MAINTENANCE COSTING METHOD FOR LOW-VOLUME ROADS

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This paper summarizes the importance of maintenance as it applies to decisions regarding low-volume road system development, especially as related to economically developing countries. The importance of the decision to pave versus using local aggregates for road surfacing is presented. Specifically, the paper presents a method of estimating maintenance requirements and costs as developed for a transportation system planning activity in the Democratic Republic of the Sudan. Examples are presented of the types of cost relations established and the philosophy of developing these costs from basic considerations of equipment need and utilization rates. The paper emphasizes the fact that the total cost to the economy, in areas with limited road systems, varies with the mileage of roads of a particular surface type to be maintained. This is a consequence of economy of scale and equipment utilization. The development of fundamental input data involved 16 months of field exploration in Sudan.

•IN most parts of the world, construction costs that are incurred when a transportation facility is put into operation are considered to be expenditures for national development and form a significant portion of the operating capital of any country. In fact, among expenditures for national development in the less developed countries, transport generally ranks first or second in magnitude. Costs of constructing new transport facilities have accounted for approximately one-third of all loans made by the International Bank for Reconstruction and Development and for one-fifth of American aid for development projects. Yet the lending agencies normally expect the borrowing countries to maintain facilities with little or no aid. A similar problem exists in the United States where no federal-aid money is available for maintenance.

It is becoming increasingly apparent that, as more and more roads are constructed within a country or a state, the maintenance costs continue to accumulate long after the money that financed the road construction has been spent. These maintenance costs are sizable, usually ranging from 23 to more than 40 percent of the total highway expenditures. But as the highway system of a region expands, the maintenance costs can increase to the point that they exceed the total expenditures previously spent for highways. For example, after the Interstate System is finished, many states will annually be spending more to maintain their portions of the Interstate System than they used to spend for new highway construction.

Because the cost of maintaining roads is great but the role of maintenance is not as politically glamorous or seemingly productive as is new road construction, there is a tendency to try to ignore highway maintenance costs when new roads are programmed for construction. In fact, instances have occurred where roads have been constructed but never maintained while new road construction continued.

To schedule the costs of maintaining a road system into the budget for overall highway expenditures, we need a systematic costing method that takes into consideration

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factors that cause maintenance costs to vary from highway section to section. Such a costing method is difficult to obtain because maintenance costs are usually not kept in a manner that allows one to correlate costs with highway design, environmental factors, and traffic loads, and little or nothing is available for new roads of new design.

This paper describes a procedure developed to predict maintenance costs of a proposed road system in Sudan. The procedural concepts may have utility for estimating highway maintenance costs on systems in other portions of the world.

IMPORTANCE OF MAINTENANCE

It must be emphasized that the failure to provide adequate support for highway maintenance results in decreased quality of service and deterioration of the initial investment. Once a highway facility has been constructed, any change in maintenance procedure will affect vehicle operating costs. Moreover, the amortization period of the construction costs can be affected by the maintenance provided after construction. This is further complicated by the fact that the quantification of this interrelation has not as yet been established.

As road facilities are extended and improved, maintenance commitments accumulate. The magnitude of this is often not realized. In the feasibility study of any one facility, the annual maintenance charge, in absolute terms, will most likely be smaller than the annual construction costs or user costs. However, for nationwide systems, maintenance costs can amount to substantial sums, especially from the viewpoint of governmental road expenditures. This is due to the fact that maintenance costs are a continuing cost that accumulates as the system is improved and expanded.

In the planning for any system of low-volume roads, especially in developing countries, the importance of proper maintenance must be emphasized and its probable costs indicated. Too often, maintenance is done as needed or as funds are available. The fact that maintenance needs to be initiated upon termination of construction is seldom noted. Deferring of such maintenance can mean the deterioration of the level of service, necessity for higher future expenditures, and possible loss of investment. Thus, the planning for maintenance should have an important position in the development of low-volume road systems.

When this is done, the developing countries will necessarily realize that it is important to construct a system to a level within the countries' ability to properly maintain it. The availability of skilled and semiskilled personnel and financial considerations must be considered. Roads that are inadequately maintained can result in a poorer overall system then would be obtained by a well-maintained system of roads with an initially lower type of surface. Thus, it is realized that the decision to pave or not to pave is of primary importance in system planning.

ROAD MAINTENANCE OPERATIONS

For costing purposes, maintenance operations can be subdivided into three general categories: routine maintenance, emergency maintenance, and periodic resurfacing of the roadways. It is virtually impossible to predict or schedule emergency maintenance factors. These are due to unusual occurrences caused by flooding, earthquakes, military action, and so forth. Because of the relatively rare occurrence of these needs and the conditions under which the work is performed, there is little information concerning their costs. Therefore, this type of maintenance is not considered in this paper.

The periodic resurfacing of roads includes the addition of gravel or the addition of a bituminous surface treatment, which is required on a relatively regular basis because of the effects of time and traffic on the road surface. The methods, equipment, and costs involved are essentially the same as used during the initial construction procedure and can be costed in a similar manner.

The costing method discussed in this paper is concerned with routine road maintenance, i.e., that which has to be conducted on a continuing basis. This can be subdivided into the following operations: surface and shoulder maintenance, maintenance of drainage facilities, maintenance of the roadside, maintenance of traffic control

devices, and maintenance of bridges and other major structures. Discussions of each of these as related to gravel versus paved surfaces can be found in the literature (1).

In summary, important consequences of a decision to use a bituminous-treated surface affect the necessary maintenance, the equipment to be used, the skill level of the maintenance personnel, the overall costs, and the foreign exchange costs. Generally, the maintenance of surface and shoulders of graveled roads can be accomplished with light trucks, tractors, some type of drag (which can be locally manufactured), and possibly motor graders. This work can be done by relatively unskilled personnel. The same is not true for the bituminous surface, with respect to either the day-to-day patching operation or the periodic resurfacing. For many countries, the cost of bitumen represents a foreign exchange expenditure.

The general cost of maintenance within the United States increases as one moves from a gravel to a bituminous surface roadway. The relative expenditure for surface maintenance decreases. One of the observed problems in a number of developing countries has been a tendency to concentrate almost solely on surface maintenance. Recommendations by the International Road Federation as applied to Latin America indicated the need for greater emphasis on nonsurface maintenance (2).

The decision to pave or not to pave has little impact on many nonsurface maintenance procedures but may affect the level of effort. An example is the necessity for more roadside maintenance for paved roads because of the higher expectancy levels of the public and because of the fact that the paved travel way is generally narrower than the available travel way on a gravel road (which often includes shoulder areas).

The maintenance of traffic control devices is another example of increased cost required for paved surfaces. In most of the developing countries, when roadways are paved they are relatively narrow two-lane roads. It is therefore important from a safety standpoint to properly sign and stripe the roadway. The striping represents a substantial expenditure that is incurred yearly under most conditions. Roadway paints are relatively specialized items and represent a foreign exchange cost. Figures published by the Highway Research Board for the United States indicate that the cost of materials amounts to almost 80 percent of the total cost of highway marking (3). In addition, the equipment in this operation is specialized and has to be imported. Trained operators are necessary. Trained personnel to properly maintain the equipment itself is also important.

MAINTENANCE COSTING METHODOLOGY

What follows is a description of a maintenance cost-estimating methodology developed for a major portion of Sudan. These costs along with construction and vehicle operating costs were prepared for inclusion in a total transportation analysis that led to the development of a multimode transportation plan for the country. The project was conducted by personnel at Arizona State University under subcontract to Lockheed Aircraft International, Inc. The basic engineering information was obtained in the field during a 16-month period in 1966 and 1967. The following presents an example of the type of maintenance equipment requirements and costs relations developed. As a part of the project, separate sets of these relations were presented for the various types of surface for each of the homogeneous areas identified (4).

Total road maintenance needs are a function of the road design, soil and environmental conditions, and traffic characteristics. The interrelation among these, as related to maintenance, is most complex and unquantified even for the most developed systems. In most cases, road maintenance is considered to be a function of traffic volume only, assuming both a fixed-cost and a variable-cost component. For example, Bonney (5) has derived an expression to indicate the maintenance costs of gravel roads: Total annual cost per mile = 496 + 13Q, where Q = daily traffic flow in vehicles per day. Actually, for any specific surface type, both the fixed cost and the variable costs will differ depending on the availability and quality of construction materials, the climatic conditions, and the topography of the area.

Significance of Homogeneous Cost Areas

Because the various items that make up the maintenance cost change depending on the location of the road as well as the road design, the total maintenance cost will vary from area to area within a country even if traffic volumes are equal in each area. Therefore, the first step in the maintenance costing procedure is to divide a region into areas of similar pavement design with equal cost of maintenance materials and maintenance equipment.

For Sudan, the equal cost areas were defined based on information gathered by the field team and on laboratory tests concerning soil characteristics, construction material availability, and water availability. The northern section of Sudan was divided into 13 areas as shown in Figure 1. Each area, A through M, displays homogeneous characteristics that tend to cause all construction and maintenance activities and costs in the area to be similar. Thus, within each area it was assumed that the distance between wells is constant, the distance between gravel sources is constant, and the physical design of the pavement structure is constant. Because each area is distinct, it follows that the construction and maintenance requirements in each area are different from those in other areas.

Preparation of Construction Equipment Packages

Knowing the areas of similar cost, our next step was to actually determine the costs associated with each area. The subject of road maintenance costing is only rarely discussed in the literature. Apparently nothing factual has been written concerning development of procedures for forecasting construction and maintenance costs for a road system. In many areas, future costs of road construction and maintenance can be determined by studying existing costs. This was impractical in Sudan because few roads have been constructed or maintained.

In the past, when individuals have forecast maintenance costs, most studies have used a fixed cost per mile for all maintenance on roads of a certain design. At the same time, planners have used relatively accurate costs for vehicle operation on the road. Actually, the analysis problem is as sensitive to changes in construction and maintenance costs as it is to changes in vehicle operating costs. Fixed cost-per-mile estimates lead to serious errors in the analysis because there is considerable economy of scale. For example, the cost of maintaining 1 mile of gravel road might be $2,500, whereas the cost of maintaining 40 miles of the same road might be $1,100 per mile. Within certain limits, which vary from project to project, the larger the project is the lower the unit price is. This economy of scale is most noticeable at the low production rates prevalent in most underdeveloped countries that can only afford to build and maintain a few miles of road each year. In light of this, it was concluded that maintenance cost formulation that considered the economy of scale of a project would best solve the analysis problem.

The issue was how to compute costs that would reflect economy of scale for an area with no history of costs on similar projects available. The problem was resolved by using the normal bidding procedures utilized by contractors for road maintenance projects. The procedure entailed determining the pavement design prevalent in the area, selecting a package of construction equipment required to handle the maintenance tasks, and costing the maintenance price per mile for projects of varying length.

For each homogeneous cost area shown in Figure 1, a package of construction equipment necessary to complete the maintenance activities was selected. This was done by selecting appropriate equipment units and then combining the units into groups termed equipment packages. For example, an equipment package for maintenance of an earth road could consist of two dump trucks, one rubber-tired roller, one water truck, one front-end loader, and one motor grader.

Next, the total hourly cost to own and operate each package was computed. This procedure involved obtaining hourly ownership and operating costs for each unit in the package and summing the individual costs to compute the total hourly costs. Severe depreciation rates recommended either by the Association of General Contractors Ownership and Expense Manual or by equipment manufacturers were utilized.

In most cases, a single package was not suitable for handling a wide range of production rates on a project. Large-sized units of equipment can be used to maintain a small project, but they cannot be used economically. Therefore, each package was customized to fit a specific range of project sizes, with the size and type of units in each package varying with the size of the projects.

The customizing procedure involved grouping specific sizes and types of construction units into packages and then determining the productivity-cost relations for each package. Thus, for an activity involving the maintenance of a gravel road, one package was selected for maintenance rates up to 230 miles per year at traffic volumes below 25 ADT, and the size of the package was increased as the traffic volume on the road increased. Typical packages suitable for maintaining unsurfaced roads in Sudan are given in Table 1.

Formulation of Maintenance Cost Equations

It is a much simpler procedure to estimate costs of a maintenance project for a highway that has a definite length and location than it is to estimate costs where the road length and completion time are variables. But, for planning purposes, the latter is the case. Use of the equipment package concept simplifies the costing process but also points up the economic consequences of inefficient use of construction equipment packages. As is shown in Figure 2, for a specific construction package the cost per mile decreases as the production rate increases until the operational efficiency of the package is exceeded, then the cost per mile begins to increase. The challenge is to develop equipment packages suited for the anticipated range of productivity.

For the Sudan project, maintenance costs were split into two categories: expected routine maintenance and resurfacing. Maintenance cost experience in Ghana and Nigeria found that resurfacing costs range from 30 to more than 50 percent of the total annual maintenance expenditure. The equipment package requirements for routine maintenance are different than the requirements for resurfacing.

Routine Maintenance Costs in Sudan

As previously indicated, the routine maintenance on aggregate roads is basically the maintenance of the riding surface and the elimination of road roughness. For bituminous surfaces, it involves the patching of potholes, the maintenance of signs and markings, and the general "housekeeping" of roadsides and drainage facilities. Figure 3 shows the expected typical relations between normal maintenance costs in Sudan and traffic volume for an earth, rock road. The routine maintenance costs of bituminous-surfaced roads operating at low-traffic volumes are relatively independent of traffic volume. This cost was estimated at $1,200 per mile for a surface treatment, $1,340 per mile for a road mix, and $1,130 per mile for a hot-mix road.

Resurfacing Costs

Gravel and bituminous surfaces require periodic resurfacing in order to maintain the standard of the roadway. The resurfacing operations for both gravel and bituminous surfaces are essentially the same in equipment, material, and personnel as those required for initial construction. The costs prepared assume the optimum use of the smallest particular construction package based on a 40-hour week. The costs were converted to annual costs by simple division of the resurfacing cost by the expected period of resurfacing. No interest calculations were included because the period of resurfacing is relatively short.

In the case of roads surfaced with crushed rock, it was assumed that the surface would be rebuilt every 6 years, and at that time 4 in. of new crushed rock would be added. In the case of roads surfaced with gravel, it was assumed that the surface would be rebuilt every 6 years, and at that time 6 in. of new gravel would be added. The resurfacing cost was determined by prorating the initial construction cost. General experience with gravel roads throughout Africa indicates that with moderate traffic volumes, gravel roads tend to lose about 1 in. of gravel per year. This rate of gravel

Figure 1. Areas of homogeneous construction and maintenance costs in Sudan.

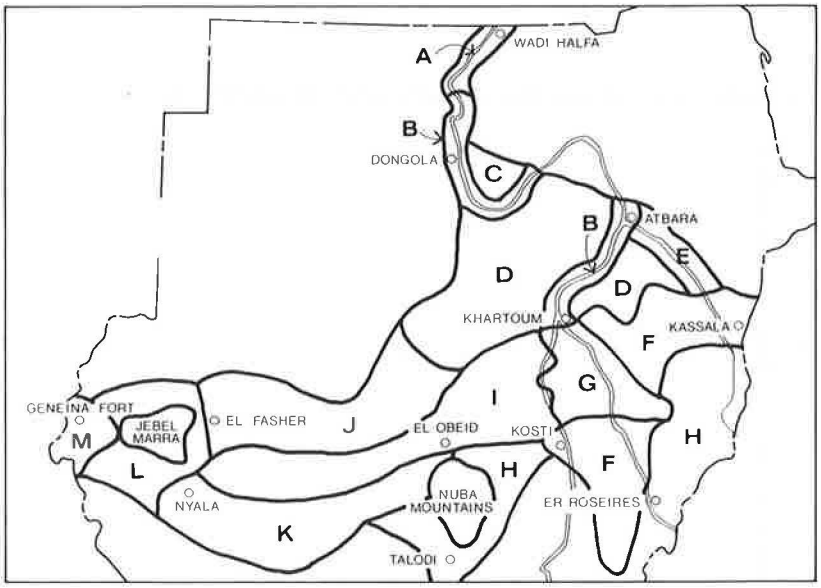


Table 1. Minimum equipment packages required for routine maintenance of unsurfaced roads.

Traffic Volume (ADT)	Road Surface		
	Earth	Gravel	Crushed Rock
0 to 24	One 5-yd truck One 2,000-gal water truck One ½-yd front-end loader One motor grader	One 5-yd truck One 2,000-gal water truck One ½-yd front-end loader One motor grader	One 5-yd truck One 2,000-gal water truck One ½-yd front-end loader One motor grader
25 to 49	Two 5-yd trucks One roller One 2,000-gal water truck One ½-yd front-end loader One motor grader	One 5-yd truck One roller One 12-ton truck One 2,000-gal water truck One 1-yd front-end loader One motor grader	Two 5-yd trucks One 2,000-gal water truck One ½-yd front-end loader One roller One motor grader
50 to 99	One 5-yd truck One 12-ton truck One 2,000-gal water truck One roller One 1-yd front-end loader One motor grader	Two 5-yd trucks Two 12-ton trucks Two rollers Two 2,000-gal water trucks Two 1-yd front-end loaders One motor grader	Two 5-yd trucks One 12-ton truck One 2,000-gal water truck One roller One 1-yd front-end loader One motor grader
100 to 399	One 5-yd truck Three 12-ton trucks Two 2,000-gal water trucks Two 1-yd front-end loaders Two rollers Two motor graders	Two 5-yd trucks Three rollers Six 12-ton trucks Three 2,000-gal water trucks Two 1-yd front-end loaders Two motor graders	One 5-yd truck Four 12-ton trucks Two 2,000-gal water trucks One 1-yd front-end loader Two rollers Two motor graders

Figure 2. Equipment package cost-productivity relation.

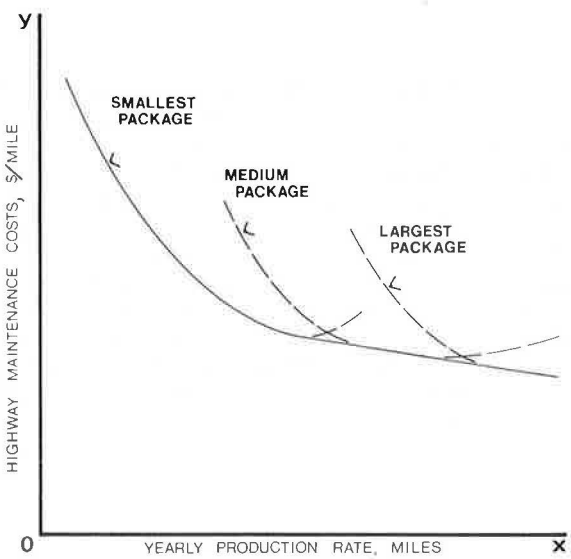
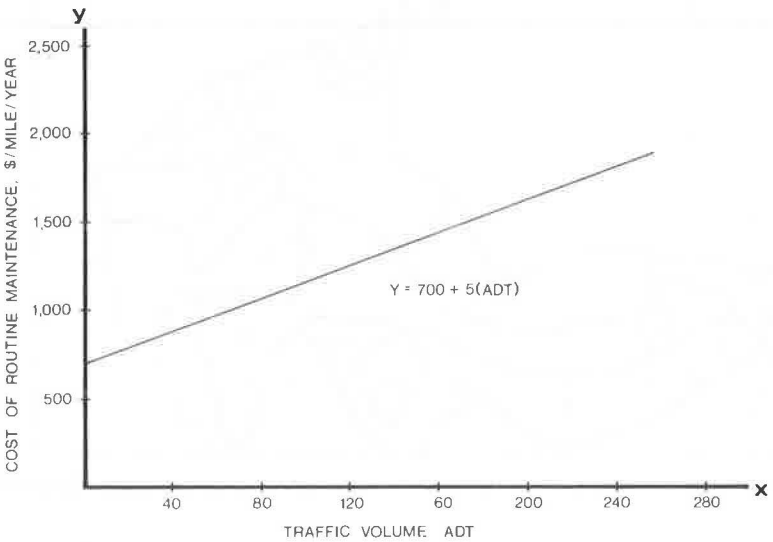


Figure 3. Routine maintenance costs and traffic volume of earth-surfaced road.



loss is relatively constant for a moderate range of traffic volumes because the dragging operation tends to have a greater effect on aggregate loss than does traffic per se. The assumption that the Sudanese crushed-rock roads will lose only $^2/_3$ in. per year was based on the fact that the aggregate used in the construction has particle interlocking characteristics not found in natural gravel. Usually, natural gravels have rounded particles that do not provide much mechanical particle interlocking. The Sudanese crushed-rock aggregate will be highly angular, and it is therefore expected that there will be a much higher degree of mechanical interlock between particles and, therefore, a decreased rate of loss. The different annual costs for certain areas for resurfacing reflect the influence of the differential length of haul from aggregate sources.

The calculation of the resurfacing cost for bituminous roadways was based on the cost of a single surface treatment repeated every 5 years. Experience has shown that this operation generally must be repeated every 4 to 6 years to counteract the effects of both traffic and aging. These costs were estimated assuming the equipment packages were being utilized efficiently and the costs were represented on an average dollar-per-mile basis.

SUMMARY

As previously indicated, the variation of maintenance costs with basic variables is currently ill-defined although they represents a significant public expenditure. That these costs can be evaluated over time when maintenance needs are met under specific known conditions is admitted. However, Sudan at this time does not have significant experience in the road maintenance procedures within its own area to quantify any cost or productivity data. This is a situation common to most developing countries and even to some states. Due to the economy of scale associated with maintenance costs and the cost variance caused by variables such as project size, construction material availability, topography, in-place soil conditions, and productivity of the labor force, generalized fixed-cost estimates are inaccurate. The equipment package costing methodology outlined in this paper presents a technique that allows estimation of maintenance costs in areas where no maintenance cost experience is available and allows consideration of economy of scale.

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DISCUSSION

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Bauman and Betz's paper presents a maintenance costing methodology that should be valuable in developing maintenance cost for new highway systems. In particular, it should be very useful to planners as they develop transportation programs in developing countries.

The authors' paper has properly stressed the importance of maintenance for low-cost roads, particularly as a factor in the planning and decision process. They placed the maintenance impact on total highway expenditures between 23 and 40 percent. An examination of the maintenance expenditures made for county and township roads in the United States during the past 15 years reveals that an average of 63 percent of total highway expenditures was spent for maintenance (6). The type of road system they discuss seems closer to the county-township type of system than the state system where the maintenance percentage for the same period was 18 percent.

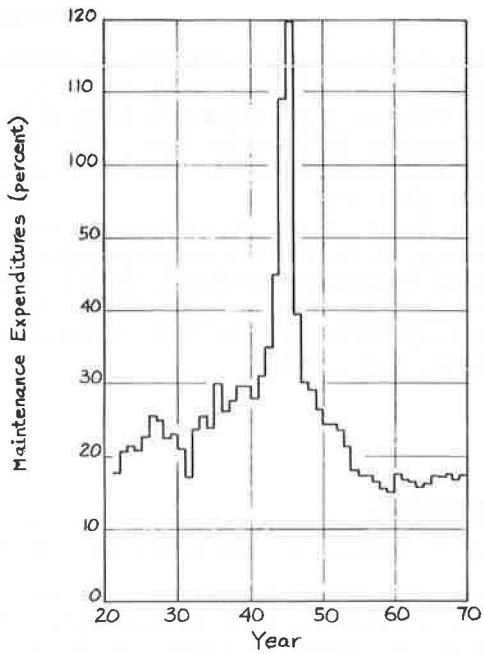
As the highway system of a region expands, the maintenance expenditures continue to increase. There also is considerable evidence in the literature to suggest that these maintenance costs further increase as traffic volumes grow. However, as a percentage of total expenditures, the picture is not so clear. Figure 4 shows the percentage of total highway expenditures for state highway maintenance in the United States. Disregarding the war years of the 1940s, there is no evidence of any general increase with time. Rather, both the capital outlay and the maintenance expenditure portions grow together.

The impact of increased traffic volume on maintenance is revealed by comparing a sampling of high- and low-volume state highway expenditures. The high-volume states averaged $24,000 per mile on maintenance, which reflected 25 percent of total road construction expenditures. This can be compared with $1,250 per mile and 13 percent for the low-volume states (6).

The authors were faced with the need to develop maintenance cost estimates for a total highway program budget. Realistic costing is needed to allow for variations in the physical and operational environments of the roads in various areas of the country. This was particularly critical to the Sudan study where a wide variation was expected in the mileage of a given pavement design from area to area. The estimating procedure developed responds to the need for having more than a single fixed maintenance cost that can be applied to roads in the planning process.

The authors divided Sudan into areas of similar pavement design and equal material and equipment cost. They then selected the equipment units that would be needed to maintain the pavement design assumed for an area, a given level of traffic volume, and a limited range of mileage of roads. The equipment was then placed into what the authors termed an equipment package, and the total hourly cost to own and operate the package was computed. The authors are not clear on how the entire maintenance cost

Figure 4. Maintenance expenditures as percentage of total state highway costs.



was included in their cost equation, i.e., as part of the equipment package or in support of the equipment package. In developing resurfacing costs, the authors note that the equipment package cost was based on a 40-hour week use assumption. No such notation is included for the maintenance equipment package. Therefore, the basis for developing hourly cost for the equipment is not clear. Some mention of the assumed range of use would be helpful. Also, an indication of some of the other assumptions that must have been made related to frequency of equipment assignment to each mile of road, treatment of supervisory cost, labor and material requirements, and housing and administrative costs would be useful additional information. However, it is assumed that the equipment package generated a total cost that could be converted to a per-mile maintenance cost by assuming a mileage in each homogeneous cost area. The model shown in Figure 3 was apparently the result of plotting per-mile expenditures from like areas of road design and mileage for different traffic volumes.

The method of costing presented by the authors was reportedly used to generate various matrices of unit maintenance cost by type of road surface and region for varying system mileage and traffic volume. The inclusion of such a matrix would have been a useful addition to the paper. Nevertheless, this paper should prove a valuable addition to the present literature on the maintenance of roads in developing areas.

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Better knowledge of road maintenance costs would be welcome in every country, but the relative paucity of information and the need to examine various road design and maintenance strategies in developing countries make better information on maintenance costs particularly important in these countries. In the United States and Western Europe, high traffic volumes, high values attached to motorists' time, and relatively low cost of capital usually make it more economical to incur higher initial costs to construct roads to higher standards to minimize road-user and maintenance costs. In developing countries, however, traffic volumes and values attached to motorists' time are often much lower, and capital is much costlier, so that staged construction, with

lower initial design standards and higher road-user and maintenance costs, may be the optimum strategy. In some of these countries, relative labor abundance makes labor-intensive methods of construction and maintenance more feasible, which has important but relatively unexplored implications for road design and maintenance.

Thus, Bauman and Betz are quite correct in seeking to gain greater understanding of road maintenance costs in developing countries and to develop methods for quantifying and predicting them. Certainly, the approach they developed in Sudan, which is similar to the work by Soberman in Venezuela, constitutes an improvement over existing procedures in many cases where the only data are average total maintenance outlay per mile of network. Formulation of maintenance costs in the form $Y = a + b(ADT)$ does take into account the fact that there may be certain expenditures, such as the costs of administration, or other economies of scale when traffic volumes expand. Developing separate relations for different types of road in different homogeneous cost regions is a further improvement.

However, this approach does not go deeply enough to answer many of the questions that need answering. Predicting maintenance outlays in this manner implicitly assumes a given maintenance policy, when in fact we want to investigate what maintenance policy should be. If one is to examine alternative maintenance strategies, it is necessary to distinguish the physical deterioration of the road from the response to that deterioration. The effect of different maintenance standards on the physical condition of the road and the effect in turn of various road conditions on road-user costs must be established, as well as the costs of the different maintenance routines. If, in addition, one is to determine the best technology to effect a given maintenance standard, it will be necessary to generate the whole set of alternative technologies specified in terms of outputs achieved by a given set of inputs (equipment packages) and prices of the various inputs.

Measurement of the physical deterioration of roads of different designs and the effect of alternative maintenance policies thereon ultimately requires some longer term experimentation, which presumably was outside the authors' terms of reference. Least is known concerning the deterioration of earth and gravel roads (of various geological compositions), but fortunately this can be measured relatively easily because deterioration occurs rather rapidly if regular maintenance is withheld. A 2-year period of study is quite sufficient to observe significant change in the condition of unpaved roads. It is more difficult to establish deterioration relations for paved roads because deterioration occurs much more slowly. The only alternative to long-term experiments would be cross-section analysis of pavements of various ages in various degrees of deterioration. However, because of the problems in defining the original construction standards of those pavements, as well as the use and the maintenance they have received over the years previous to the study, we would not be optimistic about this approach. Thus, deterioration relations for paved roads may have to be derived from time-series analysis of observations collected over several years from roads built to carefully controlled standards and subjected to normal use.

Various approaches may be used to establish the effect of different maintenance standards on road-user costs. A direct experimental approach, involving operation of a fleet of instrumented test vehicles over experimental road sections where the condition of the road surface is measured, may provide accurate information on the effect of different maintenance standards on vehicle speed and fuel consumption. A sample survey of road users, including establishment of a well-controlled set of cost accounts for a representative sample of types of vehicles operating over roads in various states of maintenance, will yield additional information on vehicle depreciation and maintenance costs.

If one wishes to relax the assumption of a fixed maintenance technology and determine the optimum technology, it is necessary to scan the whole set of feasible alternative technologies. The authors' specification of equipment packages, or input-output vectors, is thus a step in the right direction, but it is not clear that they have systematically generated the whole set of alternative technologies (or a reasonable approximation thereto). What do they mean when they say that the equipment package was "customized to project size?" What exactly does "project size" mean? Also one would

like them to specify the sources of the economies of scale they envisage. Is it simply fixities in administrative costs when either the mileage of the system or the traffic densities increase? Or do greater traffic densities or greater network mileage make different technologies with lower variable costs more economical? It is not easy to see this intuitively, but ultimately the question is an empirical one.

We at the World Bank have been very much concerned with these questions, particularly the trade-offs between road design standards and maintenance costs and the effect of different technologies thereon. Since 1969, we have been working in conjunction with other institutions to develop the methodology and empirical data necessary to determine optimum highway design and maintenance strategies for low-volume rural roads, assuming initially a fixed technology for construction and maintenance. The U.K. Transport and Road Research Laboratory, working in collaboration with the World Bank, has been conducting empirical research in Kenya since early in 1971 on road-user costs and road deterioration relations for alternative design standards and alternative maintenance policies. We hope to have completed the initial field studies of these relations by July 1973, but the study will have to be continued in order to gain longer time-series observations on paved road deterioration. At the same time, we are hopeful that similar studies may be undertaken in India and Brazil to capture a wider range of physical and economic environments. The World Bank also has under way studies on the technical and economic feasibility of alternative civil construction technologies involving different combinations of labor and equipment. An initial survey of existing evidence reached the conclusion that it is technically feasible to use labor-intensive methods of construction for most activities involved in constructing highways, including higher standard highways, and that these techniques may be economically feasible under certain circumstances in labor-abundant economies. The next phase of the study will concentrate on the adaptation of road design to labor-intensive and intermediate technologies and its implications for road design and maintenance strategies and the problems of implementing changes in technologies, design, and maintenance strategies.

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The authors discuss the importance of maintenance costs in the planning of highway systems, especially with regard to its effect on the overall economic well-being of an emerging nation. A most interesting consideration not normally imposed on the maintenance engineer-economist in this country is the major effect that foreign exchange expenditures have on the decision-making process when the physical designs to be utilized in the system are evaluated.

In the citation on the lack of formal costing knowledge of highway maintenance activities, the authors present the same general observations that others have struggled with in attempting to develop forecasting systems or formulas. For many years, maintenance cost data have been collected, summarized, and published in terms of average costs per mile of various types of designs with very little consideration of the relations among highway design, environmental factors, traffic loads, and social structure of the community. The application of such past per-mile average cost data can result in a completely inadequate financial and organizational plan for any highway system, whether considering an emerging nation without a transportation history or a highly developed community with a sophisticated network and years of experience.

The emphasis on the importance of maintenance is well made as a major element in system planning and design. The magnitude of accumulating maintenance requirements is rapidly forcing highway administrators in this country and on the international scene to focus more attention on scientific research and economic evaluations of maintenance practices. In recent years this has resulted in the so-called new maintenance management systems in many states.

These new maintenance management systems and the accompanying performance budget methods of analyzing maintenance cost factors have been highly publicized and reported in literature during the past 10 years. It was disappointing to find no mention or consideration of these highly developed techniques in maintenance costing.

In approaching the costing of maintenance operations in an environment without a past history to relate to, the authors categorize maintenance into routine, emergency, and periodic resurfacing. Emergency maintenance factors are immediately dismissed as impossible to predict or schedule. Resurfacing maintenance is analyzed as essentially the same as initial construction procedures and therefore costed in the same manner. It appears, then, that the important contribution this paper offers is a new approach to forecasting the probable costs for routine recurring maintenance under the unique conditions and limitations of an emerging underdeveloped nation and the effect of this cost on the long-range financial requirements to protect the original investment.

Although emergency maintenance might logically be a minor cost factor, it should be considered, especially with regard to the effects of natural occurrences on underdesigned highway systems. Weather history and severe seasonal weather conditions are generally well known, and the problems of maintenance operations involving design deficiencies for all weather conditions can be ordinarily recognized and can be adequately provided for by anticipating certain average activity requirements to provide capability to restore damaged or interrupted transportation services.

The costing of routine road maintenance planning values is most difficult with known existing systems. The complexities of analysis presented in this described project, to predict with confidence the cost of maintenance values for various design considerations on a nonexisting highway system, is approached in a new and unique manner. Such an approach offers a new opportunity to make further research and extend present concepts of the state of the art.

Without a history base to quantify the many variables of maintenance activities, the authors devised what might be called a system of common denominators. By grouping similar environmental characteristics, a system of homogeneous cost areas was developed in which it can rationally be assumed that all construction, maintenance, and cost factors will be similar. This same rationalization is used by several states in establishing regional performance standards for maintenance activities.

The second common denominator presented for evaluating costs was the construction equipment package. This approach is unique in concept, but it is not clearly defined in the paper, especially with regard to what activities or level of service is considered in creating the equipment packages for comparative evaluation. It would seem that a quality standard or a level of service must also be determined to establish an equipment package. The tolerance of wear or deterioration with a frequency of service requirements must certainly be involved in determining either the equipment package or the area that a given equipment package might cover. The paper intimates that such analysis was considered within the project development, but it does not dwell on how the service-level variables were constructed to determine the equipment package. Some additional development of these factors would clarify the concept of relating maintenance cost predictions on the assignment of cost factors to the hourly operation of a given equipment staffing required to perform the level of maintenance necessary to support and protect the transportation investment.

The authors have injected an analysis consideration, which provides a realistic approach to adjusting cost data, not heretofore observed by the reviewer in other maintenance cost projection exercises. The "economy-of-scale" adjustment to operational data emphasized in this paper has been observed and considered in many construction program cost estimates, but its application to maintenance cost projections may be one of the important contributions presented here and also might possibly be a subject for further research in relation to maintenance cost factors.

In summary, the project described certainly appears to have been challenging, and the approach to analysis was innovative and unique. The importance of maintenance costs to the total design considerations and financial planning of transportation systems is well presented. The homogeneous cost areas, the equipment package, and the economy-of-scale concept are analysis techniques that might be further researched for useful relations.

The paper offers an important reference background for refining the art of long-range maintenance cost predictions particularly as related to new transportation systems in emerging nations.

AUTHORS' CLOSURE

The basic elements in the discussions focus around issues concerned with assumptions used in the derivation of the equations and with appropriate policies for maintenance of a road system when funds are limited. Butler discusses the cost assumptions and raises significant questions concerning the methodology used in the derivation of the cost equations. Harral discusses important policy issues. Lanford's discussion overlaps into both policy and cost issues. This response to the discussions will attempt to clarify some of the assumptions and derivation procedures as well as comment on the policy issues.

The first major area of concern seems to relate to the cost formulation process. The process of deriving the cost formula for an equipment package was to assemble the equipment units and manpower into a package, calculate all costs on an hourly basis, expand costs to an annual basis using number of work hours per day and number of workdays per week typical in Sudan, estimate the maximum productivity of each package in terms of number of miles of two-lane road per year, and develop cost curves by holding annual equipment package costs constant and varying package productivity, thus achieving a variable cost-per-mile output. The costs used in each package were derived based on relations among hourly costs to own and operate the units of construction equipment in each package, labor costs for equipment operators and supervisory personnel, and material costs. The operational life of each unit of equipment was computed in terms of total hours of life based on manufacturer's recommendations and assuming severe operating conditions. Utilizing this technique, the economy-of-scale characteristics of an equipment package become apparent as the efficiency of utilization of the package increases.

The application of the level-of-service concept for processes concerned with routine maintenance is significant and could be used to quantify policy decisions. For the Sudan project, it was assumed that the equipment packages would operate so as to maintain all roads in their respective areas at a level sufficient to preserve the roadway in a condition as close to the original as possible. This required assumptions concerning frequency of machining, daily productivity, and material replacement based on empirical data from other studies. All assumptions are discussed in detail in the original report (4). This meant that the maintenance policy proposed for Sudan assumed a high level of service. At first glance, this assumption may not appear to be the most appropriate policy for a country with low traffic volumes on nearly all its roads and with limited funds. However, the policy for maintenance cannot be considered in an isolated context. Instead, the policy for maintenance must be considered together with the policies concerned with design and construction. If stage design techniques are properly used and a road is never overdesigned, a high level of service for maintenance appears to be the appropriate policy.

Study of the trade-offs between road design standards and maintenance policies and costs was beyond the scope of this project. But the trade-offs represent a highly significant area of concern. So the World Bank projects described by Harral, when completed, should produce some very useful data.