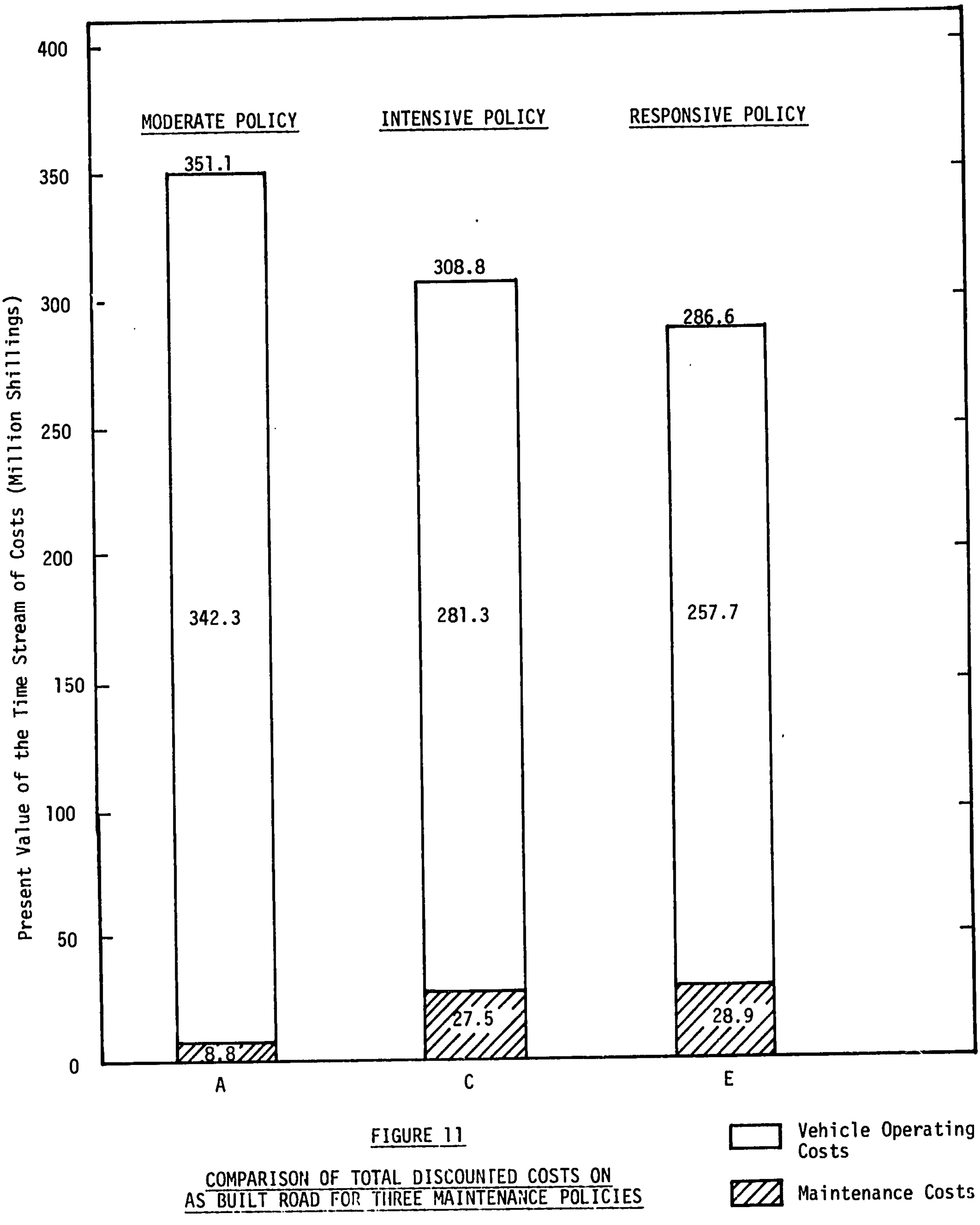


FIGURE 11

COMPARISON OF TOTAL DISCOUNTED COSTS ON AS BUILT ROAD FOR THREE MAINTENANCE POLICIES

Assuming, therefore, the minimum total cost solution is the objective, it is interesting to examine the responsive maintenance policy costs (Column E). For an additional maintenance expenditure over the intensive policy of about 1.4 million shillings, a further savings in vehicle operating costs of 23.6 million shillings occurs--an incremental benefit to cost ratio of nearly 17.0. It is perhaps easier to understand this large savings in user costs for a small increment in maintenance expenditure by examining the rate of deterioration on three segments of the road which represent about 62% of the total length.

Segment 101 is 68 kilometers long and is 37% of the entire Dar-es-Salaam--Morogoro section of the Tan-Zam Road. It has a subgrade CBR of 10% (the lowest in the project is 7%) and its pavement has a structural number of 2.12. The modified strucutral number (modified for the subgrade CBR and local environmental factors) is 2.86. Without any overlays this pavement deteriorates to a Present Serviceability Index (PSI), as calculated by the HCM, of zero with five years of operation; PSI falls below two after only 2-½ years of service.

FIGURE 12 shows the deterioration of Segment 101 expressed as PSI versus time for the intensive maintenance policy (solid line) and the responsive policy (broken line) from the opening of the road in 1973 to the end of the analysis period. Overlays under the intensive policy occur in years 1978-79 and 1984-85. Overlays for the responsive policy occur in 1975-76 (three years earlier), and in 1983-84 (one year earlier). The cost of these overlays are identical in the year they occur, however, discounting causes earlier overlays to have a higher present value in 1970, thus accounting for part of the extra cost.

Segments 103 (kilometer 88 to 103) and 105 (kilometer 118 to 144) represent about 23% of the entire Dar-es-Salaam--Morogoro section of the Tan-Zam Road. They have a subgrade CBR of 30% and a structural number of 1.36. The modified structural number is 2.44. Without any overlays, the pavement deteriorates to a PSI, as calculated by the HCM, of zero with two years of operation, passing PSI = 2.0 after only one year.

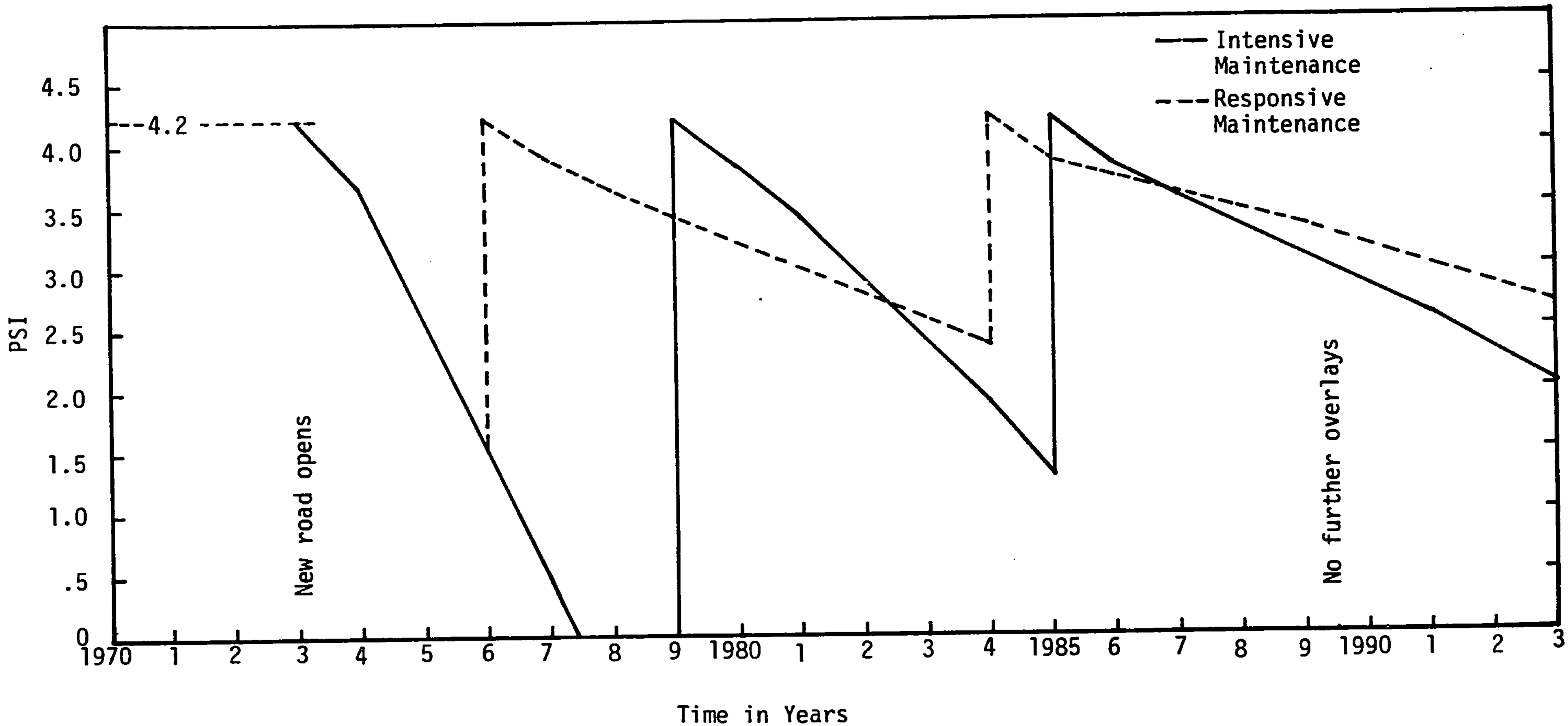


FIGURE 12

PSI VERSUS TIME FOR INTENSIVE AND RESPONSIVE MAINTENANCE POLICIES - NO OVERLOADING

(Segment 101)

FIGURE 13 shows the deterioration of Segments 103 and 105, expressed as PSI versus time for the intensive maintenance policy (solid line) and the responsive policy (broken line) from the opening in 1973 to the end of the analysis period. Overlays under the intensive policy occur in years 1978-79 and 1984-85. Overlays for the responsive policy occur in years 1973-74 (the opening year and 5 years before the first scheduled overlay) and in 1980-81 (four years before the second scheduled overlays).

The large difference in user costs between the two policies--23.6 million shillings--results because, in the case of Segment 101 for the responsive policy, the PSI goes below 2.0 for only half of 1975, whereas for the intensive policy 4-3/4 years are below PSI 2.0; 2-1/2 of which the pavement has a PSI below one. This difference is even more significant in the case of Segments 103 and 105. The implications of this difference are best understood by reference to FIGURE 14 which shows the relationship between PSI and a Vehicle Operating Cost Index.

The indexing expresses the vehicle operating cost for this road calculated at a PSI of 4.2 as 100. This permits other costs (which will be higher at lower PSI levels) to be read as a percent increase above the optimum level. At a PSI of 2.0,the vehicle operating costs index is about 108, i.e. at PSI = 2.0 vehicle costs are about 8% above those calculated at PSI = 4.2. Below a PSI of 2.0, the curve grows exponentially giving an index of 130 at PSI = 1.0 and an index of 175 at PSI = 0.4. Twenty-two percent higher costs for vehicle operation are incurred between PSI 2.0 and 1.0 than between 4.2 and 2.0. This higher cost represents the penalty incurred because the maintenance policy was unable to maintain a lower bound of PSI at 2.0. Had we specified a policy which could maintain the pavement PSI above the value of two, the penalty of 22% higher operating costs need not have been charged.

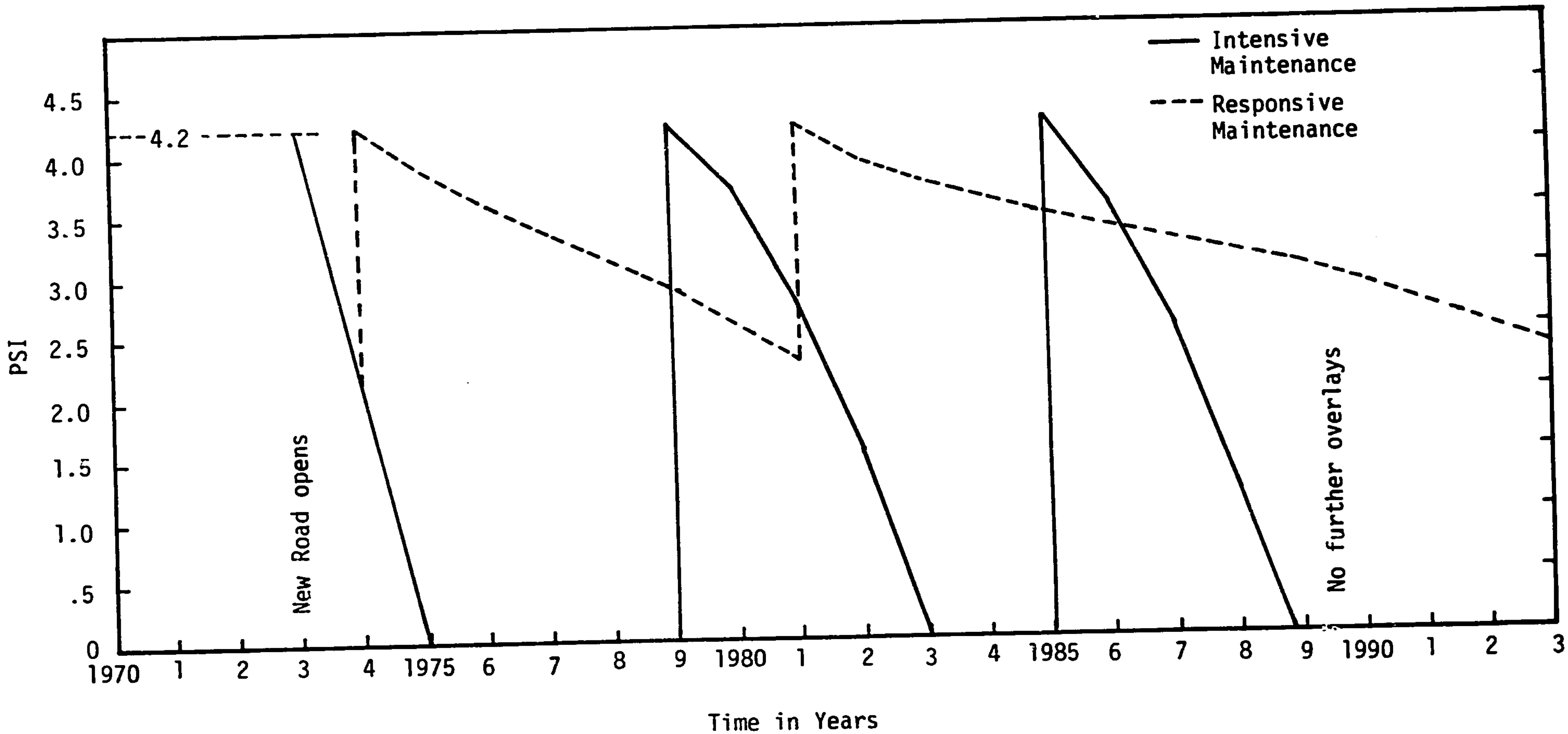


FIGURE 13

PSI VERSUS TIME FOR INTENSIVE AND RESPONSIVE MAINTENANCE POLICIES - NO OVERLOADING

(Segments 103 & 105)

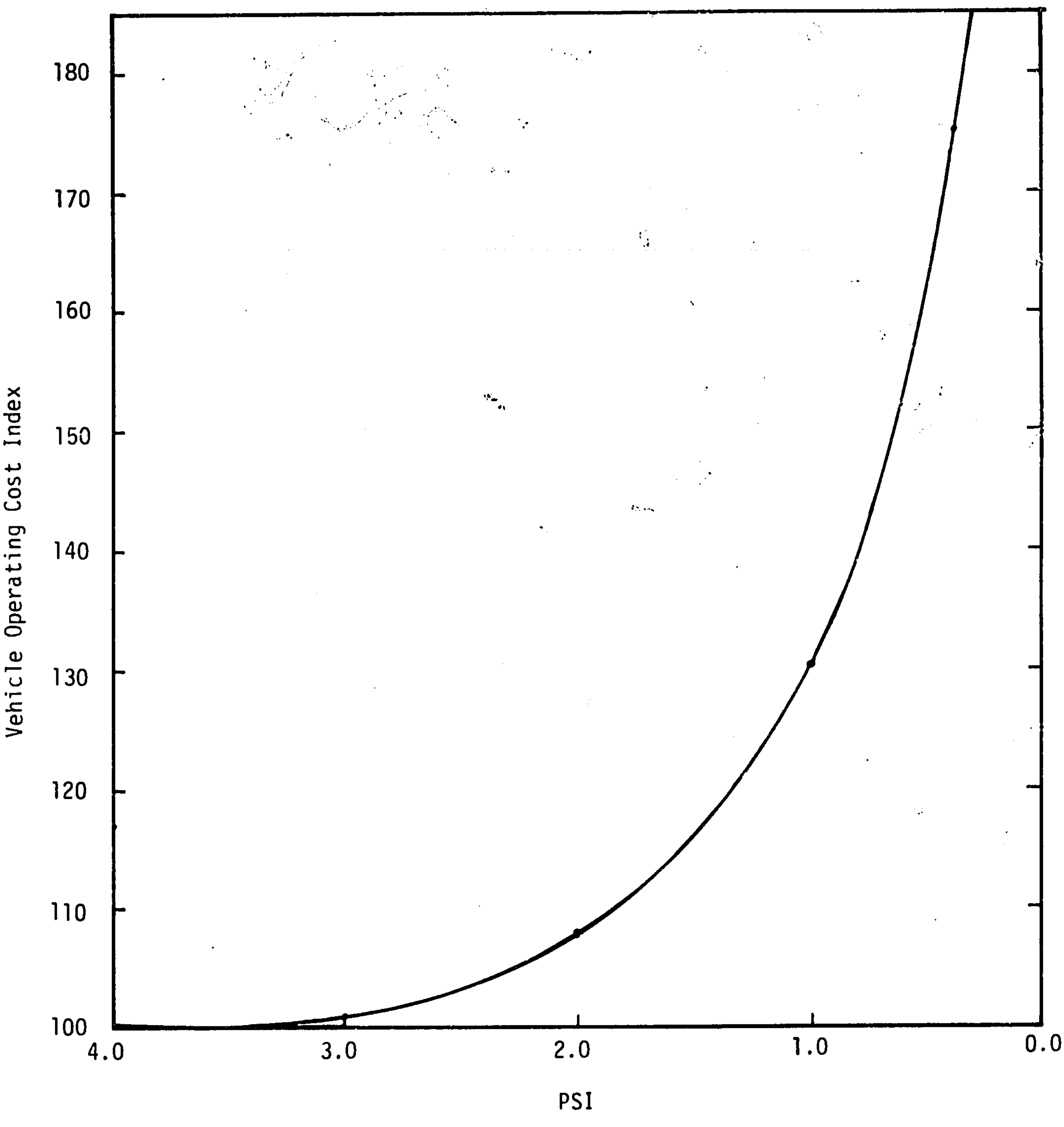


FIGURE 14

VEHICLE OPERATING COST INDEX VERSUS PSI

A PSI of 0.4 was interpreted as a virtually unserviceable road and not specifying a policy to keep the road's PSI at 1.0 incurred a 45% surcharge on costs above the costs incurred at a PSI of 1.0.

It has been shown that the HCM can be used to predict changes in deterioration due to changes in the maintenance policy and, in turn, the effect on vehicle operating costs were substantially higher, as were total costs, than if overlaying was performed.

Secondly, it was shown that substantial vehicle operating and total cost savings could be achieved if the timing of overlays was demand-responsive rather than scheduled. The incremental maintenance expenditure required for a demand-responsive policy was about 5% of the savings.

3. OVERLOADING COSTS

A serious problem affecting the performance of the Tan-Zam Highway is accelerated pavement damage due to truck overloading. A 22 ton truck-trailer combination, for example, carrying 30% extra payload applies over twice as many 18 kip equivalent single axle loads as when normally loaded (equivalence factor 4.160 vs. 2.017).

There are four basic ways to represent overloading. One method assumes total commodity transported to be fixed and as overloading increases, the volume of transport traffic required decreases. A second method assumes that the traffic volume is fixed and total commodity is increasing. The excess commodity will result from lowered prices for the excess loads picked up along the road. Thirdly, if one posits enforcement, one can suppose that some percentage of the overloaded vehicles will avoid detection. Finally, if one does not assume load limit enforcement, once can assume that a certain percentage of overloaded vehicles will be on the road. Of these possible options, the most extreme in terms of damage to the road at any maintenance policy level would be to overload all medium and heavy transport vehicles without decreasing the traffic volume or its rate of growth.

To examine the effects of overloading on the Dar--Morogoro Road, the load factor (portion of maximum payload carried) was set to 1.3 (a 30% overload) for all ten and twenty-two ton trucks in both directions. The effects of the 30% overloading at all three maintenance policies are shown in FIGURE 15, columns B, D, and F.

For both the moderate policy (columns A and B) and the intensive policy (columns C and D) maintenance costs were essentially the same. Small increases, on the order of 0.1% and 0.4% respectively, were observed for the 30% overloaded traffic. These differences resulted from the slightly higher demand for patching required for the overloaded traffic in the years just after opening or overlaying before the total quantity of patching reached the maximum specified in TABLE 22. Once the maximum was reached, maintenance costs were equal.

For the moderate policy, the vehicle operating costs were 12.3 million shillings higher due to the overloading because of the more rapid deterioration of the road. Segment 101, for example, reached PSI = 0.25 in 1975, two years earlier than in the normally loaded case.

With the intensive policy, the difference in vehicle operating costs due to the 30% overloading was 15.7 million shillings. Once again, this was the result of a more rapid deterioration of the road.

In both scheduled maintenance policy cases, the maintenance costs remained constant and the entire cost of overloading was passed on to the vehicle owner/operator in the form of higher vehicle operating costs.

The true differences are somewhat difficult to compute because the HCM does not allow PSI to drop below 0.0; yet we have no justification for assuming that the scheduled maintenance policies can in fact keep PSI at that level.

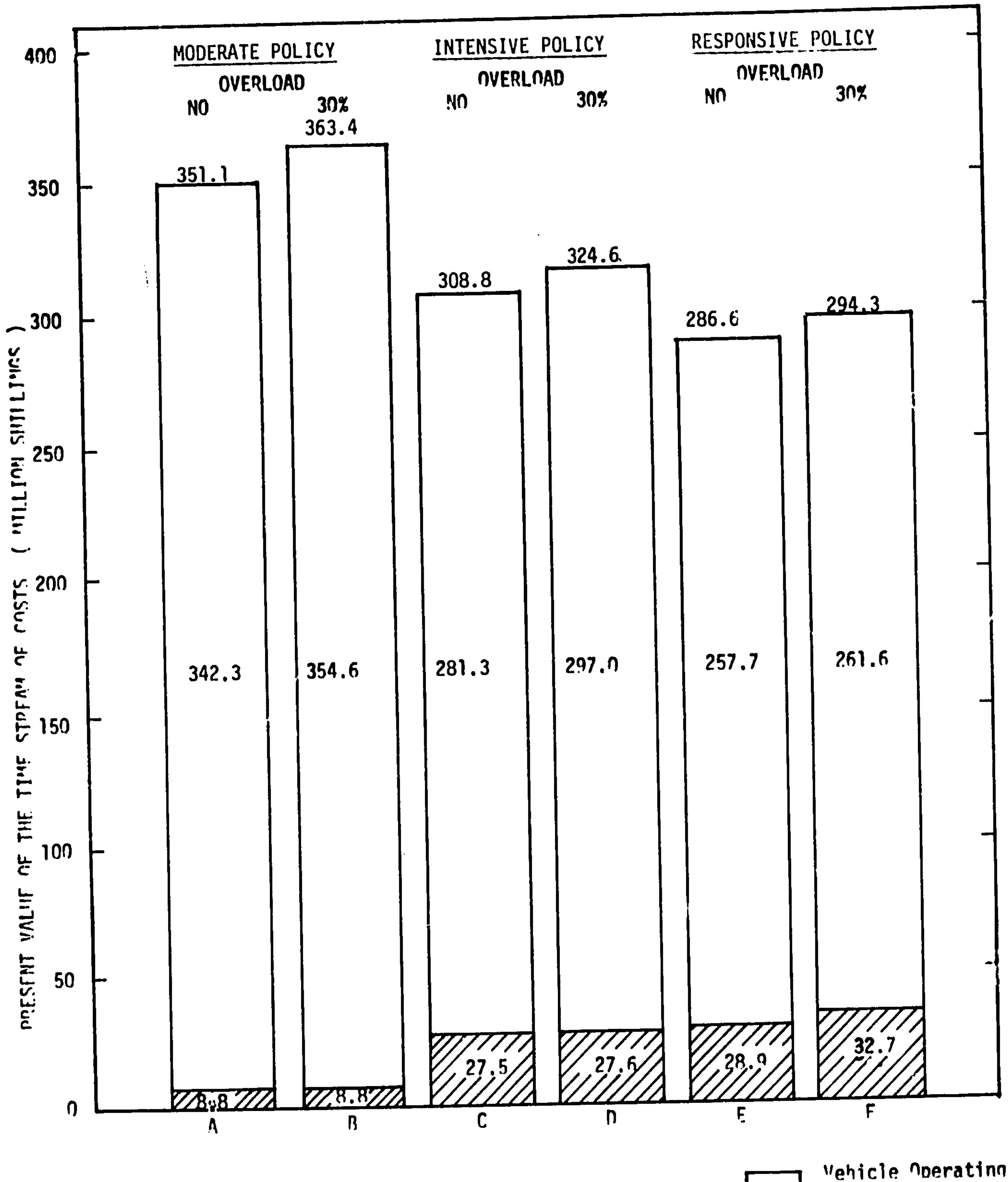


FIGURE 15

COMPARISON OF TOTAL DISCOUNTED COSTS ON THE AS-BUILT ROAD FOR THREE MAINTENANCE POLICIES AND LOADING CONDITIONS

For the responsive policy (columns E and F) the maintenance costs were 3.8 million shillings higher for the 30% overload case. FIGURE 16 shows, for Segments 101, 103, and 105, that this difference resulted from earlier overlays for the 30% overloading case; usually about two years earlier on the second overlay. Had a third overlay been permitted the spread would have reached three years in most cases.

The difference in vehicle operating costs was 3.9 million shillings, due to a normally lower PSI in the overloaded case--though not as wide a difference as in the moderate and intensive policy cases.

TABLE 23 compares the increase in the present worth of maintenance, vehicle operating, and total costs at each maintenance policy level due to 30% overloading of medium and heavy trucks.

TABLE 23

INCREASED COSTS DUE TO 30% OVERLOADING OF TRUCKS
(million shillings discounted @ 10% to 1970)

	MODERATE	INTENSIVE	RESPONSIVE
MAINTENANCE COSTS	-- (0.1%)	0.1 (0.4%)	3.8 (13.2%)
VEHICLE OPERATING COSTS	12.3 (3.6%)	15.7 (5.6%)	3.9 (1.5%)
TOTAL COST	12.3 (3.5%)	15.8 (5.1%)	7.7 (2.7%)

Summarizing, one can see that for the scheduled policies the increased costs were borne nearly 100% by the operators, whereas the responsive policy shared the extra cost equally between the operators and the

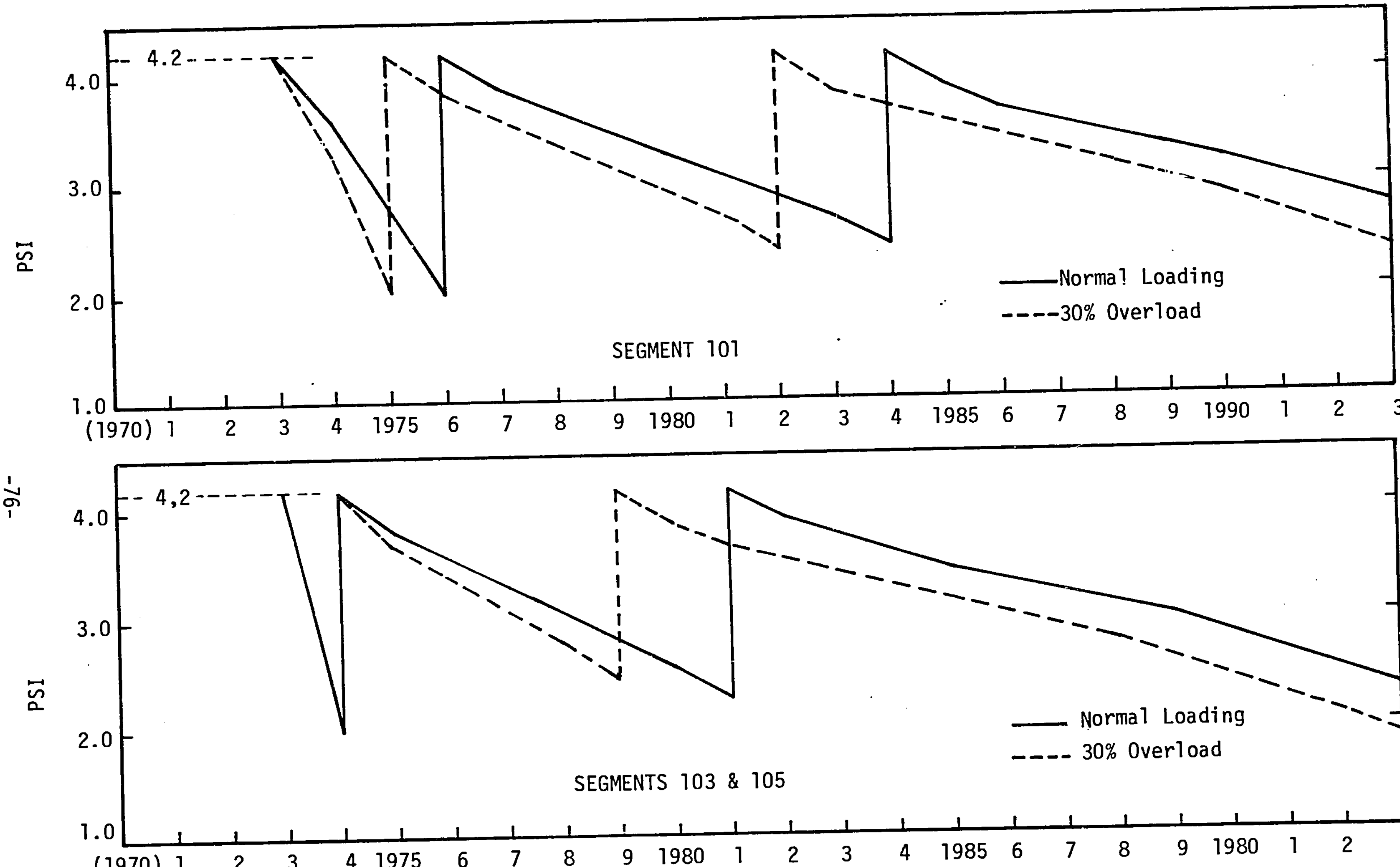


FIGURE 16

PSI VERSUS TIME - RESPONSIVE MAINTENANCE WITH AND WITHOUT OVERLOADING government. The benefit gained by sharing the costs equally was a savings of as much as 50% of the cost of the overloading.

The conclusion of this investigation is that, using the HCM, one can predict the presence and magnitude of overloading costs and the relative effectiveness of different maintenance policies in coping with the extra damage (expressed through increased vehicle operating costs). Additionally, the amount and allocation of these costs can be controlled by a proper design of the maintenance policies. In all cases the PSI responsive policy provides the cheapest solution for government and users.

Whether or not government would choose to permit overloading to any degree is a separate decision, to which this HCM analysis provides one essential set of information--the infrastructural maintenance and operating cost increments. The 30% overloading represents nearly four million tons of additional cargo over the analysis period. The economic value to the nation may warrant the increased expenditure and its financial value may warrant the increased operating costs.

4. A NEW PAVEMENT (TYPE FIVE)

Referring once again to FIGURE 15 we observe that the responsive maintenance policy even under the 30% overloading assumption (column F) provides a substantially cheaper total cost solution for the road than either of the scheduled policies even assuming no overloading. That this indicates a responsive policy as the best choice under all conditions for this road is obvious, but this conclusion poses an interesting question.

If the large savings in total cost under the responsive maintenance policy are resulting primarily from the earlier first overlay which would not permit the PSI to drop below 2.5, then the specification of a better strategy of initial design and maintenance may be possible. To examine this hypothesis, the same three maintenance policies and two traffic conditions were applied assuming a different pavement design (Pavement Type Five), described in SECTION III-B, were used on this road.

FIGURE 17 repeats the information for the as-built pavement from FIGURE 15, and superimposes on it the same costs for Pavement Type Five.

The discounted construction cost for the as-built pavement, as calculated by the HCM, is 30.4 million shillings; for Pavement Five it is 35.8. The construction difference of 5.4 million shillings (18%) is added to the maintenance and vehicle operating costs of the new pavement to enable total cost differences to be compared.

There are several advantages which can be seen for Pavement Five; the most obvious is the relative insensitivity to choice of maintenance policy or overloading condition. The full range (column B less column E) for the as-built road is 76.8 million; for Pavement Five it is 21.1 million. (The range on the as-built pavement is actually understated because of the artificial limit of PSI stopping at zero.) For example, on Segment 101 of the existing road, when traffic is 30% overloaded and the maintenance policy calls for no overlays (moderate), the PSI reaches 2.0 in 1974 and 0.0 in 1976 after which it is artificially maintained at that value. On Pavement Five, under the same conditions, the PSI reaches 2.0 in 1984 and at the end of the analysis period has a value of 0.08. This explains in part, the 60 million shillings savings shown in column B for Pavement Five over the as-built road.

Pavement Five offers an interesting tradeoff to government. If we compare the total cost of Pavement Five with moderate maintenance to the total cost of the as-built pavement with the responsive policy, we notice that Pavement Five has a higher total cost of 7.2 million shillings with no overloading, and 9.5 million shillings with 30% overloading. However,

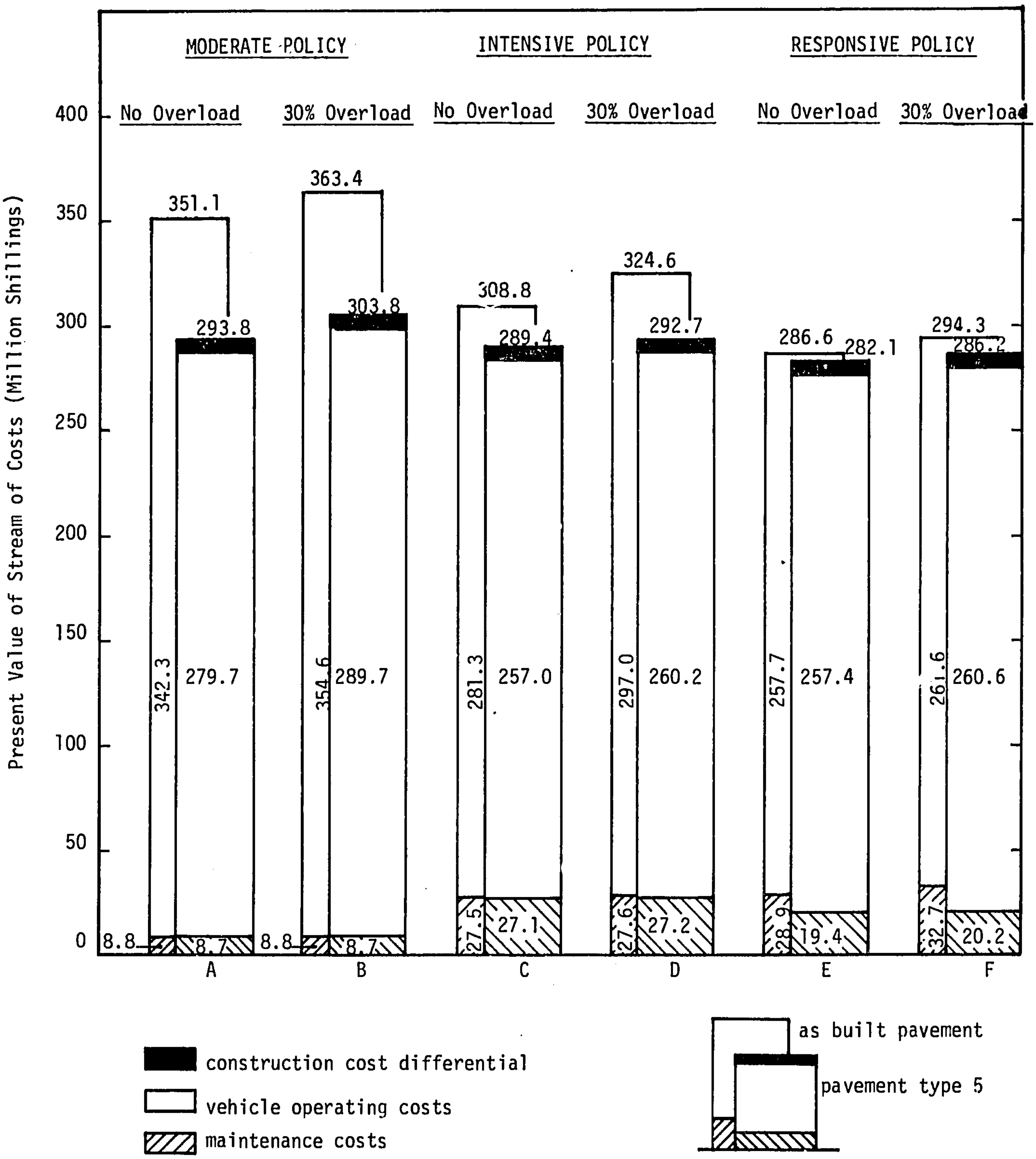


FIGURE 17

COMPARISON OF TOTAL DISCOUNTED COSTS FOR TWO PAVEMENT DESIGNS, TWO TRUCK LOADING CONDITIONS, AND THREE MAINTENANCE POLICIES the cost distribution is shifted dramatically, at the expense of the owner/operator. TABLE 24 shows the distribution of costs.

TABLE 24

Cost Distribution Comparison of the As-Built Road With Responsive Policy and Pavement Five With Moderate Policy Under Both Traffic Loading Conditions

(million shillings)

	Pavement Type 5 Moderate Policy		As-Built Pavement Responsive Policy	
	No Overload	30% Overload	No Overload	30% Overload
TOTAL COST*	293.8	303.8	286.6	294.3
COST TO USER	279.7	289.7	257.7	261.6
COST TO GOV'T*	14.1	14.1	28.9	32.7

*Includes only construction cost differential of 5.4

By using Pavement Five with only a moderate maintenance policy the government would save themselves 14.8 million and 18.6 million shillings for the no overload and 30% overload cases respectively, and increase the user cost by 22.0 and 28.1 million shillings respectively. Although Pavement Five with the responsive policy will provide the cheapest solution (both total and to government) the advantage of the moderate policy/ Pavement Five solution is the removal of any dependency on future maintenance overlaying operations (as well as unforeseen future budgetary problems) for an 18% higher construction investment.

This conclusion is of special interest in the case of an internationally funded road, where the funding agency pays the foreign currency component of the new construction, whereas the government is normally 100% responsible for any future maintenance costs.

Our original intention for running Pavement Five was to test the hypothesis that lower cost solutions could be achieved by a better strategy of initial design and maintenance. Having demonstrated this, we shall try to apply the results to a recommendation for a lower cost solution for the future maintenance of the Tan-Zam Road investment.

5. RECOMMENDATION

The recommendation we will test is in accordance with the observed savings accrued by a stronger initial pavement. We will test the total cost of maintaining the Dar-Morogoro segment to a moderate maintenance policy standard with a one-time overlay (actually a re-construction) of 10 centimeters. This overlay is twice the thickness of a normal overlay and would be applied in 1974, 1975, or 1976. This will permit a comparison of what the total costs would be if the work were done this year (1975), last year (1974), or next year (1976). We will only use the 30% overload case.

FIGURE 18 shows the maintenance costs, vehicle operating costs and total costs for the three years tested under moderate maintenance compared to the intensive or the responsive maintenance policies, for the 30% overloaded case.

The differences between 1974 vs 1975 or 1975 vs 1976 are on the order of ½%. They all fall between the intensive and responsive policies in terms of total cost and user costs. Maintenance costs are above the responsive cost in 1974, but between the intensive and responsive costs for 1975 and 1976.

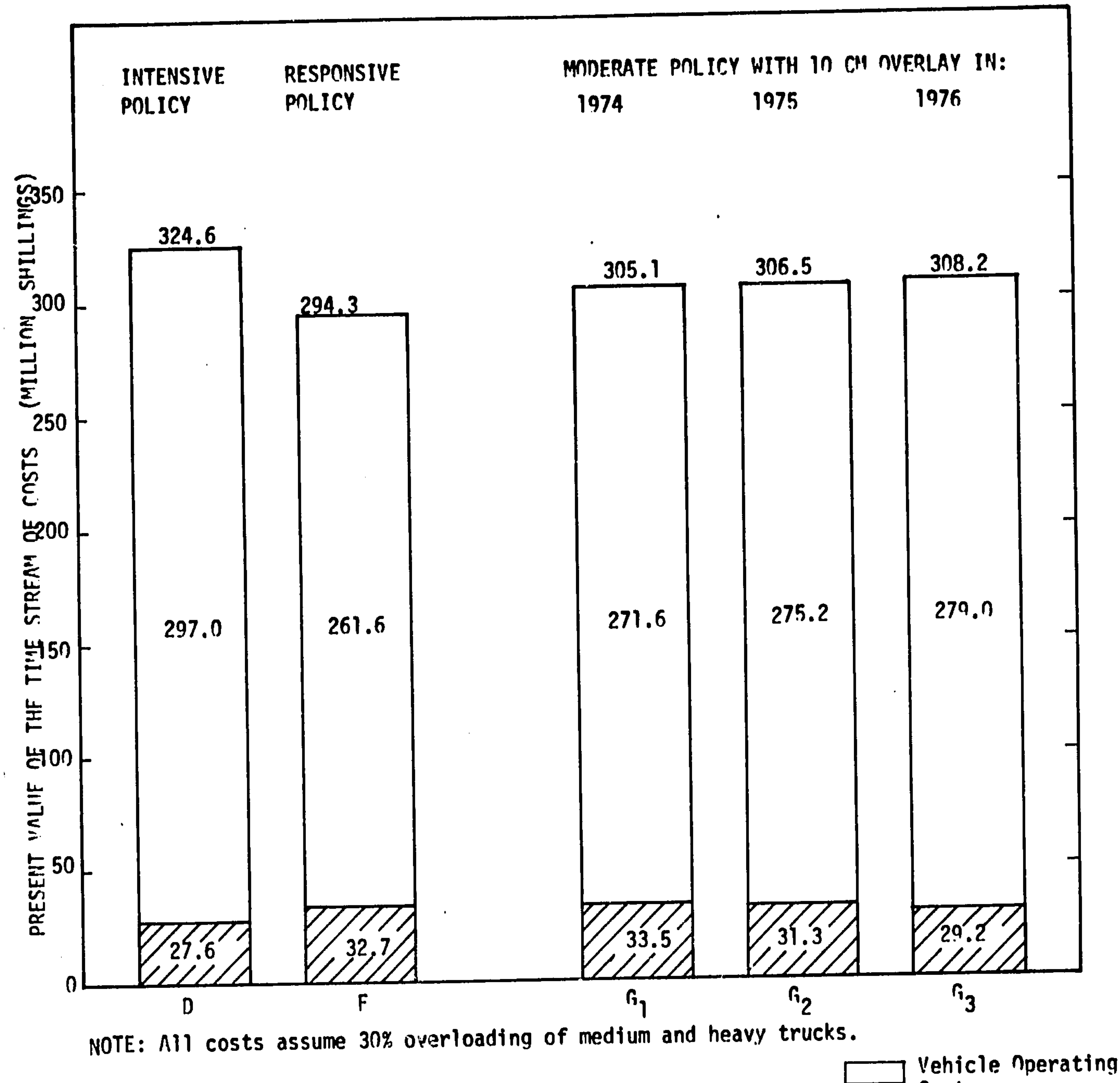


FIGURE 18

COMPARISON OF TOTAL DISCOUNTED COSTS FOR AS-BUILT ROAD. INTENSIVE AND RESPONSIVE MAINTENANCE VERSUS MODERATE MAINTENANCE WITH A TEN CENTIMETER OVERLAY IN GIVEN YEAR

Either the 1975 or 1976 solution would be a lower cost solution for government with only a 14 to 18 million shilling surcharge to the vehicle owner/operators.

Delaying the ten centimeter overlay appears to decrease the present worth of the overlay by about 2.1 million shillings per year, and increase the vehicle operating costs about 4 million per year. If we were to delay the 10 centimeter overlay until 1978 this would decrease the maintenance present worth to about 25 million shillings, the vehicle operating costs and total costs would increase to 287 and 312 million shillings respectively. However, 1978 is the year in which the first scheduled overlay would normally occur under the intensive policy. In other words, if we double the first scheduled overlay in 1978 and then return to the moderate policy, government would save about two and one-half million shillings and the vehicle owner/operators would save about 10 million shillings; a total cost reduction of about twelve and one-half million shillings over the intensive policy solution.

One question arising out of this comparison is the discrepancy in maintenance costs between the intensive policy (with two 5 cm. overlays) and the 1978 double overlay with moderate maintenance. The question arises because the present worth at 10% of the second 5 cm. overlay in the intensive policy is only 56% of the present worth of the extra 5 cm. of asphalt in the double 1978 overlay, yet the maintenance cost is higher with the intensive policy.

The explanation for this difference is patching and seal coat costs. Under the intensive policy twice as much patching is performed as under the moderate policy and seal coats are every two as opposed to every five years (see TABLE 22). The difference in the present worth of this extra patching and seal coating not only compensates for the difference in the discounted value of the second 5 centimeter overlay, but also provides the extra two and one-half million shillings savings.

Based on this extra run, the recommended strategy would be an early scheduled double overlay preceeded and followed by a moderate maintenance effort. This overlay should occur no later than 1978, the year for the first scheduled overlay under the intensive policy. Earlier placement of the double overlay would decrease vehicle costs by about four million shillings per year, but would increase the government's maintenance expenditure by about two million shillings per year. Scheduling this double overlay prior to 1975 would increase the maintenance expenditure over that expected for the responsive policy. (The reader is reminded, once again, that vehicle operating costs at PSI = 0.0 are not wholly accurate, as explained earlier. A more accurate representation of these costs might change the recommended solution by a year).

6. SUMMARY

This phase of the Tan-Zam Case Study has investigated various strategies for the post construction investment period. It was shown that, regardless of the extent of vehicle overloading, a demand-responsive scheduling of five centimeter pavement overlays would provide a lower cost solution than a scheduled policy. Naturally, a scheduled policy based on the deterioration predictions could be developed.

As an intermediate step to a final recommendation, it was shown that an additional investment of 5.4 million shillings during construction could have provided, in all cases, a road solution that was both lower in total cost as well as less sensitive to the various types of maintenance policies examined.

A final recommendation was presented which called for a double (ten centimeter) overlay sometime during 1977 or 1978 with only a moderate maintenance effort before and after the overlay. The fiscal advantages of this recommendation over the intensive policy were lower total as well as vehicle operating costs, and an equivalent or lower requirement for government maintenance expenditure. A secondary advantage was the lowered requirement for maintenance effort in the non-overlay years.

IV. SUMMARY OF CONCLUSIONS

The application and use of the Highway Cost Model was demonstrated in the present case-study in three different experiments with the model. While the results of the experiments are discussed at length in the text of the report, complete with conclusions of each experiment, a summary of major findings and conclusions is presented below.

By specifying different demand responsive maintenance policies, it was possible to compute, using the HCM, the maintenance expenditure that would be required to maintain the old and new roads such that their Present Serviceability Index never fell below a specified minimum. As a result, it was shown that the maintenance expenditure estimated by SRI was not sufficient to maintain the old and the proposed new roads at their initial qualities, i.e. to a PSI of 2.5 and 4.2 respectively, and that it would require considerable additional expenditure (in the form of overlays) to maintain either road, even at a minimal PSI of 1.0.

By analyzing the yearly reports on pavement condition, as computed by the HCM, it was possible to analyze the deterioration characteristics of the SRI pavement proposal under the heaviest traffic (Case 4) and a moderate maintenance policy that included no overlays. It was found that the SRI pavement design (based solely on the volume of traffic without any recognigtion of the underlying sugbrade strength), was grossly under-designed on subgrades with CBR of 10% or less (modified structural number less than 3.05), such that more than 75% of the road deteriorated to a PSI of 1.0 within three years of being subjected to the estimated traffic. However, on subgrades with CBR of 30% (modified structural number 3.76) the pavement lasted more than eight years before reaching a PSI of 1.0.

In a feasibility level experiment with the HCM, it was shown that the model could be used to evaluate simultaneously alarge number of alternatives in terms of different pavement designs and maintenance policies. By comparing the total discounted costs (sum of construction, maintenance, and vehicle operating), it was possible to identify the alternative with minimum total cost in each of the four possible cases of traffic projections considered in the case study. The analysis showed that savings in terms of total reduced vehicle operating costs were not sufficient to offset the capital costs involved in constructing and maintaining a new road if only a limited portion of the current and expected growth in copper traffic were to be transported over the Tan-Zam Highway.

The feasibility level analysis also showed that of the three pavement design alternatives, the DCI trench design, the DCI modified design, and the SRI proposal, the alternative with the least total costs under Traffic Case 4, was the DCI modified design with an intensive maintenance policy that included a 5 cm. overlay every six years and a major seal coat every two years. However, the deterioration characteristics of the DCI modified design showed rapid deterioration of the pavement so that for most of the time before the overlays the pavement was at a PSI below 2.0 resulting in relatively high vehicle operating costs. This was due to the initial weak design of the pavement--modified structural numbers ranged from 2.41 on a CBR of 30% to 3.48 on a CBR of 7%.

A lower cost solution than the DCI modified design was found to be, a much stronger pavement (modified structural number 4.4 on all segments) that required only a minimal maintenance effort without any overlay during the analysis period. Evaluation with the HCM showed that although the pavement cost 5.4 million shillings more to construct than the DCI modified design, it reduced maintenance costs by 12.8 million and vehicle operating costs by 42.1 million, a net savings of about 50 million shillings.

Finally, using the HCM, it was possible to examine the effects of traffic overloading on pavement deterioration and to evaluate post-construction investment strategies in terms of different maintenance policies for the as-built road. It was shown that, using the HCM, one can predict the presence and magnitude of overloading costs and the relative effectiveness of different maintenance policies in coping with the extra damage (expressed through increased vehicle operating costs). In the case of the newly built road between Dar-es-Salaam and Morogoro, it was shown that regardless of the extent of vehicle overloading, a demand-responsive scheduling of 5 cm. overlays would provide a lower cost solution than a maintenance policy with overlays scheduled for 6 year intervals without consideration of the deterioration rate.

As a final recommendation, it was shown that a one time double overlay (10 cm) sometime in 1977 or 1978, with only a moderate maintenance effort before and after the overlay, would not only reduce total maintenance and vehicle operating costs below those for an intensive maintenance policy, but also avoid any dependency on the scheduling and execution of 5 cm. overlays at different times during the analysis period.

APPENDIX A:

BIBLIOGRAPHY

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[1]. Stanford Research Institute, "Tanzania-Zambia Highway Study" Volumes I through VII September 1966.

The study was prepared jointly for the Republics of Zambia and Tanzania financed by USAID. The report provided most of the data on route alignment, topography, traffic, pavement design, construction costs and maintenance policy on asphalt concrete roads.

[2]. Lyon Associates, Inc. "Tanzania Highway - Maintenance and Organization", vols. I, II and III, August 1972.

The study was prepared for the Ministry of Communications and Works, Tanzania, and financed by USAID. The report provided the necessary data on existing maintenance practices and unit costs especially on double bituminous surface treated roads in Tanzania.

[3]. De Leuw Cather International Inc. "The Morogoro-Dar-es-Salaam Highway Project -- Recommendations regarding design modifications and estimated final construction costs" October 1971.

The report provided the details of the two pavement designs evaluated in the feasibility level experiment of the present case study.

[4]. De Leuw Cather International Inc. "Dar-es-Salaam - Port Access Road, Engineering and Economic Feasibility Study", May 1971.

[5] United Research Inc., "The Economic Feasibility of Improving Two Road in the Mtwara Region of Tanzania", September, 1968.

The above two reports, both prepared for the Ministry of Communication and Works, Tanzania, provided the necessary detailed data on vehicle design and operating characteristics.

[6] Road Research Laboratory, U.K., "Pavement Design in the Tropics--Investigation of Subgrade Conditions under Roads in East Africa", Road Research Technical Paper Number 80.

This report provided the pavement characteristics and subgrade quality of the existing bituminous road between Dar-es-Salaam and Morogoro.

[7] USAID, Department of State, "Capital Assistance Paper--ADI-DLC/P-846/2", June 1970.

The latest traffic estimates and future projectives used by DCI for its final engineering designs were obtained from this paper.

[8] Moavenzadeh, F., Berger, F., Brademeyer, B., Wyatt, R., "The Highway Cost Model: General Framework, Massachusetts Institute of Technology, June, 1975.

APPENDIX B:

DOCUMENTATION OF DETAILED INPUTS TO HCM

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1. Segment Description and Alignment Characteristics.

Figure B-1 shows a sketch of the segmentation and coding system used to describe the existing and new alignments of the case study section. Table B1a and B1b summarize the characteristics describing each segment of the two alignments.

TABLE B1a. SEGMENT CHARACTERISTICS OF THE OLD ROAD

Segment Number	Length (km)	Av. Curvature (deg/km)	CBR (%)	Av. Rise (m/km)	Av. Fall (m/km)	Annual Rainfall (mm)
110	160.25	39.69	14	8.23	15.81	825
107	3.40	16.18	7	8.94	15.60	816
111	19.25	47.17	7	11.45	15.00	846
109	10.00	3.40	35	1.52	4.56	1184

TABLE B1b. SEGMENT CHARACTERISTICS OF NEW ROAD

Segment Number	Length (km)	Av. Curvature (deg/km)	CBR (%)	Av.Rise (m/km)	Av. Fall (m/km)	Annual Rainfall (mm)
101	68.0	6.25	10	1.79	6.93	825
102	20.0	5.45	7	1.52	4.94	825
103	15.0	3.20	30	1.01	2.03	825
104	15.0	5.13	8	2.02	5.57	825
105	26.0	16.42	30	6.72	1.17	825
106	9.55	16.07	7	3.98	3.98	825
108	17.65	6.80	7	11.20	13.78	846

(Source - Geometric characteristics and rainfall data from contour maps in SRI [1] report, subgrade CBR from DCI [3]).

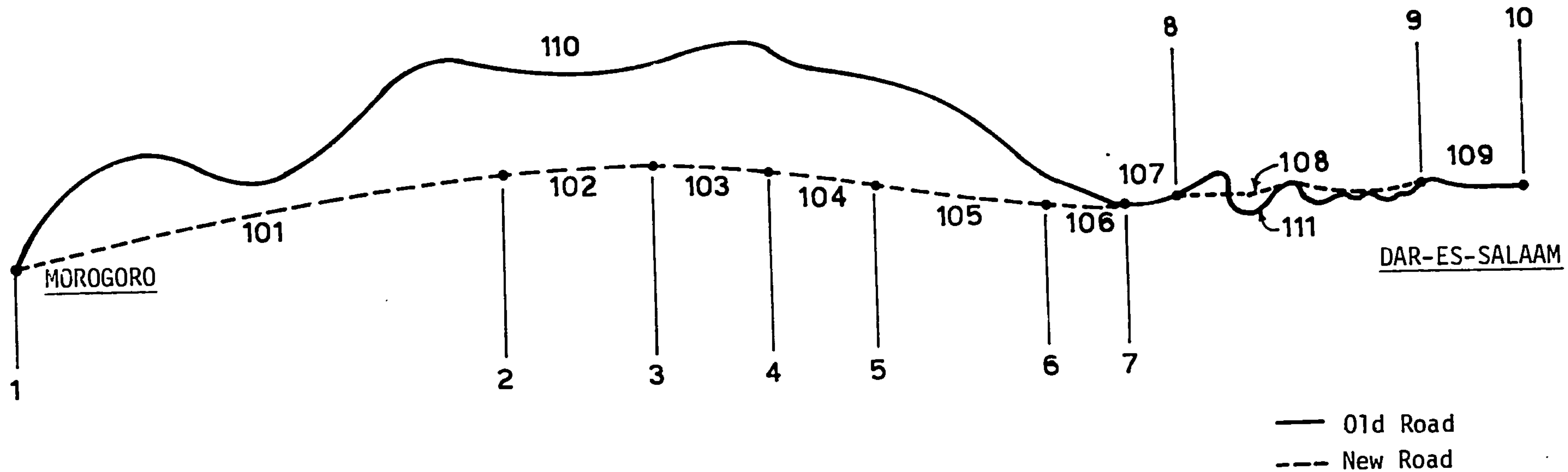

FIGURE B-1

SEGMENT CODING ALONG HORIZONTAL ALIGNMENTS
(not to scale)

TABLE B2a. CROSS-SECTION CHARACTERISTICS OF OLD ROAD

	Riding Surface	Shoulder	Ditch Side	Ditch Bottom	R.O.W.	Cut	Fill
Width (m)	3.05	1.22	1.80	.35	9.27	—	—
Slopes (rise/run)	03	.04	.33	0	—	1.0	.67

TABLE B2b. CROSS-SECTION CHARACTERISTICS OF NEW ROAD (SRI)

	Riding Surface	Shoulder	Ditch Side	Ditch Bottom	R.O.W.	Cut	Fill
Width (m)	3.65	2.43	1.82	35	19.47	—	—
Slope (rise/run)	.03	.04	.33	0	—	1.0	0.67

TABLE B2c. CROSS-SECTION CHARACTERISTICS OF NEW ROAD (DCI TRENCH DESIGN)

	Riding Surface	Shoulder	Ditch Slope	Ditch Bottom	R.O.W.	Cut	Fill
Width (m)	3.35	1.83	1.82	.35	19.18	—	—
Slope (rise/run)	.03	.05	.33	0	—	.33	.667

TABLE B2d. CROSS-SECTION CHARACTERISTICS OF NEW ROAD (DCI MODIFIED DESIGN)

	Riding Surface	Shoulder	Ditch Slope	Ditch Bottom	R.O.W.	Cut	Fill
Width (m)	3.35	1.83	1.82	.35	18.88	—	—
Slope (rise/run)	.03	.068	.33	0	—	.33	.667

TABLE B2e. PAVEMENT THICKNESSES ON OLD ROAD

Pavement Layer	Segment 110	Segment 107,111,109
Surface (DBST)	2.5 cm.	2.5 cm.
Base (crushed stone)	6.4 cm.	17.8 cm.
Subbase (sand)	37.5 cm.	0 cm.

(Source: Road Research Laboratory [6]).

TABLE B2[illegible]. VEHICLE CLASSIFICATION AND DESCRIPTION

	Med. Car.	50 passenger bus	7 ton truck	10 ton truck	22 ton truck
Fuel (1=gas, 2=diesel)	1	2	2	2	2
Horse Power	80	150	178	190	228
Vehicle Speed (km/hr)	96	80	80	80	72
Tare Weight (MT)	0.5	5.0	6.0	10.0	16.0
Vehicle payload (MT)	0.5	5.0	7.0	10.0	22.0
Number of Axles	2	2	2	2	4
Fraction of Total Load and Type of Axle (S=single, T=tandem)					
Axle 1	0.5(S)	0.5(S)	0.49(S)	0.4(S)	0.20(S)
Axle 2	0.5(S)	0.5(S)	0.51(S)	0.6(T)	0.20(S)
Axle 3	—	—	—	—	0.27(T)
Axle 4	—	—	—	—	0.33(T)

TABLE P3b. VEHICLE OPERATING DATA SET

	Car	Bus	7 ton truck	10 ton truck	22 ton truck
Vehicle Cost New (shs)					
Financial (F)	20,844	59,829	36,300	84,400	109,824
Economic (E)	17,349	49,760	30,125	70,400	91,520
Tire Cost (each)					
(F)	144	900	800	900	1,176
(E)	125	774	687	774	1,014
Parts Ratio E/F	.86	.86	.86	86	.86
Maintenance Labor (F)	10	10	10	10	10
(shs/hr) (E)	10	10	10	10	10
Utilization (hrs/yr)	375	1,500	1,600	1,600	1,600
(km/yr)	19,200	48,000	64,000	80,000	96,000
Vehicle Life (yrs)	10	8	6	8	8
Interest rate (%) (F)	12	12	12	12	12
(E)	0	0	0	0	0
Driver Wage (F)	---	450	450	600	600
(shs/month) (E)	---	450	450	600	600
Helper Wage (F)	---	250	250	300	300
(shs/month) (E)	---	125	125	150	150
Overhead (F)	---	8,539	8,022	8,360	22,939
(shs/yr) (E)	---	6,831	6,418	6,688	18,351
Insurance (F)	490	2,715	1,561	1,928	1,980
(shs/yr) (E)	392	2,172	1,248	1,542	1,584
Value of Cargo (shs/hr)	---	---	.05	.05	.05

Petroleum and Oil Costs:

Gas (shs/litre)	F	1.0
	E	.54
Diesel (shs/litre)		
	F	.83
	E	.41
Oil (shs/litre)	F	3.11
	E	2.89

TABLE B4. UNIT MAINTENANCE COSTS

(Tanzania shillings)

Activity	Unit	Cost
Surface Patching (A/C)	sq.m.	4.02
Surface Patching (DBST)	sq.m.	2.69
Seal Coating (A/C)	sq.m.	2.36
Seal Coating (DBST)	sq.m.	2.70
Overlay (A/C)	cu.m.	290.00
Overlay (DBST)	cu.m.	200.00
Shoulder Grading	km.	79.30
Shoulder Resurfacing	cu.m.	0.40
Brush Control	HECTRE	616.00
Culvert/Ditch Cleaning	cu.m.	0.75

(unit costs on asphalt concrete (A/C) roads were obtained primarily from the SRI report [1], and on Double Bituminous Surface Treated Roads (DBST), from Lyon Associates [2]).

TABLE B5. UNIT CONSTRUCTION COSTS
(Tanzania shillings)

Activity	Unit	Cost
Clearing and Grubbing	HECTRE	312.000
Excavation (unclassified)	cu.m.	3.294
Pavement Structure		
Asphalt Concrete	cu.m.	270.745
Crushed Stone Base	cu.m.	39.239
Gravel Subbase	cu.m.	14.126
Sand Asphalt	cu.m.	88.47
Drainage		
24" R.C. Pipe	Linear m.	137.795
30" R.C. Pipe	Linear m.	160.761
36" R.C. Pipe	Linear m.	183.727
42" R.C. Pipe	Linear m.	321.522
48" R.C. Pipe	Linear m.	459.318

(Sources: DCI [3] and SRI [1]).