Highway Maintenance Costs—A Consideration For Developing Areas

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The impact of maintenance costs and operations on the planning of highway systems in developing areas was reevaluated as part of a larger project concerned with the overall role of transportation in economic development. The importance of maintenance expenditures within the framework of total highway expenditures is established, taking into consideration that maintenance commitments accumulate as the highway system grows. The problem of defining the level of proper (or economic) maintenance as it is directly interrelated to capital expenditures and vehicle costs is investigated and the consequences of undermaintenance are discussed.

Maintenance expenditures are analyzed by surface type and maintenance operation. The analysis is based primarily on experience in the United States because detailed maintenance costs are lacking in developing areas. Basic factors and their complex interrelationships influencing maintenance demands are discussed. A review of methods used for estimating maintenance costs further indicates the complexity of the situation and the need for further work. The direct and indirect implications of an improved highway system in a developing area must be considered when comparing maintenance of paved roads to that of gravel roads because a higher level of equipment, skills and imported materials are needed to maintain paved roads.

•THE PURPOSE of this study is to emphasize the importance of highway maintenance in developing countries. The problems of maintenance are often neglected in the planning stage, both by the developing country and by foreign agencies providing funds for construction. Lending agencies normally expect the developing countries to maintain their highways with little or no aid. The developing countries are understandably often more interested in the dramatic aspects of highway development—construction and paving programs. The failure to provide adequate support for maintenance results in decreased quality of service and deterioration of the initial investment.

ROLE IN PLANNING

To plan any transportation facility, not only the cost of the proposed facility but also the costs of various alternatives must be estimated. Normally costs are separated into three distinct categories: (a) capital investment, including planning, design, and construction costs; (b) vehicle cost, for both operation and maintenance; and (c) cost of maintaining the fixed facility. The important characteristic of these costs is that they are highly interrelated. Any change in design affecting construction costs also directly affects future maintenance and operating costs. Once the facility has been constructed, any change in maintenance procedure will affect operating costs. Moreover, the amortization period of construction costs can be affected by the maintenance

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provided after construction. Evaluation of these effects is complicated by the fact that the extent of their interrelationship has not been established. Probably the weakest link is the lack of information on the impact of maintenance procedures and costs on construction and operation.

A further complicating factor is that these costs are met in different ways in different sectors of the economy. For example, the construction cost is generally a high lump sum expended over a relatively short period of time, normally by the government, often assisted by loans or grants from international agencies or foreign governments. Vehicle costs, on the other hand, are normally met by the private sector of the economy with little or no participation by the government. However, in most cases the government funds come from taxes on the highway users. Highway maintenance costs must be met by the government, and the government involved has relatively little financial help, either from international lending agencies or from foreign governments. Moreover, highway maintenance expenditures will continue long after construction is completed. And construction of new facilities or improvement of old ones is a continuing financial commitment on the local government.

MAGNITUDE OF MAINTENANCE EXPENDITURES

As highway facilities are extended and improved, maintenance commitments accumulate. The magnitude of these is often not realized. In the feasibility study of any one facility, the annual maintenance charge in absolute terms will most likely be the smallest of the three types of costs. However, for nationwide systems, maintenance costs can amount to substantial sums, especially from the viewpoint of governmental highway expenditures. This is true for all types of economies.

Table 1 gives the maintenance expenditures for the United States for various years from 1949 through 1960. In 1960, the maintenance bill amounted to $2.6 million, which was over 24 percent of the total highway expenditures for all governmental agencies. This is somewhat lower than the almost 32 percent for 1949. A partial explanation of the decrease is the impact of the Interstate highway program, which has provided large amounts of construction funds from the mid-1950's to date. The future impact of the maintenance of this high-cost system is now under study in the United States (1).

Table 2 gives the annual maintenance and construction costs in the Gold Coast (Ghana) before it achieved independence. The maintenance expenditures range between 26 and 32 percent of the total governmental highway expenditures. Although these figures are comparable to those for the United States, they may indicate a lack of maintenance. On local road systems in the United States, which are similar in many respects to systems in developing areas, up to 50 percent of the road budget is allocated for maintenance (3).

TABLE 1

HIGHWAY MAINTENANCE EXPENDITURES FOR UNITED STATES[a]

Year	$ (millions)	%[b]
1949	1,333	31.8
1956	2,081	25.0
1958	2,373	23.0
1960	2,607	24.2

[a]Data from Ref. 1.
[b]Of total highway expenditure for all government agencies.

Table 3 presents data developed by the World Bank in its studies of transport in various countries. Here again maintenance expenditures generally account for 26.6 to 51.5 percent (excluding Spain) of total governmental highway expenditures during the years of the proposed plans. It must be emphasized that the maintenance expenditures will probably continue to be high after the plans are completed. For the total Nigerian system, maintenance costs between £2.2 and £3.4 million/yr are given. The lower figure represents costs for the first year of the plan (1955), the second figure is that of the last year (4). In the case of Tanganyika, a 5-yr cost exceeding £7 million does not show that the maintenance costs will increase

TABLE 2

HIGHWAY EXPENDITURES IN GOLD COAST (GHANA)[a]

Year	Maintenance (£)	Construction (£)	Maintenance as % of Total Highway Expenditures
1953-54	1,100,758	2,289,472	32.4
1954-55	1,154,567	3,191,006	26.2
1955-56[b]	1,833,565	4,235,404	30.2

[a]Data from Ref. 2.
[b]Fifteen months.

with each succeeding year and should be at the level of about £1.7 million/yr by 1966 (5).

The Venezuelan figures may be somewhat deceptive. The capital expenditure of over one billion bolivars includes more than 330 million bolivars for the construction of four-lane superhighways and would likely include a lower proportion for maintenance. Superhighways probably cost less for maintenance per dollar of capital investment than less expensive facilities (6). The figures for Libya may reflect the same characteristic. Within the £2.65 million for construction is included £2 million for the construction of the Fezzan road. However, only £120,000 of the million pounds for maintenance is attributable to this road (7).

Finally, some comment must be made for the figures for Spain. As indicated in Table 3, only about 7.5 percent of the expenditure in the next 5 yr will be used for maintenance. The Spanish report explains this low figure. The road system of Spain is, for the most part, established. Because of undermaintenance and a large increase in traffic, the Spanish system will undergo a vast program of reconstruction, accounting for the high construction figures. The maintenance expenditures will not be affected until the present planning period has almost come to an end. At that time, Spain will have to spend a large proportion of its highway funds to maintain the

TABLE 3

RECOMMENDED MAINTENANCE EXPENDITURES FOR IBRD REPORTS FOR VARIOUS COUNTRIES

Country	Years	Maintenance	Construction	Maintenance as % of Total
Nigeria (Fed. only)[a]	1955-60	£1.1 × 10^6/yr	£3 × 10^6/yr	26.8
Nigeria (total)[a]	1955-60	£2.2-3.4 × 10^6/yr	£5 × 10^6/yr	30.5-40.5
Uganda (Central Govt.)[b]	1961-66	£0.847 × 10^6/yr	£1.37 × 10^6/yr	38.2
Tanganyika[c]	1961-66	£7,335,000	£6,845,000	51.5
Venezuela[d]	1960-64	Bs 400 × 10^6	Bs 1102 × 10^6	26.6
Syria[e]	1955-60	LS 6.1 × 10^6/yr	LS 11.0 × 10^6/yr	35.6
Libya[f]	1960-65	LL 1.02 × 10^6	LL 2.65 × 10^6	27.8
Spain[g]	1962-66	Pts 2.3 × 10^9	Pts 28.8 × 10^9	7.5

[a]Data from Ref. 4.
[b]Data from Ref. 9.
[c]Data from Ref. 5.
[d]Data from Ref. 6; high priority project.
[e]Data from Ref. 10.
[f]Data from Ref. 7.
[g]Data from Ref. 8.

improved system. The proportion of maintenance expenditures to total highway expenditures will then be more in line with that of other nations (8).

DEFINITION OF HIGHWAY MAINTENANCE

Highway maintenance is defined as "the preserving and keeping of each roadway, structure, and facility as nearly as possible in its original condition as constructed or as subsequently improved and such additional work as is necessary to keep traffic moving safely" (11). This statement indicates that highway maintenance is somewhat different than maintenance in the usual economic sense. The facility, once constructed, will be maintained so as not to depreciate or degenerate with time. This has important implications and emphasizes the fact that highway construction is a permanent feature of the landscape. It is the exception, not the rule, when a highway facility is abandoned. This is especially true of major networks.

The fact that the highway is not left to deteriorate is illustrated in feasibility analyses which assume that if traffic volumes remain constant, user costs will also remain constant on a vehicle-mile basis. This can only be true if the facility is maintained in its original condition. If highway maintenance were defined as maintenance is usually defined, the facility would be used up by the end of its amortization period. The changes in per mile user costs with time would then have to be evaluated. It is obvious that these would increase as the facility aged.

There are operations on existing highways that are not included in the foregoing maintenance definition. In many cases, expenditures on a given highway may leave it at a higher standard than it was originally. Such an expenditure is often termed a betterment. In a discussion of maintenance costs, it is difficult to distinguish maintenance expenditures from betterment expenditures. The greatest problem is probably the maintenance and/or betterment of the highway pavement surface itself. Usually, the surface has deteriorated and would normally be restored to original condition. However, in many cases resurfacing is used to bring the roadway to a higher standard. The problem is then to allot part of this expenditure to maintenance and part to betterment. This differentiation is especially difficult in cases such as the repaving of a concrete roadway with a bituminous surface.

In many cases, almost by necessity, the dividing line between maintenance and betterment must be somewhat arbitrary. For example, AASHO Manual of Uniform Highway Accounting Procedure classifies resurfacing with bituminous material as maintenance if the resurfacing depth is less than ¾ in. and as betterment if it is greater than ¾ in. (12). In this paper betterment is usually considered construction, not maintenance.

CONSEQUENCES OF UNDERMAINTENANCE

One of the important functions of this study is to emphasize the importance of maintenance as defined in the preceding paragraphs. Maintenance should not be neglected, but often is (13). It is most important that it be a continuous operation, starting the day construction is completed. Deferring needed maintenance can only mean higher maintenance costs in the future or loss of the long-term investment. It is unfortunate that many agencies feel that maintenance should be performed only if the money is available. This is not the case, and monies for highway maintenance should be programmed as any other expenditure.

The consequences of improper maintenance are many. The most obvious, as previously mentioned, is disintegration of the facility and the premature loss of a large initial investment. Furthermore, it will adversely affect the costs of the highway user. This means not only a decrease in anticipated user benefits but possibly other more subtle consequences as well. The highway can affect social, political, and economic activities. Economic development is most sensitive to highway user costs; for example, the encouragement of decentralization of industry or the development of cash crop economies can be influenced by relatively small changes in user costs such as those incurred by poor highway maintenance. Highway costs have less effect socially and politically than economically, probably because social and political activities depend on the movement of relatively small tonnages.

Highway facilities should be designed and constructed in accordance with the country's ability to maintain them properly. This consideration may affect initial design criteria. For example, a low-type bituminous roadway which is not or cannot be adequately maintained can experience drastic deterioration including formation of potholes and disintegration of the surface, which would probably result in considerably higher operating costs than for a relatively well-maintained gravel road. The higher investment costs would be lost due to poor maintenance. A lower type of surface, such as gravel, with initially higher vehicle operating costs would ultimately be more efficient and, therefore, preferable.

The maintenance of highway facilities is an important and complex operation. It is also an integral part of providing highway transportation, and its implications should be included in the planning process.

ANALYSIS OF MAINTENANCE EXPENDITURES

An analysis of highway maintenance expenditures based on data gathered from a wide geographical area shows great variation. Local environmental conditions produce shifts in the relative importance of the various operations with respect to the total maintenance expenditure. Location of data in an appropriate form for analysis is a major problem. The need for detailed data from developing areas is essential before a satisfactory analysis can be applied to specific areas.

This analysis attempts to show the per mile annual maintenance expenditures for various types of roadway surfaces, subdivided into the various operations. Most of the data have been obtained from individual states in the United States because of the lack of detailed maintenance data for developing areas. Although this survey received replies from 36 states, only 14 submitted data in useful form. In addition, most of these states did not subdivide their data so that they could be used in every category of surface type. Obviously, the dollar value expenditures presented cannot be applied to other areas. The goal of this analysis is not the development of absolute values but the presentation of the data in such a manner as to illustrate the relative importance of each of the maintenance operations to each type of roadway surface. Indeed, the per mile expenditures cannot even be applied from one state to another, and wide ranges of annual per mile costs exist within each operational category for a given surface type.

A major problem in dealing with maintenance expenditures is the standard of maintenance provided. Each state highway department spends the money provided for maintenance in the annual budget. The question is whether these sums would be adequate to provide maintenance sufficient to fulfill the basic definition. The data presented represent expenditures for state highway systems only. They do not include maintenance of county, township, or urban systems. In many areas these are often undermaintained. By using only the state systems, it is hoped that the data represent systems that are adequately maintained.

Maintenance expenditures for six types of roadway surfaces are included: portland cement concrete pavements, asphaltic concrete pavements, mixed bituminous roads (intermediate asphaltic pavements), bituminous surface-treated roads, gravel roads, and dirt roads. In four of these categories, the maintenance expenditures are subdivided into eight operations: surface maintenance, shoulder maintenance, drainage, roadside maintenance, snow removal and general winter maintenance, maintenance of traffic control devices, maintenance of structures, and other. This material is contained in Tables 4 through 9 (14-26).

No breakdown by operation is given for dirt or asphaltic concrete roads because of the small size of the sample. Dirt roads are not common on state highway systems; only a limited number of states segregated their data on asphaltic concrete roads, and in some instances the data were limited only to surface and shoulder maintenance.

The data are presented in this fairly complete form to demonstrate the great range in costs in most subcategories. Dealing with the aggregated data or averages would be very misleading without an appreciation of their variability. The following discussions attempt to establish some of the variations which might be expected in maintenance costs and to correct some common misconceptions concerning them.

TABLE 4

ANNUAL MAINTENANCE COST OF DIRT ROADS[a]

State	Miles of Road	Cost per Mile for Maintenance
A	286.5	1,077.63
B	144.8	306.19
C	195.9	826.32
Total	627.2	821.03

[a]Data from Refs. 14-26.

The most striking fact is that annual maintenance expenditures do not decrease with the higher types of pavements. Even with the wide variation of the data, it could be generally stated that unpaved roads have an annual maintenance cost of approximately \$800/mi. Bituminous roads cost about \$1,200/mi/yr to maintain, and concrete roadways somewhere between \$1,000 and \$1,100/mi, or possibly as much as \$1,200 (14-26). There is a decided differential between the unpaved and the paved roads.

A second important consideration is that the higher the type of roadway, the less the relative importance of surface maintenance. The evidence of this is that the percentage of total cost represented by surface maintenance expenditures decreases. The expenditure per mile for surface maintenance shows no definite trend. The tables

TABLE 5

ANNUAL MAINTENANCE COSTS OF GRAVEL ROADS[1]

State	Miles of Road	Cost/Mile	Percent of Total Cost/Mile for Maintenance
(a) Surface Maintenance			
A	38.4	655.83	65.3
D[2]	1,928.2	678.54	73.0
E[3]	2,158.2	411.40	67.2
F	76.1	440.37	82.4
Total	4,200.9	536.78	70.0
(b) Shoulder Maintenance			
A		15.57	1.5
D		37.95	3.1
E[4]		-	-
F		1.72	0.3
Total	2,042.7	36.18	
(c) Drainage			
A		103.44	10.3
D		92.56	10.0
E		80.60	13.1
F		39.67	7.4
Total	4,200.9	85.56	11.2
(d) Roadside			
A		25.52	2.5
D		87.28	9.4
E		34.16	5.6
F		48.90	9.1
Total	4,200.9	58.73	7.7
(e) Snow			
A		45.81	4.6
D		0.16	0.0
E		2.82	0.5
F		N.A.	N.A.
Total	4,124.8	1.98	

State	Miles of Road	Cost/Mile	Percent of Total Cost/Mile for Maintenance
(f) Traffic			
A		60.67	6.0
D		25.80	2.8
E		15.12	2.5
F[5]		4.00	0.7
Total	4,200.9	20.24	
(g) Structure			
A		12.68	1.3
D		6.42	0.7
E		62.10	10.2
F		N.A.	N.A.
Total	4,124.8	35.93	
(h) Other			
A[6]		85.49	8.5
D		1.15	0.1
E		5.80	0.9
F		N.A.	N.A.
Total	4,124.8	4.37	
(i) Total Cost/Mile and Maintenance			
A		1,005.00	
D		929.85	
E		612.56	
F		918.12	
(j) States Not Giving Operational Breakdown			
G	555.4[7]	508.81	
H	40.9	386.20	
C	870.1	804.69	
B	1,110.7	734.30	
J	72.9[8]	505.52	
P	2,432.0	910.92	
10 states	9,282.9	785.29	
A, D, E, F	4,200.9	767.32	

[1]Data from Refs. 14-26.
[2]Six-months return (Jan.-June) multiplied by two.
[3]State secondary roads.
[4]Included in surface.
[5]Guardrail maintenance only.
[6]Includes all supervision.
[7]Surface maintenance only.
[8]Does not include roadside, snow, or traffic.

TABLE 6

ANNUAL MAINTENANCE COSTS ON BITUMINOUS SURFACE-TREATED ROADS[1]

State	Miles of Road	Cost/Mile	Percent of Total Cost/Mile for Maintenance
(a) Surface Maintenance			
A-WB[2]	691.4	999.04	63.2
A-W/OB[3]	3,635.5	2,071.48	78.2
F	2,905.2	574.23	64.4
K	3,593.3	679.47	58.0
L	2,427.1	536.13	50.1
M	372.7	485.00	36.5
Total	13,625.2	1,013.81[4]	67.0
(b) Shoulder Maintenance			
A-WB		33.25	2.1
A-W/OB		23.80	0.9
F		84.33	9.5
K		15.98	1.4
L		284.45	26.6
M		90.00	6.8
Avg.		83.36	5.5
(c) Drainage			
A-WB		91.86	5.8
A-W/OB		89.11	3.4
F		97.12	10.9
K		27.84	2.4
L		17.45	1.6
M[5]		336.36	25.3
Avg.		68.80	4.5
(d) Roadside			
A-WB		118.75	7.5
A-W/OB		97.52	3.7
F		110.71	12.4
K		99.80	8.5
L		174.03	16.3
M[6]			
Total	13,252.5	116.15	7.7
(e) Snow			
A-WB		121.15	7.7
A-W/OB		127.33	4.8
F		N.A.	N.A.
K		134.41	11.5
L		N.A.	N.A.
M		19.80	1.5
Total	8,292.9	125.05	

State	Miles of Road	Cost/Mile	Percent of Total Cost/Mile for Maintenance
(f) Traffic			
A-WB		108.35	6.8
A-W/OB		129.42	4.9
F[7]		25.65	2.9
K		91.22	7.8
L[8]		21.61	2.0
M		136.97	10.3
Total	13,625.2	77.15	5.1
(g) Structure			
A-WB		17.12	1.1
A-W/OB		8.93	0.3
F		N.A.	N.A.
K		30.62	2.6
L		32.17	3.0
M		1.29	0.1
Total	10,720.0	21.72	
(h) Other			
A-WB		92.29	5.8
A-W/OB		100.20	3.8
F		N.A.	N.A.
K		91.77	7.8
L		5.02	0.5
M[9]		258.51	19.5
Total	1,072.0	80.82	
(i) Total Cost/Mile and Maintenance			
A-WB		1,581.81	
A-W/OB		2,647.78	
F		892.05	
K		1,171.11	
L		1,071.03	
M		1,328.39	
Total	13,625.2	1,512.93[10]	
(j) States Not Giving Operational Breakdown			
B	3,499.9	642.07	
H	1,651.6	703.46	
J[11]	451.5	638.31	
6 states	19,228.2	1,264.35	

[1] Data from Refs. 14-26.
[2] With standard base.
[3] Without standard base.
[4] $628.90 excluding State A-W/O base.
[5] Includes roadside maintenance.
[6] Included in drainage.
[7] Guardrail maintenance only.
[8] May not include stripping.
[9] Includes operational expenses.
[10] $1,099.93 excluding State A-W/O base.
[11] Does not include roadside, snow or traffic.

indicate that for the higher types of surfaces, roadside and traffic control device maintenance increase not only in absolute cost but also in their proportion of the total expenditure. This should be expected. On the higher types of roadways, the automobile user expects and demands higher levels of nonsurface facilities.

The tabulation of the data for State A for bituminous surface-treated and intermediate asphalt roads indicates that this state separated roads having a standard design base from those which did not. For bituminous surface-treated roads without a standard base, the total annual maintenance cost was somewhat more than $1,000/mi/yr greater than for those roads with an adequate base. An investigation of the individual maintenance operations for these roads indicates that this $1,000/mi/yr difference is in surface maintenance. The annual expenditures for the other maintenance

TABLE 7

ANNUAL MAINTENANCE COSTS FOR INTERMEDIATE ASPHALT (MIXED BITUMINOUS) ROADS[1]

State	Miles of Road	Cost/Mile	Percent of Total Cost/Mile for Maintenance
(a) Surface Maintenance			
A-WB[2]	1,463.8	702.91	54.7
A-W/OB[3]	1,352.6	730.16	58.7
K-ADT>2000	1,027.5	194.73	15.3
K-ADT<2000	363.1	168.44	15.4
L	2,329.0	345.56	45.6
M	1,042.8	589.00	39.8
N-1[4]	79.8	176.82	45.2
N-2[5]	78.3	1,100.81	80.4
Total	7,736.9	490.78	43.6
(b) Shoulder Maintenance			
A-WB		47.88	3.7
A-W/OB		32.32	2.6
K-ADT>2000		65.56	5.2
K-ADT<2000		40.88	3.7
L		86.09	11.4
M		85.00	5.7
N-1		6.90	1.8
N-2		19.71	1.4
Avg.		62.98	
(c) Drainage			
A-WB		64.53	5.0
A-W/OB		56.52	4.5
K-ADT>2000		50.05	3.9
K-ADT<2000		26.74	2.4
L		29.81	3.9
M[6]		229.34	15.5
N-1[6]		56.76	14.5
N-2[6]		92.61	6.8
Avg.		71.40	
(d) Roadside			
A-WB		133.88	10.4
A-W/OB		114.57	9.2
K-ADT>2000		207.48	16.4
K-ADT<2000		138.73	12.7
L		235.41	31.1
M[7]			
N-1[7]			
N-2[7]			
Total	6,536.0	177.98	
(e) Snow			
A-WB		102.67	8.0
A-W/OB		90.22	7.3
K-ADT>2000		317.34	25.0
K-ADT<2000		285.20	26.0
L		N.A.	N.A.
M		13.91	0.9
N-1		115.18	29.4
N-2		103.63	7.6
Total	5,407.9	135.68	
(f) Traffic			
A-WB		118.71	9.2
A-W/OB		90.82	7.3
K-ADT>2000		243.55	19.2
K-ADT<2000		206.05	18.8
L[8]		23.04	3.0
M		234.41	15.8
N-1		34.46	8.8
N-2		46.30	3.4
Avg.		119.71	10.6
(g) Structure			
A-WB		7.08	0.6
A-W/OB		5.62	0.5
K-ADT>2000		55.60	4.4
K-ADT<2000		74.24	6.8
L		29.39	3.9
M		3.25	0.2
N-1		1.35	0.3
N-2		5.85	0.4
Avg.		22.55	
(h) Other			
A-WB		107.24	8.3
A-W/OB		122.69	9.9
K-ADT>2000		134.10	10.6
K-ADT<2000		155.52	14.2
L		8.30	1.1
M[9]		325.21	22.0
N-1		N.A.	N.A.
N-2		N.A.	N.A.
Total	7,578.8	115.54	
(i) Total Cost/Mile and Maintenance			
A-WB		1,284.90	
A-W/OB		1,242.92	
K-ADT>2000		1,268.91	
K-ADT<2000		1,095.80	
L		757.60	
M		1,480.12	
N-1		391.47	
N-2		1,368.91	
Total	7,736.9	1,125.78	
(j) States Not Giving Operational Breakdown			
H[10]	1,651.7	703.46	

[1] Data from Refs. 14-26.
[2] With standard base.
[3] Without standard base.
[4] Avg. base + subbase = 11 in. (new pavement).
[5] Avg. base + subbase = 6 in.
[6] Includes roadside.
[7] Included in drainage.
[8] Probably excludes stripping.
[9] Includes operational expenses.
[10] Surface maintenance only.

operations for these two categories of bituminous surface-treated roads are similar. The sample includes over 4,300 mi of roadway. These figures indicate the importance of an adequate base for bituminous-treated roadways. This fact should be studied by developing areas where there is at times a tendency to apply bituminous surface treatments to roadways with inadequate or no base courses.

TABLE 8

ANNUAL MAINTENANCE COSTS FOR TWO-LANE PORTLAND CEMENT CONCRETE ROADS[1]

(a) Surface Maintenance

State	Miles of Road	Cost/Mile	Percent of Total Cost/Mile for Maintenance
A	840.2	294.22	22.0
D	1,659.3	668.09	45.0
E	631.4	122.70	30.8
F	156.5	181.91	28.5
J[2]	8,120.4	725.33	66.2
K-ADT>2000	1,293.9	284.24	21.2
K-ADT<2000	898.3	297.40	27.5
L	1,303.9	374.20	41.2
Total	14,903.9	568.61[3]	

(b) Shoulder Maintenance

State	Miles of Road	Cost/Mile	Percent of Total Cost/Mile for Maintenance
A		102.36	7.6
D		217.46	14.6
E		29.81	7.5
F		184.54	28.9
J		325.45	29.7
K-ADT>2000		84.51	6.3
K-ADT<2000		44.35	4.1
L		108.77	12.0
Avg.		230.03[4]	

(c) Drainage

State	Miles of Road	Cost/Mile	Percent of Total Cost/Mile for Maintenance
A		147.39	11.0
D		117.07	7.9
E		34.56	8.7
F		89.47	14.0
J		27.50	2.5
K-ADT>2000		40.57	3.0
K-ADT<2000		56.24	5.2
L		53.02	5.8
Total	14,903.9	50.28[5]	

(d) Roadside

State	Miles of Road	Cost/Mile	Percent of Total Cost/Mile for Maintenance
A		164.58	12.3
D		323.43	21.9
E		93.24	23.4
F		134.39	21.0
J		N.A.	N.A.
K-ADT>2000		214.42	16.0
K-ADT<2000		123.13	11.4
L		299.89	33.0
Total	6,783.5	226.07	

(e) Snow

State	Miles of Road	Cost/Mile	Percent of Total Cost/Mile for Maintenance
A		189.13	14.1
D		0.40	0.0
E		30.43	7.6
F		N.A.	N.A.
J		N.A.	N.A.
K-ADT>2000		278.74	20.8
K-ADT<2000		265.54	24.6
L		N.A.	N.A.
Total	5,323.1	146.15	

(f) Traffic

State	Miles of Road	Cost/Mile	Percent of Total Cost/Mile for Maintenance
A		177.64	13.3
D		127.29	8.6
E		65.29	16.4
F[6]		48.78	7.6
J		N.A.	N.A.
K-ADT>2000		221.85	17.1
K-ADT<2000		152.78	14.2
L[7]		50.82	5.6
Total	6,783.5	132.66	

(g) Structure

State	Miles of Road	Cost/Mile	Percent of Total Cost/Mile for Maintenance
A		94.70	7.1
D		20.67	1.4
E		19.27	4.8
F		N.A.	N.A.
J		4.26	0.4
K-ADT>2000		78.69	5.9
K-ADT<2000		49.87	4.6
L		21.65	2.4
Total	14,747.4	22.75[8]	

(h) Other

State	Miles of Road	Cost/Mile	Percent of Total Cost/Mile for Maintenance
A		168.23	12.6
D		10.25	0.7
E		2.88	0.7
F		N.A.	N.A.
J		12.88	1.2
K-ADT>2000		131.15	9.8
K-ADT<2000		89.98	8.3
L		N.A.	N.A.
Total	13,443.5	38.33[9]	

(i) Total Cost/Mile and Maintenance

State	Miles of Road	Cost/Mile	Percent of Total Cost/Mile for Maintenance
A		1,338.25	
D		1,484.66	
E		398.18	
F		639.09	
J		1,095.42	
K-ADT>2000		1,342.17	
K-ADT<2000		1,079.39	
L		908.35	
Total	14,903.9	1,122.20	
Total[10]	6,783.5	1,154.27	

(j) States Not Giving Operational Breakdown

State	Miles of Road	Cost/Mile	Percent of Total Cost/Mile for Maintenance
G[11]	689.4	675.22	
B	2,016.3	982.14	
C	318.1	881.72	
10 states	17,927.7	1,085.00	

[1] Data from Refs. 14-26.
[2] Not all 2-lane.
[3] $381/mi excluding State J.
[4] $115.80/mi excluding State J.
[5] $77.55 excluding State J.
[6] Guardrail maintenance only.
[7] Probably no stripping included.
[8] $45.41 excluding State J.
[9] $77.15 excluding State J.
[10] Excluding State J.
[11] Surface only.

Where intermediate asphaltic pavements are concerned, in State A there is almost no difference in annual per mile expenditures on those with or without the standard base, perhaps because an intermediate surface usually has some type of base. It might not be classified as a fully standard base, but a complete absence of this material would be unusual. However, this is not unusual in bituminous surface-treated roadways.

TABLE 9

ANNUAL MAINTENANCE COST OF ASPHALTIC CONCRETE ROADS[1]

State	Miles of Road	Cost/Mile for Maintenance
A[2]	1,121.2	574.45
A[3]		118.58
A[4]		34.24
A[5]		196.85
A[6]		1,387.58
C[7]	1,803.1	1,264.10
G[8]	7,267.4	523.95
J[9]	5,782.6	644.05
J[10]	5,782.6	674.15

[1] Data from Refs. 14-26.
[2] Surface and shoulders.
[3] Drainage.
[4] Structures.
[5] Traffic.
[6] Total maintenance.
[7] Total.
[8] Surface only.
[9] Surface and shoulders.
[10] Surface, shoulders, drainage and structures.

An interesting point is the relative unimportance of structure maintenance in the overall maintenance budget. This may change as the mileage of controlled-access roads increases; structural maintenance for these roads will be a more important factor. Another fact, which might not be expected, is that in many cases the savings of those states having a relatively low expenditure on snow and winter maintenance is counteracted by their expenditures on roadside maintenance.

One major variable not accounted for in any of these analyses is the fact that, in general, the higher the surface type, the greater is the volume of traffic. Thus, it is not entirely appropriate to compare maintenance cost for gravel roads with those of the higher type asphaltic or concrete roads because their traffic volumes vary. The volumes carried by many of the higher type surfaces would generate excessive costs on the gravel roadways. Because of the lack of appropriate data, there is no way to take this variation into account.

The importance of nonsurface maintenance is often overlooked in developing areas. As indicated in the Tables 4 through 9, these operations take on increased importance with the higher types of pavements. An example of this is presented in the study prepared by the International Road Federation on the maintenance of the Pan-American Highway in Central America (27). Table 10 gives the current expenditures for the maintenance of this highway in the various Central American countries. El Salvador is the only country specifying how the monies are expended. In this case, 84 percent of the total maintenance costs are used for surface maintenance. For the most part, the road is of intermediate or high surface type. Table 10 also indicates the estimated future maintenance expenditure. In no case does the Federation recommend that more than 47 percent of the total expenditure be spent on maintenance of the pavement. It does recommend a considerable increase in the general level of the expenditure. It appears, however, that most of this increased expenditure would be used for nonpavement maintenance.

This report also recommends that the United States contribute 50 percent of the cost of maintenance. If such a plan were adopted, it would represent a major change in American policy. The IRF realizes that the leading countries, by helping developing

TABLE 10

CURRENT AND ESTIMATED FUTURE MAINTENANCE EXPENDITURE ON PAN-AMERICAN HIGHWAY[a]

Country	Current, 1960		Estimated, 1960-1965	
	Cost ($/km/yr)	% on Pavement	Cost ($/km/yr)	% on Pavement
Guatemala	662	N.A.	1,126[b]	37
El Salvador	602	84	936[b]	47
Honduras	939	-	918[b]	43
Nicaragua	1,264[c]	-	1,058[b]	40
Costa Rica	-	-	875	41

[a] Data from Ref. 27.
[b] Includes one seal treatment.
[c] High cost due to base failure.

as to construct highway systems, commit the receiving countries to substantial annual maintenance costs. It is not inappropriate that the developed countries provide aid for maintenance. If for no other reason, it will help insure that their investment is not lost through lack of maintenance (27).

FACTORS INFLUENCING MAINTENANCE OPERATIONS

To understand the variability of expenditures on maintenance operations, it is necessary to understand the basic factors influencing specific operations and the complexity of the interrelationships involved. These fundamental complexities are the major obstacles to the development of a quantitative analysis that would predict maintenance costs for any roadway.

The basic factors influencing maintenance operations can be grouped into three categories.

1. Roadway characteristics. Established during the design and construction of a highway, these are difficult and expensive to alter.
2. Traffic characteristics of the highway. For the most part, these are beyond the control of the highway engineer or planner. They are related to the economy of the region and the amount of highway transport associated with it. (The one exception is the control of maximum axle loads, a most important, though often overlooked, factor in the operation of a successful highway system.
3. Environmental characteristics of the roadway. These include climate, topography, and the other characteristics associated with any given roadway. Many of the consequences of environment can be lessened through proper design and construction.

Factors thought to influence maintenance operations are pavement type, shoulder type, pavement width, right-of-way width (less pavement width), base and subgrade material, geometric design (grade-line curvature), age, traffic volume, axle load, speed, topography, precipitation, temperature, and cultural environment. Of these factors, seven might be classified as roadway characteristics, three as traffic characteristics, and four as environmental characteristics. This is not a complete listing but an enumeration of those usually considered most important.

RELATIONSHIP OF FACTORS INFLUENCING MAINTENANCE

The foregoing factors are not independent variables in relation to their impact on maintenance operations and costs. The effects on maintenance costs due to a change in any one factor depend on the existing contributions of others and, in general, on the amount of change in the other factors.

Age per se ought not to be a separate factor. That some pavements may deteriorate more rapidly with time may be a reflection of fatigue failures due to the accumulation of repeated loadings. A more appropriate index of this might be the accumulated volume of traffic and some measure of the amount and magnitude of the axle loads. Environmental conditions also influence the extent of the effect of a wheel load. Age might be a direct but minor factor in the case of asphaltic pavements, because asphaltic materials tend to oxidize with time.

Another example of the complex interrelation of these factors may be seen in the effects of topography. Topography will have an effect on the right-of-way width since the rougher the topography, the narrower is the right-of-way. More important is the effect on the pavement and shoulder widths used in design. The higher cost of earth work involved in construction in rougher topography dictates that narrower pavements and often considerably narrower shoulders be designed. The important influence of topography on the design and number of grades and curves is obvious. Not so obvious, however, is its effect on the base and subbase materials. Although a hard and fast rule cannot be established, in general, the rougher the topography, the better the chance for having good subgrade materials nearby. For example, it would be unusual to find large areas of clay or silt in mountainous areas.

Probably the most important and complex of interrelationships are those which tie together traffic volume, axle load, pavement type, and base and subgrade material.

The separate evaluation of each of these on maintenance costs is virtually impossible. In fact, their interrelationship with respect to the structural design of a roadway is not yet clearly evaluated. One can observe that higher traffic volume and axle loads generally require higher pavement types and higher quality and control of the base and subgrade materials. Further, for a given roadway, the higher the traffic volume and the higher the maximum axle load, the higher the maintenance required. However, the magnitude of the axle load is not the only criterion. The frequency of the various axle loads is the important factor. Thus far, no satisfactory index combining the effects of traffic volume and the distribution of axle loads on maintenance costs has been established.

The effects of temperature and precipitation are closely interrelated. An estimate that would combine the two and be meaningful to maintenance costs would be very difficult to make.

For each of the major maintenance operations, there seems to be no independent variable that can be readily analyzed. Moreover, the interdependence of the factors themselves seems to be of such a complexity as to greatly decrease the feasibility of estimation of maintenance operations from these basic factors.

METHODS OF ESTIMATING MAINTENANCE COSTS

Having discussed the complexity of the problem, it is appropriate to review the various methods of predicting maintenance costs. The methods are included to show the range in analysis techniques used and their relationship to the foregoing discussion.

Proponents claim various advantages for each. Many of the formulations have been developed for estimating maintenance budgets. Because they deal with expenditures and possibly various standards of maintenance, all of the methods presented are parochial. They have been derived for given areas, with given conditions, and have little or no direct application to other areas. Some present a basic form which might be adaptable to other conditions.

The simplest formulation of any maintenance cost data is the quotation of an annual maintenance cost per mile of highway. This does not take into account any of the factors influencing maintenance expenditures.

The second category is similar to the first and consists of an estimated annual maintenance expenditure per mile for various roadway surfaces (29). In the United States, many states still give no more information than this.

Most highway engineers consider the two most important factors of maintenance costs to be the surface type and the traffic volume (30). There are a number of methods of estimation based on these variables. This type of method is usually presented as an equation for a given type of roadway surface and often takes the form of a constant factor plus a linear increase with increased traffic volume. For example, a rough estimate often used for British West Africa is that the annual maintenance cost per mile for bituminous surface-treated roads is equal to £50 plus two times the average daily traffic. In other words, a bituminous treated road with 200 veh/day would cost approximately £450 ($1,260)/mi/yr to maintain.

An interesting set of equations of this form were presented by Cogeraf in his study of the Republic of the Niger (31). His equations were constructed to produce answers in terms of West African francs per kilometer per year. The following equation was presented for the maintenance expenditures expected on bituminous surface-treated roads:

$$130{,}000 + 0.88\,(M - 36{,}000) \qquad (1)$$

where M is the annual traffic expected on the roadway. The estimation of gravel road maintenance was as follows:

$$40{,}000 + 4.44\ M \qquad (2)$$

This type of formulation allows the evaluation of the traffic volume at which the maintenance costs on the two types of roadways would be equal. In this particular case, the volume amounts to about 16, 400 veh/yr or approximately 45 veh/day.

A more complex relationship was perfected in Louisiana to predict maintenance costs more adequately (32). The method, as originally developed, analyzed only portland cement concrete pavements. It took into account the age of the pavement, width of the surface, traffic volume, soil condition of the subgrade, and width of the right-of-way. A factor was developed for each of these variables (see Appendix). The five factors were added together and the value of unity was added to this subtotal to obtain a final factor. This factor was then multiplied by the cost of maintaining a basic mile of pavement. In this case, the basic mile was a concrete surface less than 4 yr old, not over 20 ft wide, not over 1, 000 veh/day of traffic, with a good subgrade and a right-of-way of 80 ft. A similar method was used recently in Ohio with the addition of surface condition and terrain factors (33).

The theoretical weakness of this approach is that it considers each of the factors an independent variable, which has been shown to be incorrect. For example, taking the Louisiana method and using a basic roadway condition except with a right-of-way width of 150 ft instead of 80 ft, it might be concluded that the maintenance cost would double. This seems unrealistic. However, it is probable that this particular set of circumstances does not occur in Louisiana; and thus, the formulation is being used in a broader concept than that for which it was designed.

A similar method presented by the Highway Research Board uses four variables to evaluate what is termed a maintenance effort index (32). These variables are the traffic on the section measured in vehicles per day per 2 lanes of pavement, type of subgrade soil, thickness of the surface, and thickness of the base or the subbase. As in the Louisiana method, this method provides an index number for each of the four variables which were summed to obtain the maintenance effort index. It is then possible from a chart to estimate the annual maintenance cost per 10, 000 sq yd of surface.

Probably the first method which recognized the interdependence of the basic factors involved was also presented by the Highway Research Board. It contains four variables concerned mostly with the surface of the roadway (32). These variables are surface width, surface type, a surface condition factor, and a traffic factor. In no case was any factor allowed to be less than 1. The development of these factors and example problems are presented in the Appendix. The individual factors are multiplied together to obtain a composite factor. As explained by Radzikowski,

> multiplication is used in this instance instead of addition—because it has been found that changes in any one of the "factors" have a corresponding effect on the magnitude of the effect of the other factors. Multiplication accomplishes this result.

This composite factor is then multiplied by the maintenance cost of a basic mile. In this case the basic mile cost would represent the maintenance of a high-type surface, 18 ft in width, with excellent subgrade conditions and traffic of less than 1, 000 veh/day.

This latter method was adapted and modified by Argentina in its attempt to analyze the same problem. The Argentine method of analysis is also presented in the Appendix (34). It is essentially the same as the one described by the Highway Research Board with some minor modifications. One of these modifications is the establishment of basic traffic figures for five types of roadway surfaces, i.e., gravel, single level bituminous surface treatment, double level bituminous surface treatment, triple level bituminous surface treatment, and high-type bituminous surfaces. Another modification is the increase in the value of the surface type factor for intermediate (bituminous surface-treated) surfaces. Finally, the Argentine method allowed for factors to be less than 1 in the case where the road width was less than 6 m. Comparison of the examples given in the Appendix indicates that the Argentine method gives estimates for single surface treatment roads which are higher by a factor of almost 2.5 than those given by the Highway Research Board method.

Probably the most sophisticated analysis thus far developed was presented by the Engineering Experiment Station of the Louisiana State University (35). This was a continuation of the basic Louisiana method previously described. It was derived for concrete pavements only. The factors considered are traffic volume, subsoil condition, surface width, right-of-way width, and surface condition. Compared with the old Louisiana method, these factors are essentially similar except that surface condition has been added and the factor for pavement age has been removed. The investigators realized the importance of the interrelationship between the various factors. With the help of an electronic computer, they combined these factors in various multiplicative and summation factors for use in regression equations. They then applied these various regression equations to the historical data for Louisiana. The following equation gave the optimal fit to the data:

$$\text{Maintenance cost (\$/mi/yr)} = -35 + 0.049Z_1 + 0.056\frac{Z_1}{Z_4} + 3.6Z_2Z_4 + 0.3\frac{Z_1Z_3}{Z_4} + 3.6Z_5 \qquad (3)$$

where

Z_1 = traffic volume (avg. No. veh/day);
Z_2 = surface condition (excellent-1, good-3, fair-5, poor-7, very poor-9);
Z_3 = subsoil condition (good-1, medium-2, poor-3);
Z_4 = surface width (ft); and
Z_5 = right-of-way width (ft).

It is important to note that this method does not necessitate the calculation of the maintenance cost of a basic mile of roadway. However, the equation is founded on Louisiana's local experience and the coefficients therefore cannot be used universally. The general form of the equation and the relative importance of each of the factors are of considerable interest. One item of note is the apparent independence of the right-of-way width factor in that it appears in only one term of the equation and then without any other factor.

To demonstrate the relative importance of each factor, the following example is given. Consider a roadway with 2,000 veh/day, a fair (5) surface condition, poor (3) subsurface condition, a 20-ft surface width and an 80-ft right-of-way. By substituting these numbers in the preceding equation, a maintenance cost of -35 + 98 + 84 + 360 + 90 + 288 = \$885/mi/yr is obtained. This example shows that the fourth and last terms in the equation carry considerable weight.

To investigate the importance of each of the individual factors, it is possible to solve the equation and determine how much of a change in any factor will bring about a given change (\$100/mi/yr) in the maintenance costs. The values obtained are valid only for this problem since they are dependent on the value of the other factors. To obtain a \$985/mi/yr cost would necessitate either an increase of right-of-way width of 37.8 ft, an increase of traffic of 735 veh/day, an increase of pavement width of 8.4 ft, a change in the surface condition factor of 1.13, or a change in the subsoil condition factor of 1.69. It would seem, therefore, that the surface condition factor is extremely important, especially considering that this factor is established by adjective means. A difference of 1.0 in this factor is only halfway between any of the five categories presented. Yet this unit difference has the same impact as the addition of arly one lane of pavement or more than 700 veh/day. This would indicate the need for a more precise measurement of surface conditions.

The relatively major effect of right-of-way width on maintenance costs may at first seem unreasonable. However, it must be remembered that this is essentially a measurement of the cost of roadside maintenance, especially mowing. In Louisiana, because of climatic conditions, this is a 12 mo/yr operation.

The question then arises whether, instead of dealing with the individual factors, some relatively simple combined index could not be developed which would show a correlation with maintenance costs. The concept of sufficiency rating has been used in the United States for a number of years to determine how well a highway meets the demands placed on it. These ratings are usually based on surface condition, safety, and service. As noted, surface conditions seem to be an important factor in the determination of maintenance costs. Most sufficiency rating systems include, under the heading of safety and/or service, indications of the road's traffic capacity as compared to the traffic using the road. As has been seen, this is another major factor in maintenance. The sufficiency rating might show a correlation to maintenance cost. The only data available of this type are given in Table 11 and were developed for Kansas (36).

The Kansas sufficiency rating is based on 100 points. The complete sufficiency rating includes the following items: (a) structural adequacy; (b) observed structural condition of the surface; (c) condition of grade and drainage facilities; (d) right-of-way width; (e) shoulder width; (f) surface width; (g) sub-standard design such as poor alignment and lack of stopping sight distance; (h) passing opportunity; and (i) traffic.

Figure 1 indicates the amount and type of maintenance conducted in each sufficiency rating group. The maintenance expenditures on all items except surface and base maintenance remain relatively constant (37). The striking fact illustrated by Figure 1 is the very rapid increase in expenditures on surface maintenance as the sufficiency rating decreases. It must be remembered that a large percentage of the rating itself is dependent on surface condition.

The poorly designed or insufficient roadway will probably necessitate very large expenditures on surface maintenance. Furthermore, these expenditures will be continuing. In other words, insufficient roadways necessitate high maintenance expenditures but remain insufficient for the most part (38). The importance of proper design and construction cannot be overlooked and the lack of it cannot be completely overcome even with increased maintenance expenditures.

TABLE 11

MAINTENANCE COSTS OF KANSAS RURAL STATE HIGHWAY SUFFICIENCY RATING, 1961[a]

Sufficiency Rating	Avg. Total Maintenance Expenditure ($/mi)
≤49	2,983
50-59	2,278
60-69	1,829
70-79	1,756
80-100	1,066

[a]Information from Ref. 36.

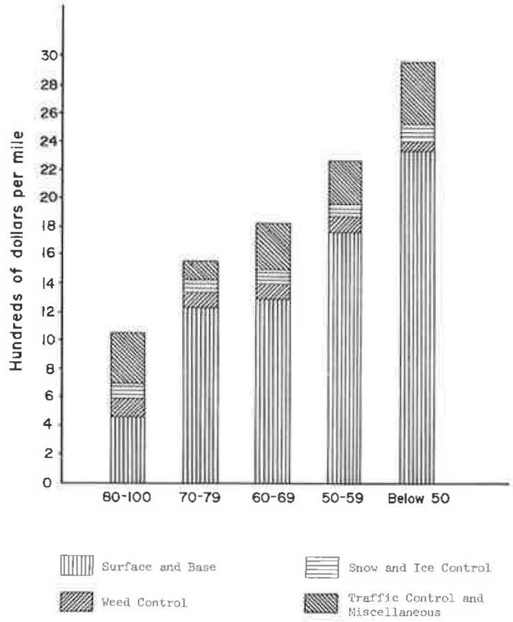

Figure 1. Maintenance costs on state highways by sufficiency ratings, FY'61.

This discussion has illustrated the increasing awareness of the complex interrelationships involved in maintenance costs. The interrelationship of basic factors has been substantiated by the complexity of the regression equations needed to predict maintenance cost satisfactorily. At this time it is impossible to present any general theory or equation with universal application. It is hoped that the various methods outlined will provide a starting point for application in developing areas. The engineer and planner who may try to adopt one or more of these methods will probably find that the limiting element is the amount and reliability of historical maintenance data.

CONSEQUENCES OF PAVING

This section discusses some of the implications local governments should consider when upgrading their highway systems from unpaved to paved surfaces. Bituminous surface-treated roads are compared with gravel roads since the two not only represent a lower type of paved surface and a high type of unpaved surface, respectively, but they account for the majority of highway mileage in most developing areas.

As indicated in Tables 5 and 6 and as previously noted, there is substantial reason to believe that bituminous surface-treated roadways will be more expensive to maintain. When one discounts from Table 6 the mileage of State A which has not an adequate base, there is still a differential in maintenance costs. When this mileage is removed, the cost of surface maintenance for bituminous surface-treated and gravel roads is approximately equal.

Although this differential is maintenance costs is often not emphasized, it does reoccur consistently in the literature (39, 40). In 1942 a comparison was made of 17 types of roadway surfaces and their maintenance costs. This included gravel roads and two types of bituminous surface-treated roads, depending on the base material. It indicated that, at that time, gravel roads in this survey cost approximately $800/mi/yr to maintain, whereas maintenance of the two bituminous surface-treated roads cost more, ranging between $1,024 and $1,500/mi/yr (41).

This differential is also substantiated in data from the developing areas themselves Table 12 gives maintenance costs for roads in Ghana (42). The periodic resurfacing expenditure for gravel roads covers the regraveling with a 6-in. depth about every 5 yr. This indicates a loss of material of at least 1 in./yr, which is in line with other experience. Gravel roads are under intensive maintenance and are dragged about once every 2 days. They are maintained to a high standard for this type of roadway. The periodic resurfacing cost for bituminous surface-treated roadways provided for resurfacing every 4 yr at a cost of £1,500/mi (42).

In most cases cited, it is probably true that the bituminous surface-treated roadways do carry higher volumes of traffic than the gravel roads. A Highway Research Board publication states that for the period between 1942 and 1947 gravel and bituminous surface-treated roadways had essentially equal maintenance cost at a traffic volume of 100 veh/day (32). There is considerable indication that because of different material and labor costs in developing areas this figure is somewhat low for them.

TABLE 12

MAINTENANCE EXPENDITURES IN GHANA, 1962

Road Type	Miles	Routine Maint. (£/mi/yr)	Resurfacing (£/mi/yr)	Total (£/mi/yr)
Gravel	3,277	263	155[a]	418 ($1,170)
Bituminous surface-treated	2,053	280	375[b]	655 ($1,830)

[a]Resurfaced every 5-6 yr with 6 in. of gravel.
[b]Resurfaced every 4 yr at £1,500/mi.

In the IBRD report for Nigeria in 1955, the same 100 veh/day figure was used as the volume to justify the provision of a bituminous surface-treated roadway. However, this roadway was only 12 ft in width and, therefore, not a full 2-lane roadway. The volume level presented as justifying a 20-ft bituminous surface was 300 veh/day. This figure would be less if a comparison between gravel surface and a 20-ft bituminous-treated surface were made without considering the 12-ft paved alternative. It was remarked in this report that better maintenance of the gravel roads might postpone the need for paving, thus indicating that a higher standard of maintenance on the gravel roads would increase the volume of traffic needed to justify paving (4).

The IBRD report for Tanganyika, in 1961, states that the Tanganyikan government uses a figure of 170/day as minimum justification for paving the roadway. Here again the report states that this figure may be too low (5). The report for Venezuela, also in 1961, specifies a figure of 200 veh/day (6). A more graphic illustration of this is given in Table 13 taken from the IBRD report on Kenya (43). This indicates again that a traffic volume of between 200 and 300 veh/day is needed to justify the paving of 2-lane roadways. These are not design figures but average daily volume figures. In other words, 200 veh/day is equivalent to 73,000 veh/yr.

Even if this level of traffic of 200 veh/day is accepted as the point where maintenance costs of paved and unpaved roads are equal, this should not be the sole criterion for paving. Other considerations may dictate that even a higher volume of traffic is needed to warrant paving.

From the standpoint of the government agency, there are important differences between these two types of surfaces. Taking the conservative viewpoint that a road will cost the same to maintain under the two surface conditions, there are important implications in considering the labor, equipment, and material which will be purchased with these funds. Table 14 indicates the proportion of total expenditures for these three commodities for two states and the two types of roadways. In general, about 45 to 50 percent is expended on labor, 20 to 25 percent on equipment, and 25 to 35 percent on material (14-26, 44). This agrees closely with data presented for Frederick County, Md., for the country road system. This showed that 45½ percent of the expenditures were for labor, 19 percent for equipment, and 35½ percent for material (45). Thus, even in developed economies, a substantial portion of maintenance expenditure is for labor. This can be related to three basic characteristics of maintenance: (a) each specific job is relatively small; (b) a large range of different operations must be performed; and (c) the specific operations are discontinuous in time (seasonal) and space (along the roadway).

The following discussion will illustrate the different labor, equipment, and material requirements for specific maintenance operations on the two types of roadways.

TABLE 13

MAINTENANCE COSTS FOR KENYA

Road Type	Veh/Day	Maintenance Cost (£/mi/yr)
Gravel:		
1	0-50	168
2	50-100	191
3	100-200	214
4	200-300	275
5	>300	395
Bituminous surface		
12-ft		200
20 to 22-ft		265

Structures

There is no essential difference in the maintenance requirements of structures on unpaved or paved roadways. In general, this is a labor intensive operation.

Drainage Facilities

Here, also, there is little difference in the amount and type of work needed for the two types of roadways. Some extra cleaning of drainage facilities may be needed on the gravel roadways since the gravel material removed from the roadway by the action of traffic generally finds its way to side ditches and culverts and may tend to accumulate there. This maintenance operation is also generally labor intensive.

TABLE 14

PROPORTION OF LABOR, EQUIPMENT AND MATERIAL IN MAINTENANCE COSTS OF UNITED STATES[a]

Road Surface	Percent of Total Expenditure		
	Labor	Equipment	Material
(a) State A			
Gravel	44	29	27
Bit. surf. treat. with std. base	45	23	32
Bit. surf. treat. without std. base	36	19	45
Intermediate bit. with std. base	48	22	30
Asphaltic concrete	50	24	26
PC concrete	55	24	21
(b) State D			
Gravel	52	24	24
All bituminous	53	21	26
Concrete	55	20	26

[a]Data from Refs. 14-26.

Roadside Maintenance

As previously defined, roadside maintenance is predominantly the control of vegetation on the shoulders and the adjacent right-of-way. In theory, this operation would be identical for the two types of roadways. In practice, however, this may not be the case. The road user expects greater vegetation control on the higher type roadway. One reason for this is that in case of emergency the user is expected to pull off the paved surface onto the shoulder or adjacent right-of-way. He expects this area to be mowed to facilitate ease of vehicle repair. On the gravel roads, however, vehicles tend to remain on the roadway in such cases.

The maintenance of roadside uses little or no material. The exception occurs where chemical means are used for weed suppression. The amount of machinery or labor used in the mowing operations can vary considerably. Where labor is relatively scarce and expensive, the use of mowing machines is highly advantageous. It should be emphasized, however, that efficient mowing is not always possible. It depends to a great extent on the original design of the facility. Most modern mowing machines cannot be used where the slopes are excessively steep. Also, the area should be clear of trees, rocks, and other impediments which would prevent a continuous swath from being cut or would injure the mowing equipment.

In many developing areas, the tractors, fuel, and mowing equipment have to be imported and, therefore, involve foreign exchange. This is an incentive to use hand labor and small tools. The level of labor needed for the two operations varies considerably. Unskilled laborers can accomplish mowing by hand; however, if modern machinery is to be used, a relatively skilled machine operator is required as well as skilled mechanics to maintain the equipment properly.

Traffic Control Devices

There is a great difference between the two types of roadways in this area. Most important are the stripping of the centerline of the roadway and possibly, appropriate no passing and other roadway markings. None of these are used on gravel roads because of the looseness of the surface. However, they are very important on paved roads.

The stripping of the asphalt roadways has significant implications for the maintaining agency. In the first place, a majority of the maintenance expenditures will be for material. Since roadway paints, especially the reflectorized varieties, are relatively specialized, it is probable that these materials will have to be imported. Figures published by the Highway Research Board for the United States indicate that cost of these materials amounts to almost 80 percent of the total cost of highway marking (46). Since the marking operation under most climatic conditions has to be repeated once a year, this can add up to a sizable amount of imports which are not incurred with gravel roads.

In addition, the equipment for this operation is specialized and has to be imported. Again trained operators and trained personnel to maintain the equipment are required. Although striping can be done by hand, it is much slower than by machine and generally produces an inferior product.

Surface and Shoulder Maintenance

The most important phase of maintaining both bituminous surface-treated and gravel roads comprises the operations performed on the surface. Furthermore, this is the area where the operations for these two types of roadways are most dissimilar.

TABLE 15

LABOR, EQUIPMENT AND MATERIAL PROPORTIONS OF SURFACE MAINTENANCE ONLY—STATE D[a]

Surface	Labor (%)	Equipment (%)	Material (%)
Gravel	42	28	30
Bituminous	41	20	39

[a]Data from Refs. 14-26.

Table 14 gives a breakdown between labor equipment and material costs for the maintenance of these roadways in two states. For State A, roadways without adequate base show a greater relative expenditure on material. For this particular roadway category, the higher maintenance expenditures are almost entirely due to increased expense of the maintenance of the surface. This would indicate that for surface maintenance itself, the cost of materials plays a more important role. This is substantiated by a comparison of Tables 14 and 15 which indicates the relative expenditures on material for surface maintenance are greater than for overall maintenance.

The surface maintenance of gravel roads can be accomplished using relatively unskilled labor. The equipment requirements are minimal and include trucks, tractors, some type of dragging device which may be locally manufactured, and motor graders. Since none of this equipment is highly specialized, it can be used for a multitude of road maintenance operations. The materials involved will generally be locally obtainable gravels or crushed rock.

The maintenance of bituminous surface-treated roadways is a much more specialized operation. The day-to-day operations are mainly the repair of local failures. This is normally done by local patching crews, using little specialized equipment and possibly some cold-mixed type of asphaltic material. The demands of this operation on labor and equipment are not too dissimilar from those for gravel roadways.

The major differentiation involves the periodic resealing of the asphaltic-treated surface. This operation must be repeated every 4 to 6 yr (47, 48). In many cases resealing accounts for the majority of maintenance expenditures and, thus, is of prime importance. Table 12 indicated that for Ghana this amounts to approximately 57 percent of the total expenditures for maintenance of bituminous surface-treated roads. Table 16 gives estimated maintenance costs in Nigeria. Here, for the 2-lane bituminous roadway, the resealing costs amount to almost 70 percent of the total maintenance expenditures (49). On the Pan-American Highway systems in Central America, with a higher type of asphaltic surface, the resealing costs range from 25 to 30 percent of the total maintenance expected (27).

The labor requirements for this operation necessitate the use of trained crews of experienced personnel (50). The problem of obtaining uniform coverage of the bituminous material followed by equally uniform coverage of the surface aggregate is most important. An excess or deficiency of either of the two materials can lead to waste and an unsatisfactory surface (51). In many cases, this necessitates further maintenance to correct the situation.

The equipment needs are also much more specialized and require a greater diversity of equipment. Besides the normal trucks, tractors, and road graders, the resealing

TABLE 16

ESTIMATES OF ANNUAL ROAD COSTS IN NIGERIA, 1959[a]

Surface Type	Veh/Day	Normal Main. (£/mi)	Resealing Cost (£/mi/yr)	Total Main. (£/mi)
Gravel	0- 100	150	-	150
12-ft surface treatment	100- 300	100	210	310
18-ft surface treatment	300-1000	150	400	550
22-ft surface treatment	1000-2000	200	480	680
24-ft pre-mixed bit. surface	>2000	200	480	680

[a]Data from Ref. 49.

operation requires asphalt tanks with heaters, asphaltic hauling tanks and aggregate hauling trucks with some type of distributing device, and rollers. Much of this equipment is usable in developing areas only for the resealing operation. Careful scheduling of the resealing operations is required to get the maximum use of this equipment or it will lie idle for long periods of time. If an attempt is made to use the equipment continuously, the resealing crews will have to cover large geographic areas and thus will be separate from the normal maintenance crews. Because of the characteristics of the bituminous material, proper day-to-day maintenance of the equipment by experienced crews is most important. The fouling or improper operation of the asphaltic distributors can lead to faulty workmanship (52).

In the resealing operation, the cost of materials is extremely important. Of major concern to developing areas is the necessary expenditure for the bituminous material itself. In the vast majority of cases, the areas involved will not have local refineries which produce the asphaltic materials. Figures published for the United States show that in the retreating of bituminous surface-treated roadways, 56 percent of the total cost is for the purchase of the bituminous material (46). Maintenance reports from New Hampshire (53) indicate that in 1962, for the retreating of over 1,000 mi of bituminous surface-treated roadways, the bituminous costs amounted to 46 percent of the total expenditure. The relative cost of this material in developing areas with respect to local labor costs would be greater and, thus, the bituminous material would probably constitute an even greater proportion of the total. An estimate that 50 percent of the resealing costs would be expended on the bituminous materials is a conservative one. Assuming that the resealing costs account for 50 percent of the total maintenance cost, which is less than indicated for West Africa, it is then apparent that approximately 25 percent of all maintenance expenditures for bituminous surface roadways would be devoted to the purchasing and importing of the bituminous material itself. If the roads are maintained to the level of $1,000 to $1,200/mi/yr, which would seem to be a conservative range, the government must import $250 to $300 of asphaltic material per year for each mile of bituminous surface-treated roadway it maintains. This may be significant for countries with limited foreign exchange or balance of payments problems.

This discussion should not be taken to indicate a discouragement of extensive paving in developing areas. It is meant to illuminate some of the problems and responsibilities undertaken when large mileages of paved roads are developed. It also indicates the need for applying local knowledge and experience in evaluating the volume of traffic needed to justify bituminous surface treating when all of these factors are included.

OTHER IMPLICATIONS OF OVER- OR UNDERPAVING

Factors other than maintenance expenditures usually predominate in any decision with respect to the paving of a presently unpaved highway or highway system. Since the decision to pave or not to pave is an important one, its implications should be carefully evaluated. This paper is concerned with the implications of maintenance, but it would seem appropriate to mention briefly some of the other consequences.

Highway transportation is a somewhat unusual operation in that the construction and maintenance of the facility rest in the hands of the governmental sector and the operation of the facility and the rolling stock thereon is usually in the hands of the private economy. Most studies investigate the joint effects of any improvement from the standpoint of the overall economy. This is appropriate. However, it is equally appropriate to investigate this problem from the vantage point of the governmental agency. Most highway improvement programs indicate the benefits of the program to be a decrease in highway user costs. However, this is normally accompanied by an increase of governmental expenditures.

Essentially, the paving of facilities shifts a proportion of total costs from the private sector to the governmental sector. Although this may decrease total transportation costs, it will generally be at the expense of increased absolute cost to the governmental agency.

If a government emphasizes the paving of large mileages of its highway system, especially if this occurs before traffic volumes are large enough to justify such paving, it will bear a disproportionally heavy load of the total highway expenditure.

Underpaving of a highway facility, i.e., carrying higher volumes of traffic on unpaved roadways than is considered economical, also has some important implications both to the economy and to the governmental sector. Since the unpaved roadways place a higher proportion of the financial burden on the public sector, lack of paved roads may act as a hindrance to development. Moreover, total costs of transportation will be higher than if a paving program were undertaken. However, since the government will be spending less on highways, the funds available may be more fruitfully invested in such areas as education, sanitary facilities, and public health. These expenditures could then be considered a subsidy by the transportation sector to the other sectors of the government, and in the long run might be profitable. It must be emphasized that either over- or underpaving of highway facilities, when carried to the extreme, will have adverse effects.

Social Implications

A highway not only transports materials and people, but it is also a communication link and, therefore, transports ideas as well. One of the major problems in many of the developing areas is the rapid urbanization of one or a limited number of cities, producing significant political and social problems for the local governments. Furthermore, in many areas the dual economy, that is, the advancing economic development of the urban area and the traditional economy in the rural area, is accentuated. No attempt will be made here to evaluate the desirability of increased urbanization.

The type of highway system provided may have some effect on the intensity of urbanization, especially as it relates to the development of a relatively small number of dominant urban areas. The type of facility to build depends on the intended function of the highway. Unsurfaced highway networks accomplish certain social and political ends. In the political field, they can be used to bring law, order, and administration, as well as the feeling of nationhood, to the rural areas. Socially, the highways are important in bringing other cultures to the traditional culture. They also bring products from the outside into the traditional area. By bringing the rural areas into contact with the urban areas, highways are the means of encouraging people to go from rural areas into the economically developed parts of the country.

The unpaved roadways, however, put a high proportion of the total transportation costs directly on the user and discourage the movement of large volumes of traffic over the facility because of the high unit cost. Thus, it would seem that unpaved road systems would tend to accelerate the urbanization but not disburse it. The disbursement of industry and development of many cash crops will depend on the ability to get the finished products to the consumer or assembled for export. These will take place only along those corridors where relatively low-cost (to the user) transportation exists. At a minimum, this would require paved roads. Thus, it would seem that if the goal is to disburse development throughout the countryside and to retard the development of the major urban complexes, the provision of a paved road system is important.

It is virtually impossible to quantify exactly when any area should develop paved or unpaved road systems. There are major differences in the highway maintenance responsibility especially as related to import items. Also, responsibility for highway maintenance moves between the public and the private sectors with respect to the percentage each bears of the total transportation costs. Finally, there are social and political goals which may or may not be attainable with a specific type of highway system.

CONCLUSIONS

1. Highway maintenance is an important part of any highway program and becomes increasingly costly as the system expands; thus, agencies lending money to developing areas should consider providing help both to safeguard initial investments and to assure the anticipated benefits.

2. Factors influencing maintenance costs are many and highly interrelated; no universal formulation has yet been derived to predict the proper amount of maintenance.

3. Higher types of roads may cost less to maintain per dollar of capital investment, but the absolute maintenance costs are generally greater, especially when paved and unpaved roads are compared; thus, in developing areas with large paving programs, the governmental sector is committed to larger expenditures to provide the economy with lower user costs.

4. For higher types of roads, the expenditure on surface maintenance accounts for a smaller proportion of total expenditure than for lower types of roads; thus, the developing countries must be prepared to provide nonsurface maintenance which is important to the proper functioning of the system. The developing countries will also have to provide a greater variety of maintenance operations, necessitating more highly trained personnel and more specialized equipment.

5. A large proportion of surface maintenance on low-cost paved roads consists of the periodic retreatment of the bituminous surface; thus, a large proportion of the expenditures are for bituminous material which usually must be imported. Maintenance of this kind requires special equipment and personnel.

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Appendix

METHODS OF ESTIMATING MAINTENANCE COSTS

Louisiana Method for Concrete Highways (32)

Determine factors from existing conditions and the following chart. The factors plus the basic factor of 1.0 are added together to obtain an overall factor. This is then multiplied by the annual maintenance cost of a basic mile of roadway to obtain the expected maintenance cost of this particular road.

FACTORS

Age (yr)

1-4	5-6	7-8	9-10	11-12	13-14	15-16	17-20	>20
0.0	0.1	0.2	0.3	0.5	0.75	1.00	1.50	2.00

Surface Width (ft)

20	24	30	40	50	60	80
0.0	0.2	0.5	1.00	1.30	1.60	2.00

Traffic Volume (ADT)

1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000	10,000	20,000
0.0	0.2	0.3	0.5	0.75	1.00	1.25	1.50	1.75	2.00	3.00

Soil Condition

Good	Medium	Poor
0	0.75	2.00

Right-of-Way Width (ft)

80	100	120	150	200	300
0.0	0.25	0.5	1.0	1.50	2.00

Example. —Given a 10-yr old concrete roadway 20 ft wide with 2,000 ADT. The subsoil condition is poor and the right-of-way is 80 ft. A basic mile costs $250/mi/yr to maintain. The factors are as follows:

basic	=	1.0
age	=	0.3
width	=	0.0
traffic	=	0.2
soil	=	2.0
right-of-way	=	0.0
Overall Factor	=	3.5

Therefore,

$$\text{Maintenance estimate} = 3.5\ (250) = \$875/\text{mi/yr}$$

Multiplied Index Method (32)

Determine factors for existing conditions and the following charts and formulas. Multiply these together to obtain the combined factor. This is then multiplied by the annual cost to maintain a basic mile of road to obtain the estimated costs of the particular section.

Surface Condition	Factor
Excellent	1.0
Good	1.5
Fair	2.0
Poor	2.5
Very poor	3.0

$$\text{Surface width factor } (\geq 1.0) = 1 + \frac{\text{actual width} - 18}{\text{actual width}}$$

$$\text{Traffic factor } (\geq 1) = 1 + \frac{\text{actual traffic} - \text{basic traffic}}{2\ (\text{basic traffic})}$$

Basic traffic is 1,000 ADT for high-type pavements, 600 ADT for intermediate type, and 100 ADT for gravel roads.

Surface type factor

High type = 1.0; Intermediate = 1.5; Gravel = 2.0

Example 1. —Given a concrete road, 20 ft wide with 2,000 ADT. The surface condition is fair. A basic mile costs $250/yr to maintain.

$$\text{Surface condition factor} = 2.0$$

$$\text{Surface width factor} = 1 + \frac{20 - 18}{20} = 1.1$$

$$\text{Traffic factor} = 1 + \frac{2000 - 1000}{2\ (1000)} = 1.5$$

$$\text{Surface type factor} = 1.0$$

Combined factor = 2.0 × 1.1 × 1.5 × 1.0 = 3.3

Estimated maintenance costs = 250 (3.3) = $825/mi/yr

Example 2.—Given a single-pass surface-treated road of 22-ft width and 1,000 vehicle ADT. The surface condition is fair and maintenance cost of basic mile is $300/mi/yr.

Surface condition factor = 2.0

$$\text{Surface width factor} = 1 + \frac{22 - 18}{22} = 1.18$$

$$\text{Traffic factor} = 1 + \frac{1000 - 600}{2\,(600)} = 1.34$$

Surface type factor (intermediate) = 1.50

Combined factor = 2.0 × 1.18 × 1.34 × 1.50 = 4.47

Estimated cost = 4.74 ($300) = $1,422/mi/yr

Argentina Multiple Index Method (34)

The method of calculation is the same as that for the Louisiana method. The value of the factors are as follows.

Surface Condition	Factor
Excellent	1.0
Good	1.5
Fair	2.0
Poor	2.5
Very poor	3.0

Surface Width (m)	Factor
5	0.85
6	1.00
6.7	1.12
7.3	1.22

$$\text{Traffic factor} = 1 + \frac{\text{actual traffic} - \text{basic traffic}}{2\,(\text{basic traffic})}$$

Basic Traffic (ADT)	Surface
100	Gravel
200	Single surface treatment
300	Double surface treatment
600	Triple surface treatment
1,000	Bituminous mat or concrete slab (high type)

Surface Type Factor

High type = 1.0; Intermediate = 1.75; Gravel = 2.0

Example 1.—Using the same example as in Example 1, Multiplied Index Method:

Surface condition factor = 2.0
Traffic factor = 1.5
Surface type factor = 1.0
Surface width factor (20 ft = 6.1 m) = 1.0

Combined factor = $2 \times 1.5 \times 1.0 \times 1.0 = 3.0$

Example 2.—Same as Example 2, Multiplied Index Method with surface condition, fair; ADT = 1,000; width, 22 ft (6.7 m); and a single surface treatment pavement:

Surface condition factor = 2.0

$$\text{Traffic factor} = 1 + \frac{1000 - 200}{2\,(200)} = 3.0$$

Surface type factor = 1.75
Surface width factor = 1.12

Combined factor = $2.0 \times 3.0 \times 1.75 \times 1.12 = 11.76$

Estimated cost = 11.76 ($300) = $3,528/mi/yr