Highway Pavement Maintenance Costs and Pavement Type Selection

Donald C. Newberry Jr.* Jesse G. Mayes†
James H. Havens‡

*Kentucky Department of Highways
†Kentucky Department of Highways
‡Kentucky Department of Highways

This paper is posted at UKnowledge.
https://uknowledge.uky.edu/ktc_researchreports/895
MEMO TO: J. R. Harbison
State Highway Engineer
Chairman, Research Committee

SUBJECT: Research Report No. 413, "Highway Pavement Maintenance Costs and Pavement Type Selection"; KYHPR-64-11; HPR-I(9), Part II

The report submitted herewith constitutes the final, and only, report on Study KYHPR-64-11. It presents long-term (1958-1971) analyses of pavement maintenance costs. It does not include analyses of construction costs or resurfacing costs. More than 40 tapes were processed to obtain the maintenance costs and construction records; pavement maintenance transactions alone filled one tape. The study was intended to answer long-standing questions concerning the significance of maintenance costs in selecting the type of pavements to be specified on various highway construction projects. Many unforeseen difficulties and uncertainties arose from a 1968 analysis; the report was withheld -- awaiting additional data and verifications. The analysis then yielded a gross or combined average of $313 per mile per year; and, from that standpoint, the results were comparable to those which had been reported by others. However, the costs according to type of pavement seemed untrustworthy because of apparent mismatches between charge codes and pavement type. In the final analysis, charges were compiled only for projects and sections which could be discretely identified according to pavement type. This reduced the sample sizes severely; and, in analyzing costs according to age and type of pavement, an unexpected bias in the sample of PCC pavements was discovered. A large portion of the BC sample was between 1 and 20 years old. This disparity tends to nullify the differences shown in Figure 5 in the report. The apparent differences in early ages, shown in Figure 6, may therefore be due to sample limitations. The interstate and parkway systems had been isolated beforehand and analyzed as a group. The effect of sample size in that group shows up strongly after an age of 8 years (see Figure 3).

I am fairly persuaded that the results of this study are significant only from the standpoint of providing insights into the order of magnitude of pavement maintenance costs and that differences according to type are very intangible and perhaps not significant. In order to be more definitive, we would have to group or "cell" pavement projects according to age, traffic, and structural capacity and would have to know the nature of the defect associated with each maintenance charge.

At this stage, I would recommend adaptive adoption of the so-called systems approach to pavement management and further uses of design strategies.

Respectfully submitted,

Jas. H. Havens
Director of Research

cc: Research Committee
A long-term analysis of pavement maintenance cost has been performed. The analysis does not include construction or resurfacing costs. The sample of pavement sections investigated were chosen to best represent the entire state. These sections were classified by pavement type; either bituminous concrete, portland cement concrete, or composite. The cost per lane mile (kilometer) per year was calculated for each pavement type by year and by age of pavement. Apparent differences in pavement maintenance costs between the two basic types of pavements were adjudged insignificant from the standpoint of determining pavement type. Because of poor or erroneous cost reporting, actual maintenance costs shown should be interpreted to be accurate in order of magnitude only.
Research Report
413

HIGHWAY PAVEMENT MAINTENANCE COSTS AND PAVEMENT TYPE SELECTION

KYHPR 64-11, HPR-1(9), Part II
Final Report

by

D. C. Newberry Jr.
Research Engineer Senior

J. G. Mayes
Research Engineer

and

Jas. H. Havens
Director

Division of Research
Bureau of Highways
DEPARTMENT OF TRANSPORTATION
Commonwealth of Kentucky

in cooperation with
Federal Highway Administration
U. S. DEPARTMENT OF TRANSPORTATION

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration or the Kentucky Bureau of Highways. This report does not constitute a standard, specification, or regulation.

December 1974
INTRODUCTION

This study originated in 1964 at the request of the State Highway Engineer. Compelling questions concerning pavement type selection and comparative costs date much further into the past. Earlier studies of "road life" and "costs" were generally controversial and not very definitive. Road life, in years, was a very confusing factor; the so-called "resurfacing cycle" was equally as elusive as "road life." Service life, in terms of accumulated equivalent loadings and structural capabilities, has been used to evaluate pavement structural design criteria and in incremental cost studies but not in evaluating total costs for the purpose of selecting the type of pavement; indeed, equality in design criteria would preclude differences in service life.

The guiding policies or principles of pavement type selection were formulated through AASHO in 1960 (1). Five principal factors and ten secondary factors were outlined; they are included in APPENDIX I for convenient reference.

It had been the policy in Kentucky prior to 1957 to specify presumably equivalent designs of bituminous and portland cement concrete pavements and to select the lowest and best bid.* Later, with the approval of federal officials, a provisional policy of selecting the pavement type on the basis of engineering, comparative estimates of construction costs, and other considerations, was established. The imperative provision was that eventually the comparative costs would be based on estimated total costs - i.e., construction costs plus maintenance costs less residual or salvage values. Otherwise, the AASHO guide has been respected as the prevailing policy in the interim.

Meanwhile, others determined or adjudged maintenance costs to be comparatively insignificant and(or) well within the limits of accuracy of the engineer's estimate of construction costs. Results reported (2, 3, 4, 5, 6) have generally been in the order of $200 to $600 per mile (1.6 kilometers) per year. In 1955, R. D. Medley (7, 8) estimated the cost of all types of maintenance in Kentucky to be $969 per mile (1.6 kilometers) for roads having less than 500 AADT and $1562 for roads having AADT's of 3000 or more.

A study of pavement life was also made in 1955 (9). Some early, off-hand estimates for the total maintenance of interstate highways were $4000 to $6000 per mile (1.6 kilometers) per year. The 1972, national average for all types of state roads was $2,420 per mile (1.6 kilometers); expenditures in Kentucky were slightly under the national average (10). References 11, 12, and 13 provide additional background information.

Only traffic lane pavement maintenance costs, together with residual or salvage value considerations, if feasible and valid, enter into the pavement-type-selection process. Residual or salvage value depends on the particular circumstances. If a pavement is to be abandoned and the land reclaimed, it is a liability; and the cost of disposal would be accounted for in the project. The residual value of the pavement would be a technical loss. If an existing pavement is to be incorporated into a new but equivalent structure, the estimated cost of a totally new structure minus the estimated cost of reinforcing the existing structure is the estimated salvage value of the existing pavement. Existing pavement layer thicknesses multiplied by estimated, fractional structural worth factors yields an estimated, equivalent like-new thickness contribution to the new structural design. The structural worth factors, treated as (100-percent deterioration)/100, multiplied by the current cost per square yard per inch of thickness of the material in place yields a salvage value more directly. Certain pretreatments or preconditioning may be necessary to render an existing pavement usable in a reinforced (overlaid) structure; the cost of preconditioning would add to the cost of utilizing the old pavement and has the effect of diminishing its residual value. A portion of the salvage value estimated at the first extension of service life extends successively into the second, third, etc.; and, therefore, the value compounds in some yet undefined way. Nevertheless, the value at any point in time is probably best and most conveniently estimated by the current cost of the material in place multiplied by the residual structural worth factor. Continual assessments of pavement conditions are, indeed, important factors in guiding decisions to defer or intensify maintenance, to overlay, or reconstruct - whether based on situational analysis or systems

*Since 1942, KRS 176.070 (2) has stated:"...the department may determine the type of improvement desired, and may advertise and receive bids for only the types determined." Presumably, this context applies to pavement type or types but not exclusively so. It may also protect the Department against counterclaims.

Section 4356t-6 (enacted in 1920) required that "...bids will be received for three or more distinct types of highways for which specifications have been adopted." This requirement was repealed by Section 4356t-17-2b.
management theory. The residual values of interstate and parkway pavements and others designed to comparable standards are expected to be very high at the end of their designed service life. Additional thicknesses required in redesigning and extension of service life actually may not greatly exceed overlay thicknesses required to rehabilitate lesser pavement structures. If the renewal or extension of service life is deferred or delayed too long, structural deterioration accelerates. In reality because of competing priorities for funding, each pavement project generates its own unique history. Collection of all pertinent data needed for statistical sampling and analyses of interacting variables has precluded, thus far, gross comparisons or regresional analyses of residual values of the two major types of pavements. Consequently, it seems improper to superimpose residual or salvage values on estimates of initial construction costs, in the pavement type selection process, until such values are duly quantified and validated. To disregard salvage values has the effect in the selection process of adjudging them to be equal and nullifying.

"Lumping" annual maintenance costs by types of pavements and obtaining averages seemed more permissible. For instance, assuming sufficient data to be available, "compiling and averaging" tests the question: Are there unique attributes of either type of pavement which collectively cause one type to require significantly greater maintenance expenditures than the other type? To obtain additional information requires sorting by attributes or classes of attributes. For example, interstates and parkways are most easily identified and isolated as a class.

In 1968, a "lumping" analysis of magnetic tape records of maintenance transactions covering 9 years (1958 through July 1, 1966) was undertaken but was not reported then. It was suspected that charge codes and project identifications were not altogether "pure". At that time, interstate and parkway records covered a relatively short term. Further analysis was deferred until additional data became available. The data finally analyzed extended from 1959 through 1971. The remainder of this report is concerned with the analysis of those records.

METHODOLOGY

A sample of pavement sections distributed over the state consisted of bituminous concrete and portland cement concrete roadways. An effort was made to select sections which were representative of the state (Figure 1). The sample contained 184 sections; of these, 118 were bituminous concrete and 66 were portland cement concrete. The entire interstate and parkway systems in Kentucky, completed through 1971, was part of the sample; thus, recent heavy designs were included in the analysis. The sample size in 1971 was 1669 miles (2686 km) of pavement. This involved 5271 lane-miles (8483 lane-km) or 3.2 lanes per mile (1.6 kilometers).

Historical information and identification data were obtained for a 20-year period or greater. Cost data were for a period of 13 years, from 1959 through 1971. This period for costs was used because the account coding systems made the data more readily identifiable and retrievable.

Bureau of Highway files contain information on maintenance sections identified by a seven-digit number with letters added to identify subsections. An example is 034-0124-W. Each of the 120 counties in the state is assigned a number, 034 being Fayette County. Each highway within a county is given a number of four digits or less; 0124 is US 27 south of Lexington towards the Jessamine County line. The letter W identifies a portion or subsection of this section. The numbers remain constant once assigned. The letter changes when a reconstruction, major maintenance operation, or other changes occur. Bureau files contain pavement structural data recorded on the basis of two layers or components.

Extraction of the complete history of a subsection proved invaluable for identification of structural components that were considered base under the two-component system. The identity of the pavement type was recovered, even though multiple paving operations may have taken place. Historical data thus obtained was used to graphically reconstruct the pavement section showing components. These graphs were extremely helpful to relate components, where applicable, with costs for analysis. Finally, pavement structural data available were added to complete the historical and identification data file (see APPENDIX II for data attributes contained in the historical and identification data file developed for this study).

A list of sections and subsections for the study sample was submitted to the Division of Data Processing for retrieval of cost data stored on magnetic tapes. At this point, it was found that cost data were readily available only for the previous 13-year period (1959 - 1971). Cost data for years prior to 1959 had been stored manually. The 1959 - 71 data were considered sufficiently valid for the selected spectrum of roads and highways.

A second data file developed for this study contained descriptions of the subsection termini (APPENDIX III). This file enabled the location of the limits of the subsections as prescribed by construction contracts. The subsection could then be located with some accuracy on a map.
The third and final data file (APPENDIX IV) compiled contained lengths, cross-section descriptions, and route identification by subsection number. This data file was invaluable in determining the cross section of the pavement.

The three data files, which complement each other, gave all identification and history required to relate the cost data. There are, of course, more data within the separate files than was used in this study.

The system of accounting for maintenance costs in Kentucky uses subledger numbers. This system assigns specific numbers to components of the roadway and maintenance operations related to these components. To retrieve maintenance costs, subledger codes were used.

One difficulty in retrieving cost data was related to a change in subledger code designations on July 1, 1966. Examples of these subledger codes for maintenance operations are indicated below:

**Post 1966 Codes:**

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>206</td>
<td>Bituminous Concrete Surface</td>
</tr>
<tr>
<td>207</td>
<td>Portland Cement Concrete Surface</td>
</tr>
</tbody>
</table>

**Note:** These two codes are for routine maintenance operations such as repairing potholes, cracks, or joints; sweeping or grading by hand or equipment; and removal of excess material such as trash, gravel, or chips.

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>216</td>
<td>Bituminous Concrete Surface</td>
</tr>
<tr>
<td>217</td>
<td>Portland Cement Concrete Surface</td>
</tr>
</tbody>
</table>

**Note:** These two codes are for "special" maintenance operations such as surface treatments of all types, including bituminous concrete. Costs are charged against these codes if the operation adds less than 3/4 inch (19 mm) to the surface thickness, or if 3/4 inch (19 mm) or more is added to the pavement thickness over 10 percent or less of the surface area in any one mile (km).

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>Shoulder and Side Approaches</td>
</tr>
<tr>
<td>302</td>
<td>Right-of-Way Mowing</td>
</tr>
<tr>
<td>306</td>
<td>Litter Cleaning</td>
</tr>
<tr>
<td>340</td>
<td>Snow and Ice Removal</td>
</tr>
</tbody>
</table>

**1958 - 1966 Codes:**

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>Bituminous Concrete Surface on Non-rigid Base (Surface 3/4 inch (19 mm) and greater)</td>
</tr>
<tr>
<td>90</td>
<td>Portland Cement Concrete Surface</td>
</tr>
</tbody>
</table>

**Note:** These codes are for comparable routine maintenance operations listed above.

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>180</td>
<td>Bituminous Concrete Surface on Non-rigid Base (Surface 3/4 inch (19 mm) and greater)</td>
</tr>
<tr>
<td>190</td>
<td>Portland Cement Concrete Surface</td>
</tr>
</tbody>
</table>

**Note:** These codes are for comparable "special" operations listed above. The four 1959 - 1966 codes listed above are examples from a series of 99 subledger numbers for routine maintenance and 99 subledger numbers for special maintenance for various surface types and thicknesses and base types.

Costs of operations performed, identified by subledger codes, were charged to respective sections or subsections; however, it was necessary in the analyses to spread the charges throughout the length in the section regardless of how concentrated the actual work might have been. Also, whereas the charge codes recognize only portland cement concrete (PCC) and bituminous concrete (BC) surface types, it was known that charges to BC sections included not only maintenance on bituminous pavement structures but also portland cement concrete overlaid with bituminous concrete. In the analyses, overlaid concrete sections were identified from the historical file and classified as a composite type of pavement (COM). COM pavements were treated as a third type; their age was counted from the time of original construction. It should be noted, however, that the change in classification from PCC to COM diminishes the sample of PCC pavements and increases the sample of COM-type pavements.

The analyses merely attempt to isolate "pure" pavement maintenance costs. At first, full reliance was given to subledger codes 80, 180, 206, and 216 for screening purposes. Later, it was discovered that many of those charges were against pavement sections classed as PCC. Consequently, it was inferred that successive or repeated bituminous patching or leveling, such as at bridge approaches, joints, other settlements, and fill-slips, were actually charged as maintenance of a bituminous concrete surface after the first instance regardless of the length of road treated in the section.

In other words, the length of road receiving the treatment was not sufficient to change its classification to BC or to identify a COM-type pavement for purposes of these analyses. Nevertheless, the charge was recorded as maintenance on BC surfaces. This had the effect of steadily increasing the annual lane-mile (lane-kilometer) cost for BC pavements and diminishing the cost for PCC pavements.
It finally became apparent that the as-built classifications, together with identifications of COM pavements as previously described, were more reliable than subledger coding. In the final analyses, all pavement maintenance costs, regardless of coding, were sorted and summed for each type of pavement for each year. These sums divided by the respective lane miles (lane kilometers) in the qualifying sample produced an average cost per lane mile (lane kilometer) for that year. Actually, a 3-year running average was completed; and those are the costs reported here.

The interstate and parkway systems provided a grand sample of modern highways worthy of analysis as an independent set. All other projects were lumped into another set and analyzed in the same way. In each of the two cases, only those sections which could be identified as being "pure in type" throughout the entire length of the section were used in these analyses. There were no COM pavements in the interstate and parkway sample set; therefore, the sample set represents almost the total systems. Only two-thirds or less of the remaining sample set qualified.

RESULTS

Interstate and Parkway System

Undoubtedly, the interstate and parkway systems provided the purest set of maintenance cost records. Although the first section of interstate was completed in 1959, significant mileage was opened to traffic by 1962. Mileage increased steadily during the period covered by this analysis. The Kentucky Turnpike, built in 1955, was the only project included in the sample which pre-dated the study period. Nevertheless, the remaining parkways provided a sampling about equal to and contemporary with the interstate system. No cross-comparison was made: instead, they were lumped together; and the 3-year running-average maintenance costs per lane per year are shown graphically in Figure 2. Naturally, the costs at the beginning of the period were nearly zero. They mounted gradually to approximately $150 per lane-mile ($93 per lane-kilometer) per year in 1970. These costs were then analyzed according to age of pavements; and those costs are shown in Figure 3. In this form, the costs appear to be erratic. There, mileage in the sample decreases as the age of the pavements increases—that is, mileage or sample size increases from right to left in the graph. This effect tends to disappear at an age of about 8 years. In other words, the rising trend from zero to 8 years of age appears to be normal. In Figure 2, mileage increased from left to right. There, new mileage entered the sample each year at or close to a zero cost level. No compensation for this effect or bias was attempted.

Mileages corresponding to Figure 3 are shown in Figure 4.

Other Highway Systems

The "lumped-by-type," three-year running average costs for calendar years 1960 through 1970 are shown in Figure 5. This sample set includes a wide spectrum of highways, other than interstate and parkways, which are undifferentiated by class, traffic volumes, or structural capacity. Costs shown have not been adjusted to the 1967 base year according to the Federal Highway Administration's maintenance cost index (10). Costs of maintenance for BC and COM pavements merge and remerge. This may be due to surges in overlay programs and lapses in the maintenance burden which follow resurfacing. Figure 6 shows average annual costs according to age of pavements. These costs were adjusted to the 1967 base year. Here again, mileage effects superimpose. Mileages by ages of pavements in the sample during the study period are shown in Figure 7. The mileage distributions are not as was expected. Mileage of COM pavements rose in the 12th through 16th year. Mileage of PCC pavements in the sample was expected to diminish after about the 20th year; instead, it rose through the 32nd year. Some very old PCC pavements have been preserved without overlays and entered the sample through areal selection. Therefore, the costs at given ages are not directly comparable.

Referring again to Figure 6, the average annual cost for all "mature" pavements appears to be about $350 per lane mile ($218 per lane kilometer) per year. This appears to be the cost of maintenance near the end of and beyond the design period. The cost during the design period are not statistically comparable.

Statewide Maintenance Costs

As a general test of the sample set and the aforementioned analyses, all pavement maintenance costs for each year from 1967 through 1971 were summed and divided by the total mileage of paved highways in the state system in each year (10). These yearly averages are shown in the upper-right portion of Figure 8. These costs are based on the subledger codes adopted in 1967. For comparison, the average per-mile(kilometer)-per-year costs for the sample set was determined for all years of data and are also shown. In the comparative years, the annual costs per mile (kilometer) for the sample set are approximately equal to the statewide averages. Greater differences were expected because of the greater influence of interstate and parkway mileage in the sample set than in the statewide system. Perhaps the differences expected were nullified by the greater number of lane-miles (lane-kilometers) contributed to the sample set. Because of data-processing difficulties, the statewide costs were not computed for the years prior to 1967. Presumably, any differences would diminish toward the beginning of the study period.
Figure 2. Three-Year Running Average Costs of Pavement Maintenance for the Interstate and Parkway Systems (Does Not Include Maintenance of Shoulders).

Figure 3. Thirteen-Year Average Costs Per Lane-Mile (Lane-Kilometer) Per Year of PC and BC Pavement Maintenance on the Interstate and Parkway Systems (Shown According to Ages of Pavements).
Figure 4. Number of Lane-Miles (Lane-Kilometers) on Interstate and Parkway Systems Used in Computing Pavement Maintenance Costs.

Figure 5. Three-Year Running Average Costs of Maintenance on PCC, BC, and COM Pavements Per Lane-Mile (Lane-Kilometer) Per Year; Based on Sample Set Excluding the Interstate and Parkway Systems (Only Those Sections Clearly Identified By Type of Pavement Were Used In This Analysis).
Figure 6. Thirteen-Year Average Costs Per Lane-Mile (Lane-Kilometer) Per Year of PCC, BC, and COM Pavement Maintenance; Based on Sample Set Excluding Interstate and Parkway Systems Shown According to Ages of Pavements (Only Sections Clearly Identified By Type of Pavement Were Used in this Analysis).

Figure 7. Sample Length Excluding the Interstate and Parkway Systems in Sections Identified By Type of Pavilion Corresponding to Figures 5 and 6 (Distribution of PCC Pavements Prevents Direct Comparison of Costs By Types of Pavements).
Figure 8. Annual Per Mile (Kilometer) Costs of Pavement Maintenance; Determined From Sample Set Including the Interstate and Parkway Systems (Statewide Averages for 1967 through 1971 Are Shown for Comparison with Costs Derived from Sample).

SUMMARY AND RECOMMENDATIONS

Summarily, apparent differences in pavement maintenance costs between the two basic types of pavements, as found in this study, are probably not significant from the standpoint of determining pavement type. Moreover, the specificity of maintenance cost coding, from the standpoint of quantifying pure and true pavement maintenance, remains in doubt. If it were possible, which it is not because of the limited detail identified by the charge codes, to eliminate from the record those costs charged as pavement maintenance and which involved patching necessitated by settlement at bridge approaches, settlement in embankments and fill-slips, leveling dips etc.; the apparent costs of pavement maintenance found in this study might have been diminished considerably. In view of these probable uncertainties in cost identification, addition of maintenance costs factors in the pavement type determination process is not recommended. To adjudge these costs to be indiscrete or the apparent differences to be insignificant for the intended purposes has the effect of having implemented the maintenance cost consideration in the AASHO Informational Guide...in the very beginning. However, seemingly imminent needs for deslicking treatments and for releveling wear- and load-induced ruts may emerge as significant factors affecting maintenance of high-volume roads. Further uses of design strategies, together with insights and foresights toward future trends and needs of the times, may forestall otherwise surprising rises in maintenance expenditures.
DISCUSSIONS

Effects of Studded Tires

Although others (14) have estimated the impact of studded tires on pavement maintenance costs, the estimates are in terms of additional per-year costs for the miles needing additional maintenance and are based on the expected number of additional overlays needed in a 25-year period. These estimates are in the order of $4000 to $5000 per mile (1.6 kilometers) per year. As many as 10 overlays have been predicted during a 25-year period where traffic volumes are high and the percentage of studded tires is also high. Wear equations have been formulated (15).

Overlaying and Resurfacing Programs

Until recently, overlaying or resurfacing, although budgeted as maintenance, has been mostly for the purpose of restructuring pavements for extended life, load-carrying capacity, and riding quality. Overlays for purposes of deslicking, smoothing ruts caused by studded tires, improving surface drainage, etc., bring forth new types of maintenance and additional costs. Present cost coding is not sufficient to identify these specific costs in future analyses of maintenance records.

Maintenance-Free Design Concepts

Ideally, pavements designed for high volumes of traffic should be maintenance free, or nearly so, during their designed service life. Some years ago, some engineers held the opinion that a pavement which does not develop some structural failures during its service life was overdesigned and that "no-defect" designs would not spread highway revenues to the maximum. Now, because of the perils associated with making pavement repairs on high-speed high-traffic-volume highways, the "no-defect" maintenance-free notions are most appealing. In other words, a low level of maintenance costs could be associated with a structural design criterion which provides a high level of confidence and certainty in the performance of pavements. Kentucky design criteria (16) have been derived on the basis of high confidence interval principles and therefore exceed the designs provided by the 1972 AASHO Interim Guide . . . (17) which is based on best-fit regression rather than on statistical limits.

Design Strategies

Planned restructuring of pavements coincident with anticipated needs for surface renewal would tend to further minimize pavement maintenance and perhaps offset the costs of surface renewals. First-stage designs would likely be for considerably less than 20 years, but the ultimate might be for considerably more than 20 years. Also, the impracticality of designing all first-stage pavements for very low volume roads to last 20 years is apparent. Optimum design strategies ultimately involve many economic considerations beyond initial construction costs. Whereas some economic factors must be quantified through historical derivation, others must be anticipated. Further implementation of design strategies would likely require a designer's commentary and plan for each project or class of highway.

Economic Modeling and Pavement Management Systems

Several economic models or equations have evolved (18, 19, 20, 21, 22, and 23) through the years. A resume of them is included here as APPENDIX V. Some are more directly applicable to specific highways or projects than to highway systems. Annual maintenance cost is common to all the models, and the period of years considered is required in most of them; however, the outputs are as specific or general as the input values.

The most recent development is the concept of pavement management systems - in which pavement structural criteria become a subsystem modeled by mathematical equation(s) and translated for computer use (24). Separate subsystems are modeled for construction costs, maintenance costs, resurfacing costs, traffic, costs to traveling public for delays during maintenance and reconstruction work, pavement conditions histories, salvage values, environmental impacts, and decision-making routines and alternatives. Continual input and feedback make the system ongoing; consequences of "do-nothing" decisions or deferment of action become apparent. The ultimate benefit of such a system could be a form of dynamic programming of funds -- that is, scheduling of work where it is needed most or where the benefits are highest. For instance, the so-called resurfacing program in Kentucky could be fully computerized and balanced for budgeting. The system would, of course, contain a complete inventory of pavements, condition, history, traffic, investments, planned obsolescence, etc. This concept merges nicely with the total highway inventory, project identifications, and information retrieval programs currently under consideration and now being partially implemented.

It would be possible, by further extension of the concept, to analyze incremental costs in terms of geometric requirements in roadway design and in terms of loads imposed by various types and classes of vehicles (including overloads). This could be extended to determine user taxing and licensing levels.
REFERENCES

11. Stokstad, O. L.; Pavement Type Selection; Michigan State Highway Department, March 1960.
25. The Cost of Constructing and Maintaining Flexible and Concrete Pavements over 50 Years; Road Research Laboratory, Report LR 256; Crowthorne, Berkshire (1969).
APPENDIX I

PAVING TYPE DETERMINATION AND DOCUMENTATION

(From Reference 1)

AMERICAN ASSOCIATION OF STATE HIGHWAY OFFICIALS

PAVING TYPE DETERMINATION AND DOCUMENTATION

The highway engineer or administrator does not have at his disposal generally acceptable theoretical or rational methods that give an absolute and indisputable comparison of the competitive pavement types for set conditions.

Prerequisites for such an evaluation procedure would, of course, involve the development of improved scientific structural design methods for both rigid and flexible pavement structures to render comparable service under similar traffic and weather conditions.

It would also involve the availability of reliable cost accounting data on the maintenance costs of the two pavement types for those comparable conditions. Here again factual information in complete desirable form is not presently available. Even though information is being developed through research it will not be wholly applicable on a national basis without modifications to adjust for the various soil and climatic conditions encountered.

Past, current and proposed major research undertakings such as the Maryland Road Test, the WASHO Road Test and the current AASHO Road Test research project, and its proposed satellite projects, together with road life and maintenance studies underway in the several State highway departments all contribute to fill in, gradually, some of the gaps.

The AASHO Committee on Design is currently in the process of converting the basic scientific relationships of pavement performance and applied loads, as developed on the AASHO Road Test, into improved rational design methods for pavements.

Pending the development of better tools, the State highway departments must rely on those that are available. Certain assumptions must be made and an empirical approach used, based on the best professional highway engineering judgement and experience available.

In other words there is no magic formula, where certain figures can be inserted and a definite answer as to pavement type required will result.

Governing Factors

To avoid criticism, if that is possible, any decision as to paving type to be used should be firmly based. Judicious and prudent consideration and evaluation of the governing factors will result in a firm base for a decision on paving type.

A list of such factors comprises the following items:

1. Traffic
2. Soils characteristics
3. Weather
4. Performance of similar pavements in the area
5. Economics or cost comparison
6. Adjacent existing pavements
7. Stage construction
8. Depressed, surface, or elevated design
9. Highway system
10. Conservation of aggregates
11. Stimulation of competition
12. Construction considerations
13. Municipal preference and recognition of local industry
14. Traffic Safety
15. Availability of and adaptations of local materials or of local commercially produced paving mixes

In the following pages, these factors are discussed and grouped, one group including all those which may be considered to have major influence, and the second, those which have lesser, or only occasional influence. The order of magnitude of influence is to be considered interchangeable within the groups and between the groups, as no single order is held to apply in all cases.

PRINCIPLE FACTORS

1. Traffic

The volume of passenger cars generally affects only the geometric or lane requirement. The percentage of commercial traffic and frequency of heavy load application generally has the major direct effect on the structural design of the pavement. Existing heavy-duty highways constitute sufficient evidence that both flexible and rigid pavement designs can meet requirements under given conditions.

If a cost comparison between competitive paving types is to be of value, it is imperative that the structural designs compared have equal capacity to carry loads. Since the matter is one of basic economics, the cost comparison must also include not only the cost of original construction, but that of needed periodic repairs and routine maintenance over the service life of the pavement, and an estimate as to what its probable useable salvage value will be at the end of that time.

It must be conceded that in these important areas, some assumption still must be made pending the results of current and further research developments not already available in guide form. When such assumptions are made, they must be made by the best qualified personnel available.

Present legal load limits are, to all intents and purposes, frozen by the Federal-Aid Highway Act of 1956, and will remain until certain studies are presented to the Congress for its consideration and further action.

Even accepting this restriction, it is reasonable and proper to make allowances in the structural designs of pavements for possible future modest legal load increases as well as the occasional overloads, whether moving by special permit or illegally, that are likely to use the pavement.

Currently, the AASHO Transport Committee is preparing new proposed vehicle weights and size regulations for consideration of the various States from data received from the AASHO Road Test and other appropriate sources. The Transport Committee assignment is to develop recommended size and weights to give an optimum balance between the best highway use and maximum highway life, for roads and bridges that can be furnished with the funds available for highway purposes.

In the projection of the density and weight of future traffic that will likely use the pavement during its lifetime, it is essential that not only normal increases be anticipated, but that consideration be given to the possibility of additional traffic being generated by potential industrial development or changes in land use for the area served.

The construction of a modern highway may also divert large amounts of heavy traffic, from other routes in the same broad traffic corridor, that should be considered by the designer.
II. Soils Characteristics

Of paramount importance is the ability of a native soil, which forms the subgrade for the pavement structure in cuts and on embankments, to withstand applied loads. Even in given limited areas the inherent qualities of such native soils are far from uniform, and they are further subjected to variations by the influence of weather.

The characteristics of native soil not only directly affect the pavement structure design, but may, in certain cases, dictate the type of pavement economically justified for a given location.

The evaluation of the characteristics of soils is, axiomatically, a requirement for each individual pavement structure design.

III. Weather

Weather affects subgrade as well as pavement wearing course. The amount of rainfall, snow and ice, and frost penetration will seasonally influence the bearing capacity of subgrade materials. Moisture, freezing and thawing, and winter clearing operations will affect pavement wearing surfaces as to maintenance costs, etc. These surfaces, in turn, will have some effect on the ease of winter clearing operations due to differences in thermal absorption or to the ability of the pavement to resist damage from snow and ice control equipment or materials.

In drawing upon performance record of pavements elsewhere, it is most important to take into consideration the conditions pertaining in the particular climatic belt.

IV. Performance of Similar Pavements in the Area

To a large degree, the experience and judgment of the highway engineer is based on the performance of pavements in the immediate area of his jurisdiction. Past performance is a valuable guide, provided there is good correlation between conditions and service requirements between the reference pavements and the designs under study. This factor should not be allowed to develop into blind prejudice. Caution must be urged against reliance on short-term performance records, and on those long-term records of pavements which may have been subjected to much lighter loadings for a large portion of their present life. The need for periodic reanalysis is apparent.

V. Cost Comparison

In any cost comparison of paving types, the matter of availability of local or commercially produced materials, and the existence and proximity of manufacturing or processing plants will be of significant importance.

Unavoidably, there will be instances where the financial circumstances are such as to make first cost the dominant factor in paving type selection even though greater maintenance costs may be involved later. Where circumstances permit, a better and more realistic measure would be the cost on the basis of service life or service rendered by a pavement structure. Such cost computation should reflect original investment, anticipated life, maintenance expenditures, and salvage value.

Original cost can be fairly accurately estimated. Doubt as to validity arises in the case where on type of pavement has been given monopoly status by the long-term exclusion of a competitive type.
The highly desirable determination of cost on a service life basis is presently adversely affected by some incomplete areas in needed factual information. One such area is the life expectancy of different paving types, a second, the matter of maintenance costs, and a third, the salvage value of pavements.

With our present state of limited knowledge as to the effect of frequency of heavy load applications, it is difficult to conceive of anything but an empirical approach to the determination of life expectancy of a pavement. The Bureau of Public Roads report “Lives of Highway Surfaces-Half Century Trends” shows a difference in the probable life for rigid and flexible pavements. It is not known if these trends hold for the pavements currently being constructed for the modern heavier traffic loadings, such as will be involved for the National System of Interstate and Defense Highways. The experience of the individual states as to assignment of probable life expectancy of different paving types, under the pertaining conditions, must for the present be accepted.

Assigned maintenance costs will seriously affect the cost comparison. If these costs are to be considered wholly valid, they must be based on accurately kept, long-term maintenance records reflecting an established maintenance standard adhered to in practice. Since traffic and structural standards in the past have been such variables, it is difficult to accurately evaluate maintenance costs. This has not been a dereliction of the highway official.

It is urged that the individual states take the necessary steps to develop factual information from Interstate System of highways, which will be valuable in the years ahead. These highways are built to modern standards. Establishment of, and adherence to, a maintenance standard, supplemented by accurate cost recording, will produce for the future more reliable data on maintenance cost and life expectancy.

Salvage value to be ascribed to pavements is somewhat open to conjecture. As it were, a large proportion of highway reconstruction involves changes in alignment or gradient which negate the salvage value. Each project actually must be considered individually.

SECONDARY FACTORS

I. Adjacent Existing Pavements

Provided there is no radical change in conditions, the choice of paving type on a highway may be influenced by existing sections thereof which have given adequate service. This will result in a desirable continuity of pavement and consequent simplification of maintenance operations.

II. Stage Construction

Where financial circumstances dictate stage construction of the type of pavement, where a thinner wearing course is later brought up to design requirements by an additional course or courses of wearing course material, flexible design becomes mandatory.

III. Depressed, Surface, or Elevated Design

Depressed and surface design may involve a high water table which will influence the choice of paving type. Elevated design, as in the case of approaches to long bridges or viaducts with concrete decks, may influence the decision in
favor of rigid pavement to preserve a desirable continuity of pavement surface. A depressed design, presenting some periodic possible drainage problems, may also indicate the use of one type of pavement over another.

IV. Highway System

It is not considered good practice to let a system designation influence the choice of paving type. Merits of the individual case and economics should prevail.

V. Conservation of Aggregates

This consideration may well have influence in choosing a paving type which will involve, in the total pavement structure, less of the scarce critical material than might be required by another type.

VI. Stimulation of Competition

It is desirable that monopoly situations be avoided, and that improvement in products and methods be encouraged through continued and healthy competition among industries involved in the production of paving materials.

VII. Construction Consideration

Such considerations as speed of construction, reduction of traffic maintenance during construction, ease of replacement, anticipated future widening, need for minimum of surface maintenance in highly congested locations, seasons of the year when construction must be accomplished, and perhaps others may have a strong influence on paving type selections in specific cases.

VIII. Municipal Preference, Participating Local Government Preference and Recognition of Local Industry

While these considerations seem outside of the realm of the highway engineer, they cannot always be ignored by the highway administrator, especially if all other factors involved are indecisive as to the pavement type to select.

IX. Traffic Safety

The particular characteristics of a wearing course surface, the need for delineation through pavement and shoulder contrast, reflectivity under highway lighting, and the maintenance of a non-skid surface as affected by the available materials may each influence the paving type selection in specific locations.

X. Availability of and Adaptation of Local Materials or of Local Commercially Produced Paving Mixes

The prevalence of adaptability of local materials may influence, or the availability of commercial produced mixes particularly on small projects, may influence the selection of pavement type.
Conclusion...

In the foregoing, there have been listed and discussed those factors and considerations which influence, to various degree, the determination of paving types. This has brought to the fore the need, in certain areas, for the development of basic information that is not available at present. It has also served to point out that, in general, conditions are so variable, and influences sufficiently different from locality to locality, to necessitate a study of individual projects in most instances.

The public, although a critical judge, cannot be expected to be aware of the variety of considerations which influence the decisions of a highway administrator.

Consequently, whatever factors control the selection of the pavement type should be made part of the project file and should carry the identity of the person or persons involved in the entire process of making recommendations and in making the final decisions. It is very important that the reasons for reaching the decision be fully documented in the project file.

The judgment of the decision may be disputed at some subsequent time, but if the reasons are fully outlined and documented, the matter becomes only a difference of opinion and the reasons of the person or persons, who are responsible for the decision, are a matter of record for any future review or investigation.
**APPENDIX II**

**HISTORICAL DATA ATTRIBUTES**

<table>
<thead>
<tr>
<th>COLUMN</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Control Serial Letter</td>
</tr>
<tr>
<td>2-4</td>
<td>County Number</td>
</tr>
<tr>
<td>5-8</td>
<td>Maintenance Control Section Number</td>
</tr>
<tr>
<td>9-10</td>
<td>Maintenance Control Subsection Letter</td>
</tr>
<tr>
<td>11-15</td>
<td>Length in Thousandths of a Mile (Decimal Point Assumed To Be between Columns 12 and 13)</td>
</tr>
<tr>
<td>16-17</td>
<td>Pavement Type Code Number (Subledger Number)</td>
</tr>
<tr>
<td>18-19</td>
<td>Month Acceptance Date</td>
</tr>
<tr>
<td>20-21</td>
<td>Year</td>
</tr>
<tr>
<td>22-24</td>
<td>County Number</td>
</tr>
<tr>
<td>25-28</td>
<td>Maintenance Control Section Number Previous Maintenance</td>
</tr>
<tr>
<td>29-30</td>
<td>Maintenance Control Subsection Letter Control Number</td>
</tr>
<tr>
<td>31-34</td>
<td>Thickness Surface</td>
</tr>
<tr>
<td>35-38</td>
<td>Type Base</td>
</tr>
<tr>
<td>39-42</td>
<td>Thickness Base</td>
</tr>
<tr>
<td>43-46</td>
<td>Type Base</td>
</tr>
<tr>
<td>47-63</td>
<td>Federal Project Number</td>
</tr>
<tr>
<td>52</td>
<td>Dash</td>
</tr>
<tr>
<td>57</td>
<td>Dash</td>
</tr>
<tr>
<td>64-80</td>
<td>State Project Number</td>
</tr>
<tr>
<td>70</td>
<td>Dash</td>
</tr>
<tr>
<td>75</td>
<td>Dash</td>
</tr>
</tbody>
</table>

**ABBREVIATIONS FOR SURFACE AND BASE TYPES**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>COM</td>
<td>Composite</td>
</tr>
<tr>
<td>PCC</td>
<td>Portland Cement Concrete</td>
</tr>
<tr>
<td>BSFC</td>
<td>Bituminous Surface</td>
</tr>
<tr>
<td>TBM</td>
<td>Traffic Bound Macadam</td>
</tr>
<tr>
<td>TBL</td>
<td>Traffic Bound Limestone</td>
</tr>
<tr>
<td>GR</td>
<td>Grade</td>
</tr>
<tr>
<td>DR</td>
<td>Drain</td>
</tr>
<tr>
<td>GV</td>
<td>Gravel</td>
</tr>
<tr>
<td>RA</td>
<td>Rock Asphalt</td>
</tr>
<tr>
<td>WBM</td>
<td>Water Bound Macadam</td>
</tr>
<tr>
<td>DGA</td>
<td>Dense Graded Aggregate</td>
</tr>
<tr>
<td>CCB</td>
<td>Calcium Chloride Stabilized</td>
</tr>
<tr>
<td>BSB</td>
<td>Bitumen Stabilized Base</td>
</tr>
<tr>
<td>CLI</td>
<td>Bituminous Concrete Class I</td>
</tr>
</tbody>
</table>
### APPENDIX III

#### TERMINI DATA ATTRIBUTES

<table>
<thead>
<tr>
<th>COLUMN</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Control Serial Letter</td>
</tr>
<tr>
<td>2-4</td>
<td>County Number</td>
</tr>
<tr>
<td>5-8</td>
<td>Maintenance Control Section Number</td>
</tr>
<tr>
<td>9-10</td>
<td>Maintenance Control Subsection Letter</td>
</tr>
<tr>
<td>11-45</td>
<td>Terminus Description</td>
</tr>
<tr>
<td>46-80</td>
<td>Terminus Description</td>
</tr>
</tbody>
</table>
04700019 HNCL OF E-TOWN
1640.2 FT N OF E-TOWN
04700019 EAPPX 0.5 MI S OF RADCLIFF
MEADE CO LINE
04700019 STA 0600
STA 160620.7
04700019 ESTA 28607.5
STA 162809.4
04700019 ESTA 160620.2
STA 289800
E04700019 ESTA 162809.4
STA 289800
A04700019 DAPPX 0.5 MI S OF RADCLIFF
MEADE CO LINE
A04700019 CPCC PAVING (47-19-R)
MEADE CO LINE
B04700019 CJCT US 60 AT TIP TOP
MEADE CO LINE
A04700019 B4200 FT S OF RADCLIFF
4.465 MI TOWARD LOUISVILLE
A04700019 ANCL OF E-TOWN
APPROX. 0.5 MI S OF RADCLIFFE
A0470459 HNCL E-TOWN
SCL OF RADCLIFF
A0470459 ENCL OF E-TOWN
JCT US 31-W
A0470459 DJCT OF WOODLAND DR IN E-TOWN
NEW NCL OF E-TOWN
A0470459 C1640.2 FT N OF NCL OF E-TOWN
JCT US 31-W
A04700019 CSTA551650
STA 557800
A04700459 H1640.2 FT N OF NCL OF E-TOWN
JCT US 31-W
A0470459 AS END OF BR OVER SHAWS CR
JCT OLD US 31-W
A0470459 7.5 MI S OF KY 447 OVERHEAD
NCL OF RADCLIFF
A0473019 YSCL OF RADCLIFF
732 FT. S OF C-PKWH. IN RADCLIFF
A0473019 VSCL OF RADCLIFF
NCL OF RADCLIFF
C0473019 TNCL OF E-TOWN
10.289 MI N OF E-TOWN
C0473459 JSCL OF RADCLIFF
.5 MI. S OF KY 447 OVERHEAD
C0473459 ISCL OF RADCLIFF
JCT OLD US 31-W
C04700019 MNCL OF CYTHIANA 3S END OF RR BRIDGE
NEW NCL OF E-TOWN
PENDLETON CO LINE
A04900012 JNCL OF CYTHIANA
5.960 MI NORTH OF CYTHIANA
A04900012 H3.0 MI NORTH OF CYTHIANA
6.0 MI NORTH OF CYTHIANA
A04900012 GNCL OF CYTHIANA
3.0 MI NORTH OF CYTHIANA
A04900012 ENCL OF CYTHIANA
PENDLETON CO LINE
A04900012 D5.702 MI NORTH CYTHIANA
EXTENDING SOUTH TO US 27 AT LAIR
A04900012 NSCL OF CYTHIANA
BOURBON CO LINE
A04900012 M.396 MI. N OF BOURBON CO LINE
EXTENDING SOUTH TO US 27 AT LAIR
A04900012 LJT OF OLD US 27 NEAR LAIR
BOURBON CO LINE
A04900012 KO.396 MI. N OF BOURBON CO LINE
JCT OF OLD AND NEW US 27
A04900012 JO.396 MI. N OF BOURBON CO LINE
JCT OF OLD AND NEW US 27
A04900012 IHURONN CO LINE
0.396 MI NORTH OF BOURBON CO LINE
A04900012 HO.396 MI N OF BOURBON CO LINE
JCT OF OLD AND NEW US 27
A04900012 MAURRURN CO LINE
SCL OF CYTHIANA
A04900012 BHURURR CO LINE
JCT US 27
A04900012 ENCL US 62-APP 1.8 MI S OF CYTHIANA
CL OF CYTHIANA
A04900012 AJCL US 62-APP 1.8 MI S OF CYTHIANA
JCT US 62-APP 1.8 MI S OF CYTHIANA
A04901922 DJCT US 62-APP 1.8 MI S OF CYTHIANA
END OF APPROACH NW OF JCT US 62
A04901922 EJCT US 62-APP 1.8 MI S OF CYTHIANA
BROADWELL
A04901922 NJCL US 62 S OF CYTHIANA
JCT US 27 NEAR LAIR
A04901922 AJCT US 62 S OF CYTHIANA
JCT US 27
A04901922 AJCT US 62
JCT US 27
A0500020AD2.345 MI N OF NCL OF BONNIEVILLE
LARUE CO LINE
A0500020AC2.345 MI N OF NCL OF BONNIEVILLE
2.345 MI N OF BONNIEVILLE
A0500020ACNCL OF BONNIEVILLE AT KY 72R
SCL OF BONNIEVILLE
A0500020ACNEW NCL OF MUNDFORDVILLE
EXTENDING S & PARALLEL WITH 165
A0500020AYJT CRUSS RD NEAR E SIDE OF 165
1.553 MI S OF LARUE CO LINE
A0500020AX589.5FT. N OF BACON CREEK BRIDGE
6.558 MI N OF NCL OF MUNDFORDVILLE
A0500020AW5.3 MI N OF NCL OF MUNDFORDVILLE
2.315 MI N OF NCL OF MUNDFORDVILLE
A0500020AVNCL OF MUNDFORDVILLE
4.76 MI N OF NCL OF MUNDFORDVILLE
A0500020ATJCT NEW 31-W
LARUE CO LINE
A0500020AS1.553 MI S OF LARUE CO LINE
LARUE CO LINE
A0500020AR3.153 MI S OF LARUE CO LINE
1.553 MI S OF LARUE CO LINE
A0500020AT589.5 FT. N OF BACON CR. BRIDGE
3.153 MI S OF LARUE CO LINE
A0500020AP6.568 FT. N OF BACON CR. BRIDGE
589.5FT. N OF BACON CR. BRIDGE
A0500020AQ5.3MI. N OF NCL OF MUNDFORDVILLE
6.568 MI N OF MUNDFORDVILLE
A0500020ANCL OF MUNDFORDVILLE
2.315 MI N OF NCL OF MUNDFORDVILLE
A0500020AM2.315 MI N OF MUNDFORDVILLE
5.300 MI N OF MUNDFORDVILLE
0580017 TJCT US 460, NW OF PAINTSVILLE
0580017 SNCL OF PAINTSVILLE
0580017 RNCL OF PAINTSVILLE
0580017 PS, 2.24 M S OF NCL OF PAINTSVILLE
0580017 CNEAR NIPPA
0580017 RNAR NIPPA
A0580697 CSCL OF PAINTSVILLE
A0580697 SFCL OF PAINTSVILLE
A0580697 DFCL OF PAINTSVILLE
A0580697 CSCL OF PAINTSVILLE
A0630011 WNWCL OF LONDON
A0630011 SNWCL OF LONDON
A0630011 RNWCL OF LONDON
A0630011 JNWCL OF LONDON
A0630011 JNWCL OF LONDON
A0630011 IX 367 FT N OF OHXING AT PINE LODGE
A0630011 RR 92 FT S OF OHXING AT PINE LODGE
A0630011 RNWCL OF LONDON
A0630011 F500 FT S OF TRIPLE CULVERT
A0630011 E300 FT N OF HAZEL PATCH CREEK
A0630011 DWCL OF LONDON
A0630011 RNWCL OF LONDON
A0580031 GJCT KY 490-9 MI, N OF PITTSBURG
A0580031 DJCT KY 30
A0580031 EJCT KY 30
A0580031 DAAPPROX, 9.0 MI N OF PAINTSVILLE
A0580031 CAPPROM, 9.0 MI N OF PAINTSVILLE
A0580031 BAPPROX, 3.3 MI N OF PAINTSVILLE
A0580031 AAPPROM, 3.3 MI N OF PAINTSVILLE
A0640053 OSF CURV LINE OF IMPHATAN AVE
A0640053 N, 7.33 MI S OF KY 32
A0640053 MJCT LOUISA BY-PASS
A0640053 KJOHNSON CO LINE
A0640053 J7.988 MI S OF LOUISA
A0640053 FJOHNSON CO LINE
A0640053 EJOHNSON CO LINE
A0640053 D7.988 MI S OF LOUISA
A0640053 C8 MI S OF SCL OF LOUISA
A0640053 BJOHNSON CO LINE
A0701030 ETNENNESSE RIVER
A0720171 FAPP 2 MI SW OF KUTTAWA
A0720171 EW END OF CUMBERLAND RIVER BRIDGE
A0720171 B3 MI W OF KUTTAWA
A0730032 SML CL OF PAUDUNA
A0730032 LFLORIDA ST IN PAUDUNA
A0730032 JEC OF PAUDUNA
A0730432 DEND OF MP-73-0432-C NEAR JCT US 68
A0730432 AREAR JCT US 68
A0760151 WNWCL OF RICHMOND
A0760151 RNWCL OF RICHMOND
A0760151 GNWCL OF RICHMOND
A0760151 DINTERSECTION WITH CONC. PAVEMENT
A0760151 ANWCL OF RICHMOND
A0760151 RNWCL OF RICMOND
A0760151 CNWCL OF RICHMOND
A0790073 L1.609 MI SE OF JCT US 664 AND KY 583.521 MI SE OF US 664
A0790073 GJCT KY 58 E OF BRIENSBURG
A0790073 FJCT US 68 N OF BENTON
A0790073 DJCT US 68 N OF BENTON
A0790073 CNWCL OF BIRMINGHAM
A0790073 38.521 MI E OF JCT US 68

NEAR NIPPA
EXTENDING NORTHWEST TO US 460
NEAR NIPPA
LAWRENCE CO LINE
Dogwood Branch
LAWRENCE CO LINE
0.3 MI SE OF JCT US 23 AND US 460 SCL OF PAINTSVILLE
0.3 MI SE OF JCT US 23 AND US 460 SCL OF PAINTSVILLE
2.521 MI S OF PAINTSVILLE
0.3 MI SE OF JCT US 23 AND US 460 535 FT S OF PINE LODGE
535 FT S OF OVERHEAD AT PINE LODGE
0.5 MI S OF VICTORY
MT VERNON
500 FT S OF TRIPLE CULVERT HP CREEK
1357 FT N OF OHXING AT PINE LODGE
892 FT S OF OHXING AT PINE LODGE
300 FT N OF SAME CULVERT
0.5 MI S OF VICTORY
500 FT S OF HAZEL PATCH CREEK
0.5 MI S OF VICTORY
W END OF BRIDGE AT ROCKCASTLE CO LN
ROCKCASTLE CO LINE
ROCKCASTLE CO LINE
900 FT S OF ROCKCASTLE RIVER
900 FT S OF ROCKCASTLE RIVER
4.812 MI N OF LONDON
4.812 MI N OF LONDON
EXT S & W TO JCT WITH LOUISA BY-PAS
APP R MILES S OF LOUISA
0.733 MI S OF KY 32
SCL OF LOUISA
1.878 MI S OF LOUISA
SCL OF LOUISA
1.878 MI S OF LOUISA
JOHNSON CO LINE
1.878 MI S OF LOUISA
JOHNSON CO LINE
6.134 MI S OF SMITHLAND
W END OF CUMBERLAND RIVER BRIDGE
WCL OF KUTTAWA
PROPOSED CUMBERLAND RIVER BRIDGE
FLORIDA ST
TENNESSEE RIVER
TENNESSEE RIVER
MARSHALL CO LINE
MARSHALL CO LINE
S END OF CLAYS FERRY BRIDGE
S END OF CLAYS FERRY BRIDGE
S END OF CLAYS FERRY BRIDGE
KY RIVER
CLAYS FERRY BRIDGE
JCT US 25 AND US 421
JCT US 25 AND KY 169
JCT KY 58 2.1 MI S OF BEGINNING
TVA RESERVOIR
TOLL FERRY AT TENN. RIVER
TOLL FERRY AT TENN. RIVER
WCL OF BIRMINGHAM

27
0920084 QJCT US 231-.75 MI. S OF CROMWELL
0920084 SCCL OF BEAVER DAM
0920084 MNAR RD TO ABERDEEN SCHOOL
0920084 LSCL OF BEAVER DAM
0920084 JWCL OF BEAVER DAM
0920084 DNCL OF BEAVER DAM
0920084 CJCT US 62
0960017 WSCL OF BUTLER
0960017 WLY 177, WEST OF MERIDIAN
0960017 USCL OF BUTLER-N END OF PTN RR UNDOS. KY 177 W END OF MERIDIAN
0960017 TS END OF LICKING R. BR. AT FALMOUTH OLD US 27 NEAR BETHEL CHURCH
0960017 SS END OF LICKING R BR
A0960017 JEND OF CONC PAY
A0960017 HS END OF LICKING R BR
A0960017 GS END OF LICKING R BR
A0960017 FN END OF NEW CONST OF FA367-B(2)
A0960017 BJCT KY 22 2.450 MI N OF FALMOUTH
A0960017 ANCL OF FALMOUTH
A0960017 SSECL OF FALMOUTH
A0960017 MJCT US 27
A0960017 LHARRISON CD LINE
A0960017 K0.5 MI N OF HARRISON CD LINE
A0960017 IHARRISON CD LINE
A0960017 H0.707 MI S OF SECL OF FALMOUTH
A0960017 EHARRISON CD LINE
A0960017 RHARRISON CD LINE
A0960017 AHARRISON CD LINE
A0960017 MOLD US 27 NEAR BETHEL CHURCH
A0960017 LN END OF LICKING R. BR. E OF BUTLER
A0960017 KJCT US 27 NEAR BETHEL CHURCH
A0960017 KJCT US 27 NEAR BETHEL CHURCH
A0960017 KJCT US 27 NEAR BETHEL CHURCH
A0960017 KJCT US 27 NEAR BETHEL CHURCH
A0960017 KJCT US 27 NEAR BETHEL CHURCH
A0960017 H LICKING R BRIDGE
A0960017 H700 FT S OF RR OVERHEAD
A0960017 GLICKING R BRIDGE
A0960017 FEND OF TB M 1.422 MI N OF JCT US 27
A0960017 FEND OF GRADE 3.679 MI N OF US 27
A0960017 FEND OF TB M 3.873 MI N OF JCT US 27
A0960017 EEND OF TB M 3.873 MI N OF JCT US 27
A0960017 DEND OF GRADE 3.679 MI N OF US 27
A0960017 DEND OF TB M 1.422 MI N OF JCT US 27
A0960017 BJCT US 27 NEAR BETHEL CHURCH
A0960017 AJCT US 27 NEAR BETHEL CHURCH
1000135 TSCL OF SOMERSET AT OAK HILL RD.
1000135 SFW US 127
1000135 R1.322 MI. S OF SCL OF BURNSIDE
1000135 QN END OF BURNSIDE REVISION
1000135 JI.731 MI NW OF NCL OF BURNSIDE
A1000135 E1600 FT N OF CUMBERLAND
A1000135 ES END OF TOLL BR AT NCL OF BURNSIDE 1600 FT N OF CUMBERLAND RIVER
1000135 CS END OF TOLL BR AT NCL OF BURNSIDE 1600 FT N OF CUMBERLAND RIVER
1000135 B1600 FT N OF CUMBERLAND RIVER
1000335 HN OF N END OF PITMAN CREEK BRIDGE
A1000335 GS END OF CUMBERLAND R BR
A1000335 FS1.322 MI S OF BURNSIDE
A1000335 DS END OF CUMBERLAND R BR
A1000335 C345 FT S OF BURNSIDE
A1000335 A 3860.74 FT N OF PITMAN
A1000535 IJCT KY 80-W OF NCL OF SOMERSET
1000535 IJCT KY 1247 NEAR NORWOOD
1000535 HJCT NEW US 27 NEAR OAK HILL RD
A1000535 S WCL SOMERSET CREEK BRG
1000535 D1.557 MI N OF JCT US 27
1000535 AJCT US 27 SMI S OF SWCL SOMERSET
1001335 INCL OF BURNSIDE
1001335 ESCL OF BURNSIDE
1001335 BSCL OF BURNSIDE
1004535 NWCL OF SOMERSET
1004535 NWCL OF SOMERSET
1100126 DLOGAN CO LINE
1100126 DLOGAN CO LINE
1100134 TENNESSEE STATE LINE
1110134 FF CORPORATE LIMITS OF CADIZ
A1110134 DECL OF CADIZ
1110254 JCT S OF CUMBERLAND RIVER BRIDGE
1110254 12.307MI. W OF CUMBERLAND RIVER BR.
1110254 NWCL OF CADIZ
A1110254 GE END OF CUMBERLAND RIVER BRIDGE
A1110254 F9.022 MI W OF WCL OF CADIZ
A1110254 BAR OVER TENN R AT EGGNERS FERRY
A1120018 FNCL OF BEDFORD
A1120018 CJCT US 42 IN BEDFORD
1120018 BJCT KY 36 IN MILTON
1120018 AJCT US 42 IN MILTON
A1190267 JEND OF SHAWNEETOWN TOLL BRIDGE
A1190267 TENNESSEE STATE LINE
A1190100 TENNESSEE STATE LINE
A1190100 INCL OF CADIZ
A1190100 FLAT ROCKS
1717515009 ELCL OF DIXON
1717515009 CHOPKINS CO LINE
1180100ABKY 92 JCT S OF WILLIAMSBURG
1180100AASCL OF WILLIAMSBURG
A1180100 TENNESSEE STATE LINE
A1190100 BEGINNING OF BLACKTOP NEAR SAXTON
A1190100 TENNESSEE STATE LINE
A1190100 LSAXTON
01183010 L459 FT S OF SAXTON
A1180100 LEND OF BLACKTOP
1180100 TENNESSEE STATE LINE
1180100 HO.489 MI N OF TENN STATE LINE
1180100 HO.376 MI N OF TENN STATE LINE
1180100 63.378 MI S OF SAXTON
A1180100 BEGINNING OF BLACKTOP N OF JELLICO
A1180100 LEND OF BLACKTOP
1180100 0659 FT S OF SAXTON
1180100 JELLICO
A1180100 BSAXTON
1180100 TENNESSEE STATE LINE
1180260 IAPP .45MJ. N OF SAXTON SCHOOL
A1180260 HINT OLD US 25 NEAR JELLICO
1180260 GEND OF CONC AT SAXTON SCHOOL
1180260 FEND OF CONC AT SAXTON SCHOOL
A1180260 EINT OLD US 25 NEAR JELLICO
1180260 DINT OLD US 25 NEAR JELLICO
1180260 8866 FT S OF ARCH CULVERT
1180260 8866 FT S OF ARCH CULVERT
A1180260 40.489 MI N OF TENN STATE LINE
1200095 INEW ECL OF VERSAILLES
1200095 GNW ECL OF VERSAILLES
A1200095 EECL OF VERSAILLES

JCT OLD US 27
OLD US 27 NEAR BOURBON
JCT KY 80, 1.15 MI W OF NWCL SOMERSET
JCT KY 80, 1.546 MI N OF NWCL SOMERSET
SCL OF BURNSIDE
S END OF CUMBERLAND RIVER BR.
S END OF CUMBERLAND RIVER BR.
JCT KY 80
NWCL OF SOMERSET
SW OF HADENSVILLE-REG OF PCC PAVING
SW OF HADENSVILLE-END OF CONCRETE END OF RA
CHRISTIAN CO LINE
CHRISTIAN CO LINE
E END OF EGGNER'S FERRY BRIDGE
E END OF CUMBERLAND RIVER BRIDGE
2.3074 MI E OF CUMBERLAND RIVER BR.
E END OF EGGNER'S FERRY BRIDGE
WCL OF CADIZ
WCL OF CADIZ
S END OF OHIO RIVER BR AT MILTON
S END OF OHIO RIVER TOLL BR
S END OF OHIO RIVER TOLL BR
JCT KY 80 IN MILTON
2.985 MI W OF MORGANFIELD
2.985 MI W OF MORGANFIELD
THE ROCKS OPP SHAWNEETOWN
WCL, OF MORGANFIELD
HOPKINS CO LINE
SCL OF DIXON
JCT KY 471 AT PLEASANT VIEW
EXT. S TO JCT KY 92 NEAR 175 INTCH.
OLD US 25-W
5.1 MI S OF WILLIAMSBURG
END OF BLACKTOP NEAR SAXTON
SCL OF WILLIAMSBURG
SAXTON
459 FT S OF SAXTON
0.576 MI N OF TENNESSEE STATE LINE
2.564 MI N OF JELLICO
0.549 MI N OF TENNESSEE STATE LINE
459 FT S OF SAXTON
END OF BLACKTOP NEAR SAXTON
459 FT S OF SAXTON
SAXTON
SCL OF WILLIAMSBURG
2.364 MI N OF JELLICO
2113.21 N OF BR. OVER CLEAR FORK R.
APPROX. 0.45 MI N OF SAXTON SCHOOL
2113.2 FT N OF CLEAR FORK BRIDGE
2113.2 FT N OF CLEAR FORK BRIDGE
SPUR TO US 25-W
689 FT N OF DOUBLE ARCH CULVERT
689 FT N OF DOUBLE ARCH CULVERT
SPUR TO US 25-W
NEAR SAXTON SCHOOL
W END OF SHANNON RUN BRIDGE
W END OF SHANNON RUN BRIDGE
W END OF SHANNON RUN BRIDGE

30
0590315 VROOM CO LINE
0590315 OBEACHWOOD RD N OF 175
0590315 NBEACHWOOD RD S SIDE 175
0590315 MBEACHWOOD RD N SIDE 175
0590315 LBUSSERTARK RD
0590315 KBUSSERTARK RD
0590315 JRIETCH AVE EXTENDING NW
0590315 1327 FT NW OP OF 175 STA 300675
0590315 HINTER DALE & SUMMIT IN CRESCENT PK
0590315 GERLANGER RD
0590315 FDONALDSON RD NE SIDE OF INTER
0590315 JCT DONALDSONGERLANGER RD
0590315 DDONALDSON RD
0590315 C900 FT NE OF DONALDSON RD
0590315 BONLADSON RD
0590315 ABOONE CO LINE
0590675 BGRANT CO LINE
0590675 AGGRANT CO LINE
0597315 800 FT S OF 5TH ST IN COVINGTON
0597315 NO.25MI W OF US25642 IN FT MITCH
0597315 UIPN ARNOLD ST
0597315 TINTER 12TH ST
0597315 SINTER HIGHVIEW DR,200 FT S OF 175
0597315 RN CURB ORCHARD RD
0597315 ORCHARD RD 306 FT SE OF 175
0597315 PO.25 MI W OF US 25642 IN FT MITCH
0597315 BO.25 MI W OF US 25642 IN FT MITCH
0620661 CN END OF KY 224 INTERCHANGE
0620661 RN END OF KY 224 INTERCHANGE
0620661 AHRDIN CO LINE
0630246 RNW END ROCKCASTLE RIVER BRIDGE
0630246 APP 1.1MI, NW OF US25 CROSSING
0720911XACALLDWELL CO LINE
0760281 6.791 MI, S OF DUNCANNON ROAD
0760281 FN END BARNES MILL ROAD INTERCHANGE
0760281 DN END BARNES MILL RD, INTERCHANGE
0760281 CBYPASS RD 0.207 MI E 175
0760281 BRANSMILL RD W OF 175 INTERCHANGE
0760281 AS END US 25 INTERCHANGE
0760831 OS END CLAYS FERRY BRO,FAYETTE CO LNS END US25 INTERCHANGE
0760831 CJCT US 25
0760831 BS END CLAYS FERRY BRIDGE
0760831 AJCT SIMPSON RD,E CLAYS FERRY INTER
0770720EMORGAN CO LINE
0790483CJCT WITH PROPOSED I24 S OF CULVTCY
0790483JBAPP .2MI W OF JACKSON SCHOOL ROAD
0790483JAGRAVES CO LINE
0840182CBANDERSON CO LINE
0840182CAANDERSON CO LINE
0870557 KJCT WITH RELOCATED QUISENBERRY RD.
0870557 JUS 60 INTERCHANGE NE OF MT.STERLINGBATH CO LINE
0870557 1700+ N IF US 60
0870557 1700 FT W OF US60
0870557 GCCLARK CO LINE
0870557 F180 FT L 164 STA 1200600
0870557 E180 FT R 164 STA 103428.31
0870557 OGRASSY LICK RD
0870557 CPROUIT
0870557 B200 FT L STA 833600 164
0870557 A2.75 MI NE OF STERLING
0.25 MI W OF US 25642
NORDMAN LANE E OF BEGINNING
438 FT W TO SCHULTZ PROP
605 FT W OF BEACHWOOD RD
1192 FT NE OF BEGINNING
1210 FT E OF BEGINNING
INTER OF HIGH ST
1500 FT NE OF BEGINNING PARALLEL 175
1410 FT SW OF BEGINNING
3980.7 FT E TO SCHWARTZ PROP
ERLANGER RD
418 FT SE PARALLEL TO DONALDON
220 FT S OF OLD WATSON RD
600 FT S OF VIDIX PROPERTY
ERLANGER RD
0.25 MI W OF US 25642
BOONE CO LINE
BOONE CO LINE
S END OHIO RIVER BRG PIER 4
800 FT S OF 5TH ST IN COVINGTON
500 FT W
INTER PIKE ST
200 FT N OF 175
EXTENDING 796.2 FT NW
NEAR LESLIE AVE 294 FT NW OF 175
NEAR 5TH ST IN COVINGTON
NEAR 5TH ST IN COVINGTON
HART CO LINE
HART CO LINE
N END OF KY 224 INTERCHANGE
WHITLEY CO LINE
WHITLEY CO LINE
JCT US 62 E OF FODYVILLE
N .487 MI, N OF DUNCANNON ROAD
ROCKCASTLE CO LINE
N END BARNES MILL RD INTERCHANGE
KY 21 INTERCHANGE NEAR REREA
0.098 MI N
EXTENDING NE ALONG W SIDE OF RAMP B
S END BANKSMILL RD INTERCHANGE
NS END US25 INTERCHANGE
0.136 MI NW OF BEGINNING
1.0 MI, N OF MCL OF RICHMOND
EXTENDING N 0.592 MI
E OF SLYERSVILLE NEAR KY 114
US 62 S OF CULVERT CITY
JCT WITH PROPOSED I24 S OF CULVERT PROP .2MI W OF JACKSON SCHOOL ROAD
ANDERSON CO LINE
ANDERSON CO LINE
APP .2 MI, W OF BATH CO LINE
APP .446 MI E OF BEGINNING
700 FT W US60
US60 600 FT N BRIDGE 164
180 FT R 164 STA 1045600
180 FT L 164 STA 952600
180 FT L 164 STA 879600
JCT PROUITT RD
CLARK CO LINE
1180350 10.2 MI S OF SCL OF WILLIAMSBURG
1180350 H0.9 MI NW US 25 NEAR SAXTON
1180350 G4.070 MI N TENNESSEE STATE LINE
1180350 F4.070 MI N TENNESSEE STATE LINE
1180350 ERIVER RD NEAR END FRONTAGE RD 7
1180350 DUS 25 W SIDE OF 175
1180350 CKY 471 W SIDE OF 175
1180350 RJCT KY 471 W SIDE OF 175
1180350 A4.070 MI N TENNESSEE STATE LINE
1190603EAMOUNTAIN PKWY SE
1190603E0.7 MI NW OF CAMPTON
1190603EAPowell CO LINE
1200775CBANDERSON CO LINE
1200775CAANDERSON CO LINE

4.07 MI N OF TENNESSEE STATE LINE
0.701 MI NW OF BEGINNING
0.6 NW BRG WOLF CREEK RD PLEASANT VW
TENNESSEE STATE LINE
0.16 MI N OF BEGINNING
RIVER RD 0.79 MI N OF BEGINNING
0.205 MI N
0.13 MI N OF TENNESSEE STATE LINE
TENNESSEE STATE LINE
310 FT NW OF OLD KY 15
MORGAN CO LINE
0.7 MI NW OF CAMPTON
JCT US 60 2.0 MI E OF VERSAILLES
JCT US 60 1.6 MI E OF VERSAILLES
## APPENDIX IV

### MILEAGE DATA ATTRIBUTES

<table>
<thead>
<tr>
<th>COLUMN</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Card Number</td>
</tr>
<tr>
<td>2-4</td>
<td>County Number</td>
</tr>
<tr>
<td>5-8</td>
<td>Control Section Number</td>
</tr>
<tr>
<td>9-10</td>
<td>Subsection Letter</td>
</tr>
<tr>
<td>11-12</td>
<td>Control Serial Number</td>
</tr>
<tr>
<td>13-16</td>
<td>Section Length</td>
</tr>
<tr>
<td>17-20</td>
<td>System</td>
</tr>
<tr>
<td>17</td>
<td>Mileage Classification</td>
</tr>
<tr>
<td>18</td>
<td>Designated System</td>
</tr>
<tr>
<td>19</td>
<td>Subsystem</td>
</tr>
<tr>
<td>20</td>
<td>Traveled Way System</td>
</tr>
<tr>
<td>21-25</td>
<td>Surface Type</td>
</tr>
<tr>
<td>21-22</td>
<td>Roadway 1</td>
</tr>
<tr>
<td>23-24</td>
<td>Roadway 2</td>
</tr>
<tr>
<td>25</td>
<td>Type Groups</td>
</tr>
<tr>
<td>26-30</td>
<td>Pavement Width</td>
</tr>
<tr>
<td>26-27</td>
<td>Roadway 1</td>
</tr>
<tr>
<td>28-29</td>
<td>Roadway 2</td>
</tr>
<tr>
<td>30</td>
<td>Width Group</td>
</tr>
<tr>
<td>31-33</td>
<td>Median Strip Width</td>
</tr>
<tr>
<td>33</td>
<td>Number of Traffic Lanes</td>
</tr>
<tr>
<td>34</td>
<td>Access Control</td>
</tr>
<tr>
<td>35-38</td>
<td>Federal Aid Number</td>
</tr>
<tr>
<td>39-43</td>
<td>Route Number</td>
</tr>
<tr>
<td>39</td>
<td>Identification of Route</td>
</tr>
<tr>
<td>44-47</td>
<td>Acceptance Date</td>
</tr>
<tr>
<td>48-49</td>
<td>Current Year</td>
</tr>
<tr>
<td>50-56</td>
<td>Traffic</td>
</tr>
<tr>
<td>50-54</td>
<td>Average Daily Traffic</td>
</tr>
<tr>
<td>55-56</td>
<td>Traffic Groups</td>
</tr>
<tr>
<td>57-62</td>
<td>Vehicle Miles</td>
</tr>
<tr>
<td>63</td>
<td>Traveled Way System Group</td>
</tr>
<tr>
<td>64</td>
<td>Rural-Urban Group</td>
</tr>
<tr>
<td>65</td>
<td>Rural-Municipal Group</td>
</tr>
<tr>
<td>66</td>
<td>State Maintained</td>
</tr>
<tr>
<td>67</td>
<td>Lane Classification Groups</td>
</tr>
</tbody>
</table>
The generally accepted definition of annual highway costs contains factors for initial construction, maintenance, periodic resurfacing, overhead, and interest on initial expenditures. Annual cost factors have been combined in various equations so that annual road cost per mile (km) can be estimated.

One of the first equations was suggested by Agg (18) in 1929:

\[ C = r \left\{ \frac{A + B}{r} + \frac{E}{(1 + r)^n - 1} + \frac{E_1}{(1 + r)^{n_1} - 1} + \ldots \right\} \]

where \( C \) = total average annual road cost per mile,
\( A \) = construction cost per mile,
\( B \) = yearly maintenance cost (every year) per mile,
\( E \) (or \( E_1 \)) = expenditures per mile for periodic maintenance every \( n \) (or \( n_1 \)) years (replacement is an E-value), and
\( r \) = rate of interest in current financing.

In 1934, Johannesson (19) simplified Agg's equation by introducing a constant

\[ K = \frac{r}{(1 + r)^n - 1} \]

as the multiplying factor for the E's in Agg's equation. Breed (2), also in 1934, introduced an approximate equation:

\[ C = \frac{(A + S)r}{2} + \frac{(A - S)}{n} B + E/n. \]

Breed introduced the term \( S \) for the estimated salvage value of the highway at the end of \( n \) years.

Bateman (20), in 1948, offered this equation:

\[ C_h = \frac{r}{l} + B + A_1 + A_2 + D \]

where \( C_h \) = annual cost of highway operation,
\( l \) = value of highway or investment,
\( A_1 \) and \( A_2 \) = annuities for periodic maintenance required at intervals for several years, and
\( D \) = annual cost of administration.

The annuities can be expressed in terms of actual expenditures by

\[ A_1 = \frac{E_1 r}{(1 + r)^{n_2} - 1} \]

and

\[ A_2 = \frac{E_2 r}{(1 + r)^{n_2} - 1} \]

where \( E_1 \) = expenditure for periodic maintenance occurring every \( n_1 \) years and \( E_2 \) = expenditure for periodic maintenance occurring every \( n_2 \) years.

In 1963, Buldock (21) suggested the following equation:

\[ C = CRF \{ A + E_1 PWF_{n_1} + E_2 PWF_{n_2} + \frac{1 - (Y/X)}{I(F_1 or E_2/PWF_{n_1})} + M + O + D \}

where \( C \) = total annual cost per mile (1.61 km),
\( CRF = \frac{r}{(1 + r)^n - 1} \) = capital recovery factor,
\( n \) = analysis period (years),
\( A \) = total construction and right-of-way cost per mile (1.61 km),
\( E_1 \) = first resurfacing cost per mile (1.61 km),
\( E_2 \) = second resurfacing cost per mile (1.61 km),
\( n_1 \) = number of years after construction that future work is performed,
\( Y \) = number of years from last resurfacing and end of analysis period,
\( X \) = estimated life (years) of last resurfacing,
\( M \) = total annual maintenance cost per mile (1.61 km),
\( O \) = annual operation cost per mile (1.61 km),
\( D \) = annual administrative and overhead cost per mile (1.61 km), and
\( PWF = \) present worth factor, single payment, defined as \( 1/(1 + r)^n \).

A comprehensive relationship was offered in 1969 by Winfrey (22):

\[ C_T = H \cdot U \]

38
where \( C_T \) = total annual economic cost of highway transportation,
\( H \) = total annual economic cost of the highway facility, and
\( U \) = total annual economic cost to the road user.

The term for the cost of the highway facility can be expanded to introduce the following:

\[
H = -I_a - D - O - M
\]

where \( I_a \) = annual uniform capital cost of depreciation (return of capital) and vestcharge (return on capital),
\( D \) = annual administrative expense allocable to the highway or facility,
\( O \) = annual operating expense for traffic services, highway operations, and police services allocable to the highway of facility, and
\( M \) = annual maintenance expense for the physical components of the highway or facility.

The depreciation cost can be further expanded to

\[
I_a = (-I + S)(CRF - r - n) \cdot iS
\]

\[
I_a = -I(CRF - r - n) + S(SF - r - n)
\]

where \( I \) = initial investment or construction outlay or the equivalent present worth of the initial investment plus subsequent investments,
\( S \) = estimated terminal value at the end of \( n \) years,
\( r \) = rate per year of vestcharge,
\( n \) = analysis period (years) or service life,
\( CRF \) = capital recovery factor, and
\( SF \) = sinking fund factor, \( i/[1 + (1 + i)^n] - 1 \).

This equation may be modified to account for additional investments due to reconstruction or resurfacing in the following manner:

\[
I_a = -I_0 (CRF - r - n) + S(SF - r - n)
\]

\[
I_a = I_x(PWF - r - x)(CRF - r - n)
\]

where \( I_0 \) = initial investment at zero time,
\( S \) = terminal value from \( I_0 \) and \( I_x \) combined,
\( I_x \) = additional investment at age \( x \), and
\( PWF \) = single-sum present worth factor.

The final equation for the economic cost of highway transportation becomes

\[
C_T = -I(CRF - r - n) + S(SF - r - n) - K - G_K(GUS - r - n) - U(EUS - r - n)
\]

where \( K \) = \( D + O + M \) (combined for convenience),
\( GUS \) = equivalent uniform gradient factor = uniform period-end investment equivalent to the series of period-end increasing amounts,
\( EUS \) = equivalent uniform exponential increase factor = product of \( CRF \) and \( PWF \), and
\( G_K \) = gradient increase per year.

Winfrey and Zellner (23) summarized these relationships for the annual cost of transportation in the following manner:

\[
TAC = ACC + AUC + AMC
\]

in which \( TAC \) = total annual transportation cost (\$),
\( ACC \) = annual highway capital cost (\$),
\( AUC \) = annual road-user time and running costs (\$), and
\( AMC \) = annual highway maintenance cost (\$).

Moyer and Lampe (6) used Baldock’s equation to study annual costs of flexible and rigid pavements of highways in California. Annual maintenance costs were found to range between $320 and $520 per mile ($198 and $323 per kilometer).

A detailed study of costs for both flexible and rigid pavements was completed recently by the Road Research Laboratory (25). Construction and maintenance costs were estimated from current contract costs and extrapolated to cover a period of 50 years. Cost factors were developed for a one-inch (2.5-cm) depth of pavement per one square yard (0.84 m²) of roadway surface. Four different structural designs for the two pavement types were standardized for use in the study. The classical engineering cost estimate was used as the basis for the study.

Methods of computing highway costs have been reviewed above. They range from relatively simple methods to the sophisticated method of Winfrey and Zellner (23). Cost components generally considered in the annual cost equations are:

a. initial construction costs,
b. maintenance costs,
c. surfacing and resurfacing (periodic only) costs,
d. overhead costs, and
Baldock extended the equations, using the capital recovery factor and present worth factor, to account for the value of the road over a specific period. In addition, the annual operating cost was considered. Breed also took into account the salvage value at the time of reconstruction. Winfrey's equation is probably the most inclusive and attempts to account for all reasonably relevant factors.

Annual maintenance cost is a relatively small part of the total annual cost of the highway facility. Moyer and Lampe indicated that California's average annual maintenance costs amounted to only 3 to 5 percent of the total annual pavement cost. This cost, though being small, is continuing and must be taken into consideration when determining annual road costs.

The service life of pavements must be considered properly to perform an annual cost analysis. The Federal Highway Administration statistically classifies pavements as being retired when they are resurfaced, reconstructed, abandoned, or transferred from one system to another. Baldock (21) indicated that the average life of a high-type bituminous concrete pavement was 16.8 years and for portland cement concrete pavement was 25.5 years. There is, however, a great difference in opinion on the service life because of the high variance in the resurfacing cycle and the definitions of service life and retirement used.

An average pavement life of 16 years for bituminous concrete and 25 years for portland cement concrete might seem reasonable to some but not to others. A pavement should not be "retired" before or after resurfacing; it has a residual value.