A COMPARATIVE ANALYSIS OF THE ECONOMIC DESIRABILITY OF ASPHALTIC CONCRETE AND PORTLAND CEMENT FOR HIGHWAY CONSTRUCTION

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PREFACE

The relative desirability of Portland Cement and asphaltic concrete as highway surfacing materials is a subject that produces violent arguments, but one on which there is little useful information. The experienced engineer, familiar with the intricacies of highway construction and design, has little factual information at his disposal which is really useful in deciding between the two materials in a given situation and, therefore, must rely, to a great extent, on his subjective evaluation. The taxpayer, having little or no appreciation of the various factors affecting the performance of the two materials, while he must pay for these roads, has not even sufficient information at his disposal to make an educated guess regarding the relative desirability of asphaltic concrete and Portland Cement.

Before a decision can be made relative to a surface material on a given project, it is necessary to examine all the factors which will affect the road and to coordinate all the efforts which have been directed towards determination of the magnitude of their effects. In order to do this, it would be necessary to review many different reports and theories. The purpose of this study is to show, in one paper, the effects of the various factors such as traffic, maintenance, and construction costs on the Oklahoma test road to expose the area where further experimental research is necessary and discuss what is being done in this area, and finally to reduce factors of consideration to a minimum and submit for consideration a guide for decision making relative to these two materials.

Appreciation is expressed to the Ideal Cement Company, whose financial assistance made this work possible. Also, indebtedness is acknowledged to Dr. Paul E. Torgersen, Professor Phillip Manke, and Professor H. G. Thuesen for their valuable guidance and advice; and to the following for the loan of reports and papers, and the gift of experience and advice which made this study possible: The Oklahoma Highway Department; The Highway Research Board of the National Academy of Science; the National Bureau of Public Roads; and the Kansas State Highway Department. In particular, credit goes to Mr. B. H. Myers, Office of Information and Statistics, Oklahoma State Highway Department, who spent considerable time and effort in locating information, no matter how difficult to find, which would be helpful in this work.

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INTRODUCTION

History of the Oklahoma Test Road

In May of 1953, the 24th Legislature of the State of Oklahoma passed House Joint Resolution 536, authored by Collins and Long of Seminole. This Resolution authorized and instructed the Oklahoma Highway Commission to "conduct adequate and conclusive tests of Portland Cement and asphaltic concrete pavement on an approximate four-mile section on one of Oklahoma's heavily traveled roads." (1). The reasons underlying the initiation of this Resolution were described in House Joint Resolution 536 as follows:

1. The Legislature felt that a review of the paving materials being commonly used on Oklahoma roads was in order, due to the expectation of enlarged highway programs in the future.
2. There were doubts in the minds of individual Legislators as to the feasibility of continued use of asphaltic concrete as a paving material, due to the fear that excessive maintenance costs on this type of paving would

seriously reduce the amount of money available for the construction of new roads in the future.

3. That the people of the State of Oklahoma needed reassurance that everything was being done to insure that the roads being built were the best obtainable and incorporated the most desirable paving materials from the viewpoint of the maximum miles of good road for each dollar spent in the highway program.

In order that these issues should be resolved, House Joint Resolution 536 instructed the Oklahoma State Highway Commission to:

1. Lay a test road consisting of Portland Cement and asphaltic concrete paving. Each material was to be used in approximately four miles of paving and the two materials were to be layed in parallel sections in order that each would be subjected to the same soil and traffic conditions.
2. Maintain detailed information concerning the costs incurred relative to each type of paving material "so as to determine the durability, lasting qualities, first costs, and surface maintenance costs under truck and auto traffic." (1).
3. Bring the location and purpose of this project

into public view by the erection of appropriate signs at the test location and the release of progress reports to the press.

4. Make periodic reports to the Legislature and to a Citizens Committee, whose membership was outlined in House Joint Resolution 536, as to the progress and results of this test road. (1).

In addition to these requirements stipulated by the Legislature, it was decided, by the Highway Commission, to review all plans and specifications with, and solicit advice and consultation from, The Portland Cement Association and The Asphalt Institute relative to their area of interest.

These instructions have long since been carried out and the Oklahoma test road has been open to traffic and observation since January 15, 1955. Obviously, the results are not all in since, at this time, both sections of paving are serviceable links in heavily traveled highways, but sufficient information is available to point the way to some interesting observations concerning the relative desirability of the two major paving surfaces used in our time.

Scope and Objectives of This Study

The objective of this study is to analyze the Oklahoma test road from an economic standpoint, from its inception to the present, and draw such conclusions as are justified by a test of this duration. In addition, the various possible outcomes of this road test will be evaluated and a set of rules will be presented which may be generally useful in deciding between the two surfacing materials in a given situation. These rules may be useful in supplementing or replacing those used by various states at the present, since they are more specific than the "rules of thumb" now prevalently used, and incorporate the effects of the time value of money and present worth, as explained by Thuesen (2), and inflation as well as the relative service life of the surfaces.

Another area of interest which will be discussed is a comparison and critical evaluation, to such a degree as possible, of the results of several other projects of a related nature which either have been or are being conducted in the United States. In this regard, an accelerated life testing experiment carried on by the National Academy of Science, Washington, D.C., and sponsored by the American Association of State Highway Officials, which has recently been completed in Illinois, will be examined. This test effort will, henceforth, be referred to as the AASHO road.

Finally, a brief discussion of the more intangible variables, such as safety and ease of travel, which have bearing on the desirability of various paving materials will be presented in regard to Portland Cement and asphaltic concrete.

It is hoped that an unbiased comparison, emphasizing, impartially, the relative merits of both types of surfacing materials will be effected, and that this comparison will then prove instructive to the many persons interested in this matter from a personal, practical or academic point of view, thus making a significant contribution to the store of information available regarding Portland Cement and asphaltic concrete as highway paving materials.

Justification of the Study

It is felt that a study of the Oklahoma Test Road and other similar projects is justified for several reasons. The primary reasons are:

1. There is need for an objective summary and evaluation of the Oklahoma Test Road and incorporation of the results of other studies in this area in order to fill an existing informational vacuum.
2. To aid in satisfying the curiosity of the people of the State of Oklahoma concerning the relative merits of the two surfaces. That this curiosity exists is evidenced by the fact that, according to Highway Department officials, the single question most frequently asked by the public, at the exhibits, lectures, etc., sponsored by the Department, is "which surface provides the best and most economical

road in the long run, asphalt or Portland Cement." (3).

3. There is a need for the establishment of decision criteria relative to the two surfacing materials which have been objectively arrived at and are based on consideration of the several variables pertinent to the relative desirability of Portland Cement or asphaltic concrete in a given situation.

Creditation of Information Sources

The information contained herein was obtained primarily from a collection of reports, bulletins, and communiques concerning the Oklahoma test road, which were provided by the Oklahoma Department of Highways, Frank D. Lyons, Director; the Highway Departments of Texas, Arkansas, and Kansas, and the official reports on the AASHO test road, which were published by the National Academy of Sciences - National Research Council.

CHAPTER II

DESCRIPTION OF RELATED RESEARCH EFFORTS IN HIGHWAY PAVING

While there are, and have been, many testing efforts being conducted, and already completed, in the United States in an attempt to clearly define the desirability of asphaltic concrete versus Portland Cement paving, only two of these projects have been chosen for discussion at this time. These two are (1) a field test project, analogous to the Oklahoma test, sponsored by and constructed in the State of Indiana, and (2) a detailed destructive testing effort carried on under the auspices of the Highway Research Division of the Academy of Science, Washington, D.C., and sponsored by the American Association of State Highway officials. These two projects were chosen for review because they represent the primary types of research being carried on at the present time in this area.

The Indiana test road is a similar effort to the Oklahoma test road in that it also is a field test of the two surfaces under normal design practice and regular traffic conditions. It is an effort to compare the two surfaces incorporating the actual climatic and traffic conditions of a particular locale. It is in this type of testing that the most information concerning the relative durability of each material under actual conditions is to be found. Unfortunately, field testing of asphaltic concrete and Portland Cement has become popular so recently that there are no significant results apparent at this time in regard to the actual life of either surface. It is encouraging, however, to note that while the results of this type of effort are primarily of regional interest, the fact that it is being carried on, in other than the Oklahoma area, points out the consideration of the worth of field projects which is given them by the country as a whole. The actual results of this project are, like the Oklahoma test project, only partially in and are of limited interest in this study due to the regional restrictions mentioned above. For this reason, no further reference is made to the Indiana test effort.

The AASHO test road, on the other hand, typifies (and is) the most advanced example of the type of basic research conducted under artificially established usage conditions. The results of this type of testing are universal in interest in that at least certain of the factors involved apply to all paving, regardless of location.

This experiment was carried out under the more sophisticated principles of factorial design, incorporating careful replication, and an extremely detailed analysis of many variables and effects was made. The experiment was designed to show, among other things, the effect of different designs and wheel loads on the serviceability of both flexible and rigid type pavements. (4) From these results, it can be seen under what designs and wheel loads each type of paving is completely unsuitable from a service standpoint. Cost, however, was not a primary factor of interest in this experiment and, as a result, the conclusions per se are of limited interest to anyone not involved in the more technical aspect of highway construction.

The AASHO road was a combination of six paving loops which were each divided into sections and different design characteristics (surface depth, sub-base depth, etc.) were incorporated into each section. At completion of construction, certain wheel loads (representative of those found in practice by and confined to a constant load on each lane of each loop) were applied by driving vehicles of these loads around the loops repeatedly. In all, a total accumulation of 1,114,000 axle load applications (the measurement criteria used) was attained during the test and this represented over 17 million miles of driving. In order to measure the serviceability of the sections, a serviceability index was established (along with appropriate rating procedures) which used as a criteria the ability of a section to serve public needs. This index and the accompanying rating procedures were developed by agreement of a large number of highway experts. This index was based on a combination of many factors which affect the evaluation of the conditions of a roadway. The scale used ran from a minimum of zero to an ideal of five. It was determined then that a new, well built road (such as the two surfaces of the Oklahoma test road) rated approximately 4.5 on the serviceability index. It was also generally agreed that at a serviceability index rating of 2.5, most states would (according to normal practice and expected continued use of the road) consider resurfacing of the roadway desirable. (4).

Many other variables and effects were, of course, measured during this test, but the above service ratings of each of the sections (made at two-week intervals) and the loads applied were considered, after a thorough study of the official AASHO reports, to have the most bearing and applicability to a study of the Oklahoma test road. A major restriction applying to the direct projection of the AASHO serviceability results on the Oklahoma test road was found to be the fact that, due to the relatively short time during which the AASHO experiment was operative, certain important variables, affecting the actual service life of a road in normal use, were held to be insignificant. One of the most important of these is weather and the resulting wear due to erosion, etc. It was, therefore, found that when an attempt was made to project, from the AASHO findings, the road life of the two surfaces on the Oklahoma test road, there was no correlation between these predictions and the experiences of the Oklahoma Highway Department in the past. This finding was substantiated by an evaluation study of the AASHO results which was recently completed by the Oklahoma Highway Department.

It is because of these difficulties, inherent in an accelerated testing program, that field testing is of such importance, both for its own sake and as a means of providing adequate information with which to qualify the results of projects like the AASHO road.

CHAPTER III

DESIGN OF THE OKLAHOMA TEST ROAD

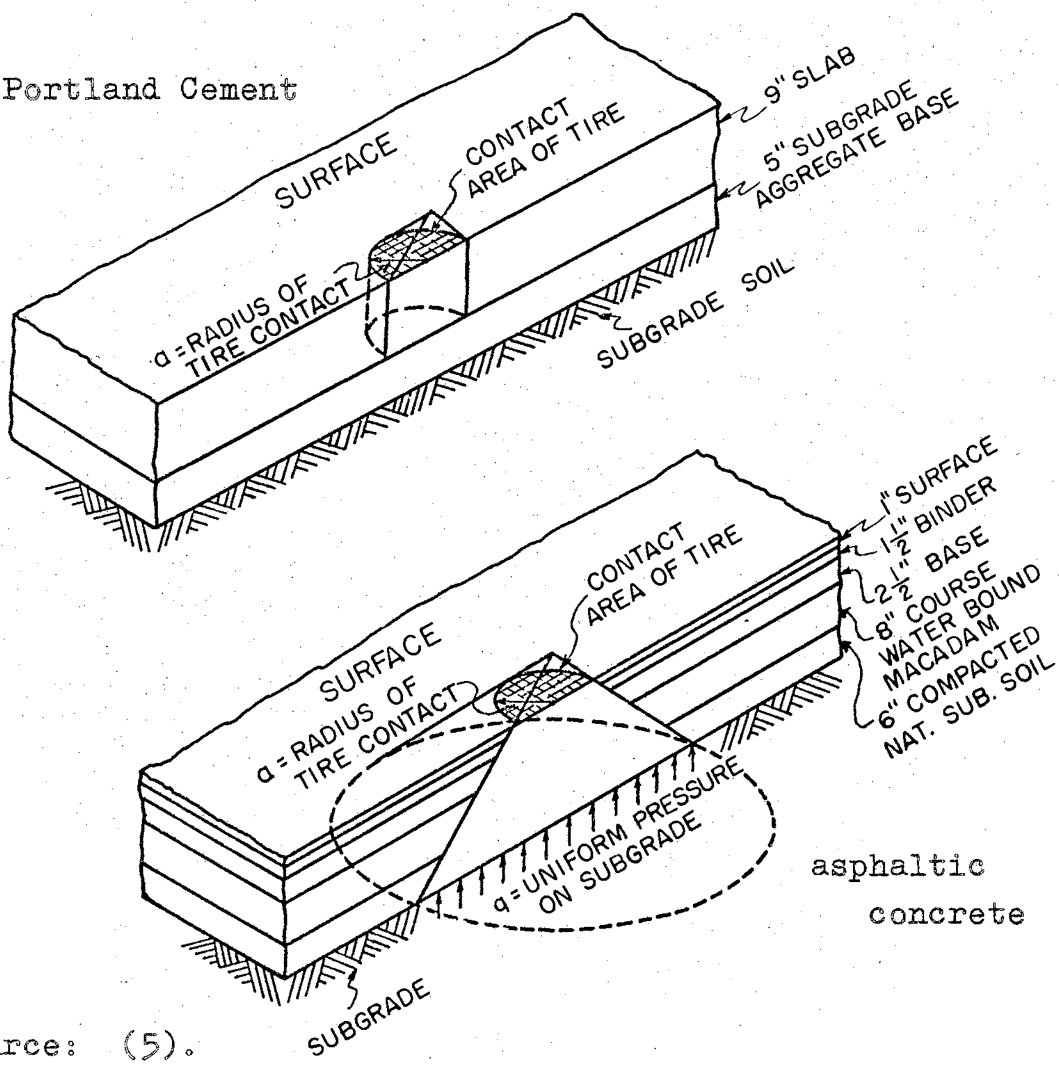
A Preliminary Discussion of the General Characteristics of the Two Surfaces

One of the major difficulties encountered in an attempt to directly compare Portland Cement and asphaltic concrete as paving surfaces stems from the inherent difference in the design concepts and strength characteristics between the two surfacing materials. These inherent differences introduce many extra variables which tend to restrict the validity of generalizations about the desirability of either. Some of these variables will be pointed out in this discussion.

The first basic difference between Portland Cement and asphaltic concrete is that Portland Cement is a rigid surface paving material, while asphaltic concrete is a flexible surface paving material. The effect of this difference is that, in Portland Cement paving, the cement slab carries the entire applied load as well as providing the riding surface of the highway, while asphaltic concrete provides only the riding surface and moisture protection as the applied load is distributed through and carried by the sub-base soil. In Portland Cement paving, the sub-base primarily provides only a means of giving the cement slab a uniform resting place. This, of course, means that, for a given load, the sub-soil conditions and availability of proper sub-base materials are major design considerations in regard to asphaltic concrete. In Portland Cement paving, on the other hand, while the sub-base is still important, as a strength (and cost) factor, is is secondary to the thickness of the cement slab. (It should be pointed out, at this point, that both types of paving can be designed to adequately carry any given wheel load.) In order to better show the difference in design and method of load support, the following typical sections are displayed with approximate load distributions superimposed on them.

These sections should illustrate the fact that the first costs of Portland Cement paving are dependent primarily upon the design load; the first costs of asphaltic concrete are dependent on the design load (designates depth of sub-grade preparation), and on the availability of adequate quantities of sub-grade materials. It is for this reason that, in the case of extremely high loading or especially impact loading, the depth of asphaltic concrete sub-grade preparation required would raise the first cost to a point equal to or exceeding that of Portland Cement. In these cases, there is no doubt as to which material is the most desirable. The loads encountered in highway design, however, are not of this magnitude and, therefore, the desirability question is not so clear.

Portland Cement



asphaltic concrete

Source: (5).

Figure 1. Typical Designs for Asphalt and Portland Cement Paving

In summary, it can be said that there is no question about the fact that maintenance costs on asphaltic concrete exceed that of Portland Cement. The question is this: Under normal highway usage conditions, do the combined first costs and maintenance costs of asphaltic concrete exceed that of Portland Cement prior to the time that the Portland Cement surface requires resurfacing. This control point, the resurfacing of the Portland Cement, was chosen for this study for several reasons. The first reason being that when an overlay is put on a Portland Cement highway section it is common practice to use asphaltic concrete for this overlay. The second reason for using the original Portland Cement surface as a "control" is that, it is also common practice to consider all maintenance costs from this time on as being maintenance on an asphalt road. The third reason is that the author was advised by Phillip Manke, Professor of Civil Engineering at Oklahoma State University, that the road obtained under this practice was, to all intents and purposes, entirely new and distinct from either of the original two roads and that further maintenance could be justifiably credited to asphalt since this additional maintenance was primarily made up of riding surface repair and the riding surface is now asphaltic concrete.

With the above characteristic differences and assumptions in mind, one can now examine the Oklahoma test road and attempt to project the cost picture on this road to the control point, the resurfacing of the Portland Cement section.

The Roadway Design of the Oklahoma Test Road

As previously mentioned, the design and construction of the two paving sections were of the standard type generally authorized by the Oklahoma Department of Highways, but with the additional feature that the services and advice of the engineers and laboratory and field testing facilities of The Portland Cement Association and The Asphalt Institute were solicited in an effort to obtain the best sections of the two surfaces possible at the time. Each of the respective interests involved were invited to recommend changes in the roadway design and to join in the inspection of the construction of the roadways. With only one exception, the changes requested by the two associations were incorporated in the final design. This one exception concerned a recommended compaction of the road bed embankments on the asphalt sections to 100% of Standard Proctor Density. This was recommended by the Asphalt Institute. After investigation by the State Highway Department and with the concurrence of the Bureau of Public Roads, it was decided that a compaction of 95% of Standard Proctor Density should be used. This was, however, an increase of 5% over the 90% compaction level normally used on asphalt construction at that time. (6).

The general design features and location of the test road are as follows:

> The Oklahoma test road is a four-lane divided highway with dual 24 foot wide pavements and a 30

foot wide center median strip. The outer road shoulders are 10 feet in width. The maximum gradient is approximately 3.0% and the maximum curvature is 2 degrees. Horizontal sight distance is unrestricted. The test roadway was divided into a checker board with the south half of the project on the west side (south bound traffic) and the north half on the east side (north bound traffic) being surfaced with Portland Cement concrete pavement. The alternate sections (south half, east and north half, west) were surfaced with asphaltic concrete. This layout will make possible effectively identical traffic conditions on each surface material.

The site selected for the test road was on U.S. Highway 77 (now part of Interstate Highway 35) immediately north of Oklahoma City, Oklahoma, and extending approximately 4 miles north. (6).

Figure 2 is a reprint from press release by the Oklahoma State Highway Department showing the sections surfaced with each material and a typical paving section. This section shows the essential differences in construction between the two surfacing materials as well as the test layout.

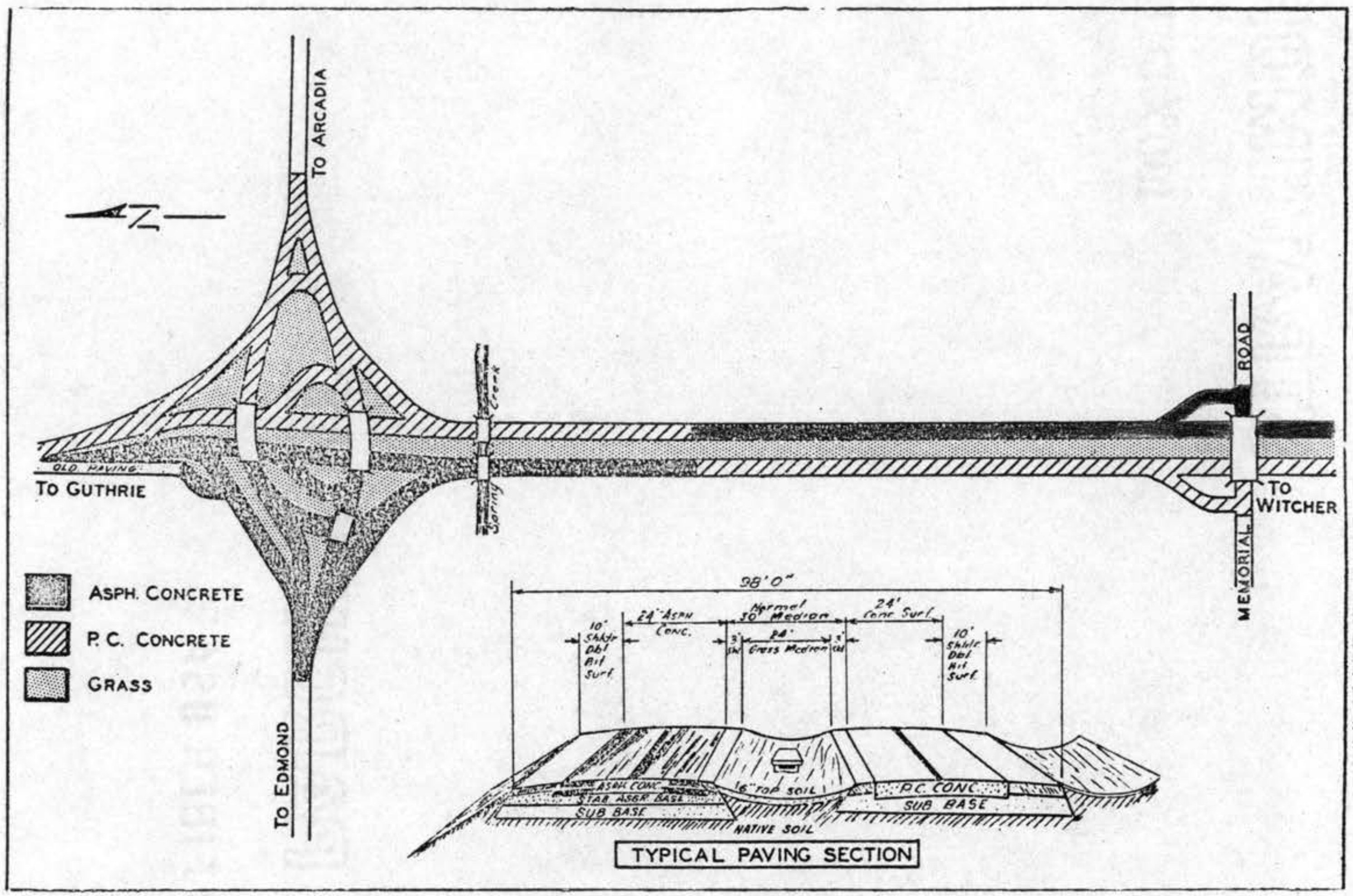


Figure 2. Typical Paving Sections and the Layout of the Oklahoma Test Road

CHAPTER IV

ANALYSIS OF PAST TRAFFIC DATA AND PROJECTION OF PROBABLE FUTURE CONDITIONS

The traffic conditions experienced on any highway are, of course, among the most important factors affecting the service life of the road. In addition, it is generally accepted that, especially in the case of extreme conditions, the load and frequency of the traffic has a direct bearing on the desirability of the road surfacing material. Certain criteria will be advanced in the conclusion of this dissertation which may be used to define these extreme conditions. It is the purpose of this section to discuss the actual traffic conditions experienced on the Oklahoma test road, project these experiences into the future, and, therefore, to provide information pertinent to the economic analysis of the test road which follows.

The calculations found in this section are based on the results of the permanent traffic recorder placed on the test road and manual spot traffic checks made periodically by the Oklahoma Highway Department. This information is published annually and the traffic information on the Oklahoma test road has been displayed in four annual reports for the years 1957, 1959, 1960, 1961. (7). A statistical regression analysis was run on this data and the projections of future traffic conditions indicated by this analysis are displayed in Table I, which follows the plotted raw data shown in Figure 3.

The linear regression equation was determined to be of the form $y = a + bx$ where y = the average number of vehicles per day and x = the time in months since the opening of the test road (assumed for this analysis to be January 31, 1955).

Solving the equations:

$$a = \frac{\Sigma x^2 \ \Sigma y - \Sigma x \ \Sigma xy}{n\Sigma x^2 - (\Sigma x)^2} \cong 742$$

$$b = \frac{n\Sigma xy - \Sigma x \ \Sigma y}{n\Sigma x^2 - (\Sigma x)^2} \cong 25.4$$

$$\rho = \frac{\Sigma xy}{\sqrt{\Sigma x^2 \ \Sigma y^2}} \cong .8691$$

where:

Σx = 2712

Σy = 133,190

n = 48

Σx^2 = 2,113,253

Σy^2 = 3,818,611,880

Σxy = 78,076,690

$(\Sigma x)^2$ = 7,354,944

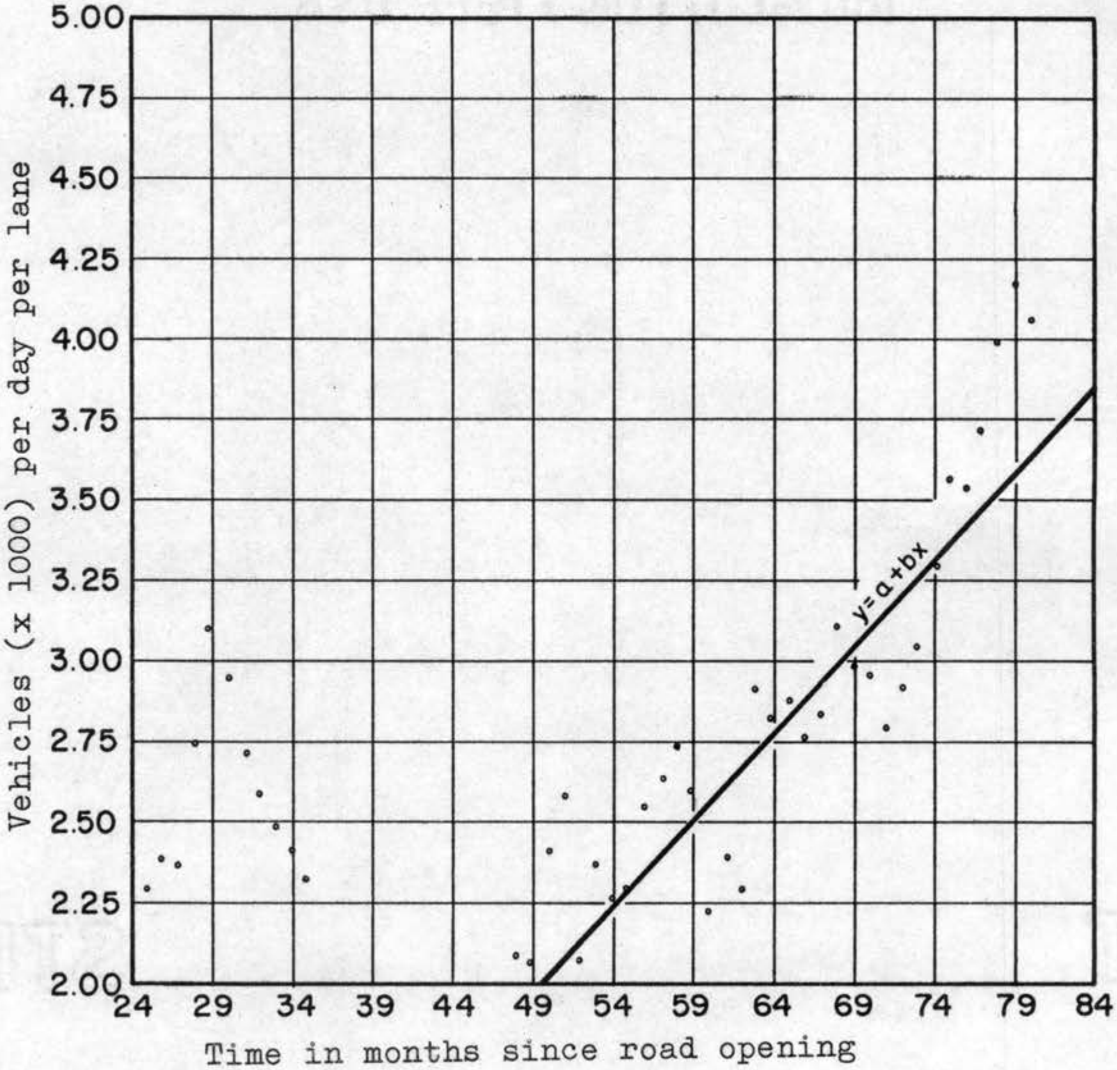


Figure 3. Graph of Traffic History on the Oklahoma Test Road

TABLE I

PAST AND PROJECTED FUTURE TRAFFIC FREQUENCY ON THE OKLAHOMA TEST ROAD

	Average number of vehicles by type/day/direction							
			Single unit trucks			Trk-Trctr-Semi		
	Pssngr	Light/ Trks.	2 Axle- 4 Tr.	2 Axle- 6 Tr.	3 Axle	3 Axle	4 Axle	Full/ Trailer
Year	76.23%	7.29%	1.3%	5.88%	0.27%	4.02%	4.63%	0.38%
1955*	1974	189	34	152	7	104	120	10
1956*	1903	182	33	147	7	100	116	10
1957*	2001	191	34	154	7	106	122	10
1958*	1860	178	32	144	6	98	113	9
1959*	1753	168	30	135	6	92	106	9
1960*	2153	206	37	166	8	114	131	11
1961*	2706	259	46	209	9	143	164	13
1962	2308	221	39	178	8	122	140	12
1963	2465	237	42	190	9	130	150	12
1964	2774	265	47	214	10	146	168	14
1965	3005	287	51	232	11	158	183	15
1966	3238	310	55	250	11	171	198	16
1967	3470	332	59	268	12	195	212	17
1968	3702	354	63	286	13	200	225	18
1969	3935	376	67	304	14	208	239	20
1970	4078	390	70	315	14	215	248	20
1971	4197	401	71	323	15	221	255	21
1972	4197	401	71	323	15	221	255	21
1973	4197	401	71	323	15	221	255	21
1974	4197	401	71	323	15	221	255	21
1975	4197	401	71	323	15	221	255	21

*Actual measured figures. (7).

$n\Sigma xy = 3,747,681,120$

$\Sigma x\Sigma y = 361,211,280$

$n\Sigma x^2 = 101,436,144$

$\Sigma x^2 \Sigma y = 281,464,167,070$

$\Sigma x \, \Sigma xy = 211,743,983,280$

The equation of the line was determined to be

$$y = 742 + 25.4x$$

and a correlation coefficient was found to be 0.8691. This indicates excellent correlation and would probably be even better if there were not present a cyclical effect within each year. This cyclical effect, which may be observed on the plot, is due to increased travel during the good weather period and a corresponding decrease during the winter months. While this effect tends to distort the calculated correlation, it is constant enough in magnitude to not have a disturbing influence in the long run. The regression line is superimposed on the traffic graph and extended past 1961 as an estimate of the future traffic conditions to which the road will be subjected. This increase in traffic load is not expected to diminish soon due to the periodic opening of new sections of Interstate Highway 35 (of which the Oklahoma test road is a part), which contributes an increase in traffic with each new section opened. This intermittent addition of more sources of traffic and increased incentive to use this particular route is, in itself, a source of some variability in the traffic pattern. As can be observed at the final period from which traffic data was available, a rapid increase is present. This increase is due to the fact that the last six months of actual data correspond to the summer and early fall of 1961 and also to the period after the addition of a critical section of Interstate 35 which effectively linked Kansas City, Missouri with Oklahoma City, Oklahoma (only about 35 miles was still uncompleted). This type of situation will not occur frequently, therefore, it is expected that a more stable pattern as well as a return to the analytical projections will continue. It is important to note that even small scale contributions to an increase in traffic will cease to come from this addition of segments of Interstate 35 as this roadway will be completed to Kansas City, Missouri, and far enough south of Oklahoma City to have little additional significance within the next several years. It is for this reason that an upper limit of 5500 vehicles per day (in each direction) has been placed on the traffic projections. This is somewhat higher than the 62.7% increase predicted by the Bureau of Public Roads for the next twenty years. (3). Other factors may alter this value, but in the light of present information, it is reasonable to use this value (expected to be reached in mid-1970 after approximately 15.5 years of service) for cost calculations. By the same token, the opening of the Oklahoma test road was accompanied by the opening of additional sections of Interstate 35 which, for some time, gave a somewhat stable influence to the traffic pattern of the road. This can be observed at the left edge of the graph and continues over into 1959. During this period, there was limited advantage to using the road and a more distinct seasonal influence is observed.

As much of a factor in determining road life as the frequency of traffic is the type of traffic. By type of traffic, the reference is to the size and weight of the traffic load. By manual sampling on the Oklahoma test road, the breakdown shown in Table II was obtained. (7).

TABLE II

TRAFFIC DISTRIBUTION ON THE OKLAHOMA TEST ROAD

Type Vehicle	Avg. wt.*/ vehicle	% of traffic
Passenger	4,000 lbs.	76.23
Lt. trailer comb. and single unit trucks (panels and pickups)	5,195 lbs.	7.29
Single unit trucks		
2 axle - 4 tired	6,797 lbs.	1.30
2 axle - 6 tired	11,165 lbs.	5.88
3 axle single unit	21,428 lbs.	0.27
Trk.-Trctr. and Semi's		
3 axle	25,157 lbs.	4.02
4 axle	36,214 lbs.	4.63
5 axle	--	--
Full trailer comb.	23,327 lbs.	0.38

*Excepting passenger cars, these weights are based on a ten year average of findings of loadometer studies by Oklahoma State Highway Department.

This concludes the discussion of present and probable future traffic conditions on the Oklahoma test road. The information contained herein will be referred to later when the economic structure of the test road is considered.

CHAPTER V

EVALUATION OF ACTUAL TEST ROAD EXPENDITURES FOR PERIOD THROUGH DECEMBER 31, 1961

Preliminary Discussion of Cost Classes

The costs which have been incurred in association with the Oklahoma test road can be subdivided into three major areas of interest. The first two of these areas are concerned with the initial construction of the road and are classified as:

1. Incidental construction. This class includes all construction required to ready the roadway for surfacing.
2. Paving items. This class includes all costs relative to the actual surfacing of the prepared roadway.

The third primary cost classification is, of course, maintenance of the road after it was approved by the State and was opened to traffic.

The cost class, incidental construction, was not considered as an item of 'first cost', as provided in the House Joint Resolution 536, by the State due to the fact that this is a cost common to any type of highway construction and is a function of the soil composition and condition rather than being a function of the surfacing material used. (6). This segregation of the 'incidental construction' costs, having been confirmed by several sources as legitimate in view of the purpose of the test project, has also been utilized in this report.

"1st" Costs

With the above reservations established, the initial construction cost of the surfacing of the Oklahoma test road is as follows:

Portland Cement Section. The contract for the construction of the Portland Cement segment of the Oklahoma test road was awarded to Dahlgreen and Brooks of Oklahoma City, Oklahoma, for a low bid of $444,602.31. This bid included incidental construction costs of $26,074.52. The actual, rather than estimated, cost of surfacing the cement segment was $419,510.60 (exclusive of incidental construction costs). (6).

In determining the cost of construction of both the Portland Cement and asphaltic concrete segments, it will be considered as standard practice to use actual cost figures. While there is some justification for the stand that the contract amount reflects the true cost to the State, since this is the amount paid, it is a justified conclusion that the actual construction cost is the best criteria for comparison of the two surface materials. It is felt that this is a more stable cost while the contract amount of the low bid reflects, in addition to the surface used, the good judgment of the estimator, the conditions of the economy and other variables which are of no concern in this comparison. It is fortunate, indeed, that no penalties or excessive weather conditions arose which would have tended to distort the actual cost picture. If these conditions had been present and not of a type to be segregated, then the argument for using estimated costs as more truly representative of average conditions would have had considerably more merit.

Asphaltic Concrete Section. The low bid estimate (accepted by State) on the asphaltic concrete segment of the test road was submitted by Metropolitan Paving Company, of Oklahoma City, Oklahoma, for the amount of $353,007.58 of which $30,849.65 was associated with incidental construction costs. The actual surfacing cost of the asphaltic concrete section was $316,043.19 (exclusive of incidental construction costs). (6).

Comparison of the "1st Costs"

From the above costs, it can be readily seen that the difference in "1st costs" between the two surfacing materials was $103,467.41 with the Portland Cement surface being the more expensive of the two.

While no breakdown of the actual costs incurred on this project is obtainable, and not really necessary, anyone interested in an approximate breakdown may refer to that included in the original estimates included in the accepted contracts. Reproductions of this information are included as Appendix A.

Maintenance Costs

The maintenance cost comparison is of particular interest due to the large amount of publicity accorded this class of costs, not only on the Oklahome test road, but on all types of construction using these two materials. This publicity, of course, has been fostered by the respective institutes. "1st costs" have also been publicized, but there is little doubt existing as to the fact that Portland Cement is usually more expensive to install under normal highway construction conditions. The real argument is whether there is sufficient difference in maintenance costs during the life of the roadways to justify (or necessitate) this added initial expense.

In the following summary of maintenance costs, it will be seen that the totals given below do not correspond exactly to those shown in the total expense breakdown (reproduced from Oklahoma State Highway Department releases and included as Appendix B). The reason for this deviation is that, in the opinion of experts in highway construction, certain of the costs shown in these releases do not reflect on the surface used, but on other factors of the environment. Included among these are (a) seeding, sodding, and planting, (b) all roadside repairs, (c) traffic services except traffic lines, (d) cleaning, repairing, and installing culverts. (3), (8). With these considered omissions, the maintenance cost breakdown for the years 1956-1961 is as follows in Table III.

TABLE III

MAINTENANCE HISTORY ON THE OKLAHOMA TEST ROAD

Year	Asphaltic Concrete	Portland Cement
1956	$ 185.31	$ 222.77
1957	1,742.79	771.17
1958	695.94	620.31
1959	1,602.03	1,623.11
1960	2,551.53	2,409.64
1961	51,726.21 (47,867.74 resurfaced)	2,992.30
Total	$ 58,503.81	$ 8,639.30
Total Less Resurfacing	$ 10,636.07	$ 8,639.30

Graphically, the combined "1st costs" and maintenance costs for the period 1956-1961 may be displayed as follows in Figure 4.

The following graph (Figure 4) shows reasonably well the cost picture that has been experienced on all highway comparisons except that it, like all other efforts in this area, does not go far enough. In the next chapter, the cost picture will be evaluated in the light of the possible number of asphaltic concrete resurfacings, which may be experienced prior to the time that the Portland Cement section requires resurfacing (the control point chosen for this study as explained previously). An analysis of these combined actual and projected costs will then be made on several time-value bases to show the relative effect, if any, of this consideration on the desirability of the two surfacing materials, Portland Cement and asphaltic concrete.

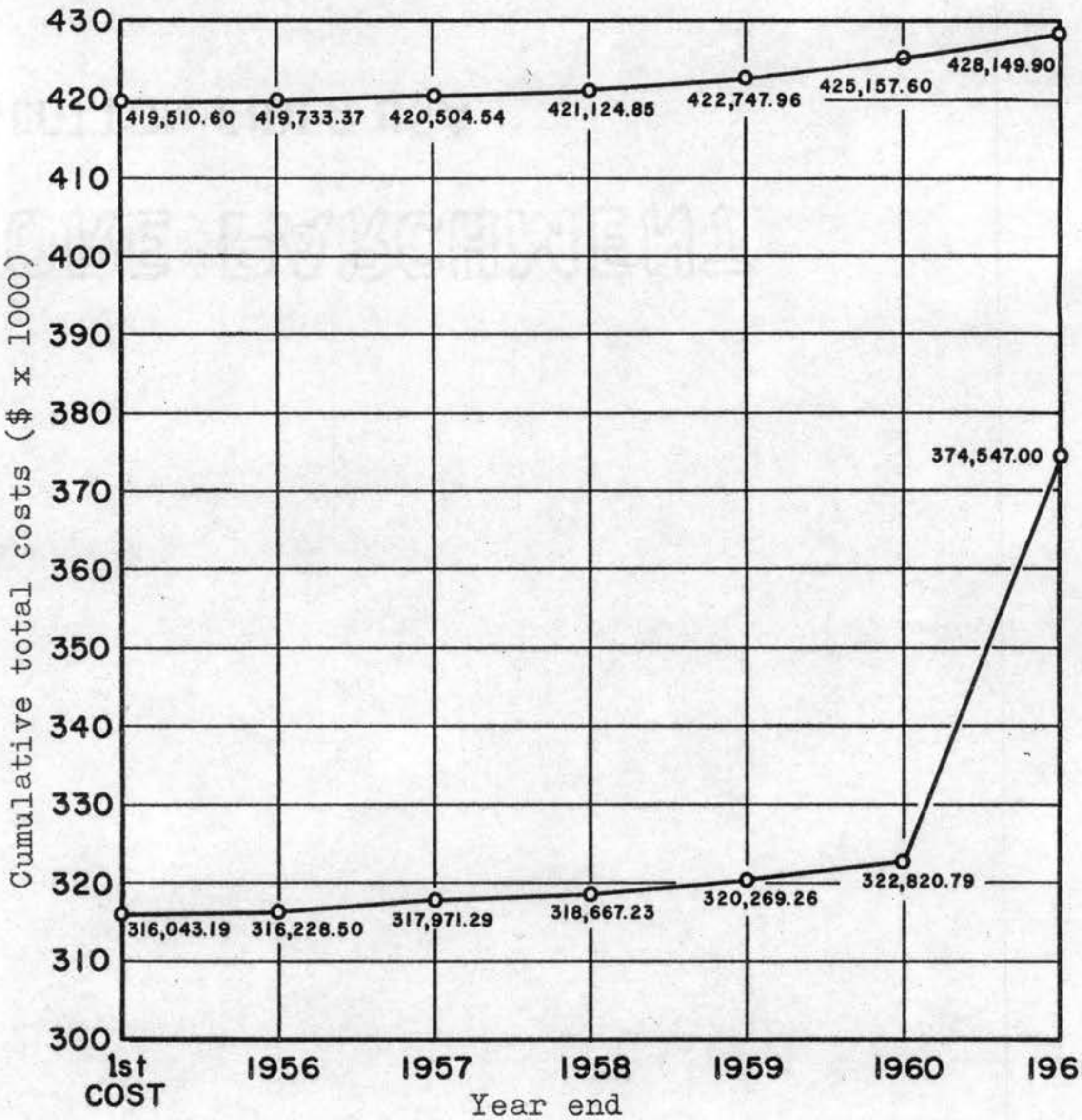


Figure 4. Cumulative Cost History on the Test Road

CHAPTER VI

EVALUATION OF THE RELATIVE COSTS TO BE EXPERIENCED UNDER VARIOUS PERFORMANCE RATIOS

Explanation of the Method of Comparison Used

The original intent of this study was to compare the actual experienced costs of the Oklahoma test road and then to estimate the end result of the test by applying these cost figures to projections of the life of the two surfaces. These projections were to be obtained from evaluation of either the AASHO road findings or actual road history information which would then be applied to the Oklahoma road. As has been explained earlier, the projections made using the AASHO findings were totally unrealistic when compared to reasonable estimates of road life. They indicated road life spans which were much too long. At this point, the alternative of using actual road experience in this State and others as a base for projection was examined. Here it was found that, while road histories told when a section was resurfaced, it did not tell why, nor was there any reason to believe that this resurfacing was done at the time that it was first necessary. In short, too many factors other than need affect the time, in practice, that a roadway is resurfaced. The determination of which roads in Oklahoma will be resurfaced or reconstructed is based on an official Sufficiency Rating Index. Under this system, each section of roadway in the State is evaluated under the criteria of its ability to handle adequately the traffic load being placed on it. The roads are then rated as completely adequate, adequate, inadequate, and critically inadequate. The factors which may place a road in the critically inadequate category, which, due to available finances, is the area where work is normally performed, are surface condition, surface width, alignment, sight distance, and other factors of safety, and the free movement of the traffic load. (9). With this rating system, certainly a realistic one, it is conceivable that a brand new road, which was suddenly subjected to a large increase in traffic, might be critically inadequate and, therefore, widened and resurfaced while an old, seldom used road whose surface was in deplorable condition might be rated as adequate. It was for this reason that projections of the life of the two surfaces were not obtainable from road histories. This also points up the need, for comparative purposes, of either expansion of the test road program under various traffic conditions, or adequate record keeping of the point at which roads needed resurfacing for condtions of surface alone, whether or not this resurfacing was done. Since the project of the test road results on a reasonable basis was found to be impossible, it was decided to evaluate the outcome of the road under several performance ratios and indicate decision rules which would apply under each. The performance ratio was determined to be the number of times that the asphaltic concrete section required resurfacing prior to resurfacing the Portland Cement section.

In addition to the performance ratio, the effect of inflation, as it affects highway construction costs, and the time value of money were considered. Using Table IV, once the true performance ratio has been determined by field tests, a person may choose the rate of return, by reviewing the next section, that he deems desirable and look up the probable outcome of the cost picture of a roadway. He may in addition make a decision relative to surface material by computing the ratio of the estimated 1st cost of Portland Cement to that of asphaltic concrete and comparing it with the value found in Table IV, and if it is larger he should choose asphaltic concrete; if it is smaller, he should choose Portland Cement. A qualification of the indiscriminate use of the table results in that Table IV is applicable to roadways on which the traffic load is similar to those found on the Oklahoma test road. If the estimated traffic load differs greatly from that given in Chapter IV and the performance ratio has been determined for these conditions, then the procedure developed

TABLE IV

PRESENT WORTH AND CRITICAL RATIO TABLE

LIFE RATIO NO.		INTEREST RATE	RESURFACE RATIO	n_1	n_2	n_3	n_4	n_5	n_6	1st COSTS	s_1	s_2	s_3	s_4	s_5	s_6	PRESENT WORTH	RATIO OF 1st COSTS TO BRING TO EQUIVALENCE
				(N$_i$ = Years to Resurfacing i)														
1	PORTLAND CEMENT	0	3.00							$ 419,510							419,510	1.3105
	ASPHALTIC CONCRETE			6	11.46	—	—	—	—	316,043	47,867	51,527	—	—	—	—	415,437	
	PORTLAND CEMENT	5%	3.00							419,510							419,510	1.1840
	ASPHALTIC CONCRETE			6	11.46	—	—	—	—	316,043	35,718	29,468	—	—	—	—	381,229	
	PORTLAND CEMENT	10%	3.00							419,510							419,510	1.1180
	ASPHALTIC CONCRETE			6	11.46	—	—	—	—	316,043	27,021	7,266	—	—	—	—	360,330	
2	PORTLAND CEMENT	0	3.25							419,510							419,510	1.3688
	ASPHALTIC CONCRETE			6	11.46	15.41				316,043	47,867	51,527	13,634	—	—	—	429,071	
	PORTLAND CEMENT	5%	3.25							419,510							419,510	1.2060
	ASPHALTIC CONCRETE			6	11.46	15.41	—	—	—	316,043	35,718	29,468	6,471	—	—	—	387,700	
	PORTLAND CEMENT	10%	3.25							419,510							419,510	1.1275
	ASPHALTIC CONCRETE			6	11.46	15.41	—	—	—	316,043	27,021	17,266	3,142	—	—	—	363,472	
3	PORTLAND CEMENT	0	3.50							419,510							419,510	1.4325
	ASPHALTIC CONCRETE			6	11.46	15.41	—	—	—	316,043	47,867	51,527	27,268	—	—	—	442,705	
	PORTLAND CEMENT	5%	3.50							419,510							419,510	1.2289
	ASPHALTIC CONCRETE			6	11.46	15.41	—	—	—	316,043	35,718	29,468	12,942	—	—	—	394,171	
	PORTLAND CEMENT	10%	3.50							419,510							419,510	1.1371
	ASPHALTIC CONCRETE			6	11.46	15.41	—	—	—	316,043	27,021	17,266	6,785				366,615	
4	PORTLAND CEMENT	0	3.75							419,510							419,510	1.5025
	ASPHALTIC CONCRETE			6	11.46	15.41	—	—	—	316,043	47,867	51,527	40,902	—	—	—	456,339	
	PORTLAND CEMENT	5%	3.75							419,510							419,510	1.2526
	ASPHALTIC CONCRETE			6	11.46	15.41	—	—	—	316,043	35,718	29,468	19,413	—	—	—	400,642	
	PORTLAND CEMENT	10%	3.75							419,510							419,510	1.1468
	ASPHALTIC CONCRETE			6	11.46	15.41	—	—	—	316,043	27,021	17,266	9,427	—	—	—	369,757	
5	PORTLAND CEMENT	0	4.00							419,510							419,510	1.5796
	ASPHALTIC CONCRETE			6	11.46	15.41	—	—	—	316,043	47,867	51,527	54,535	—	—	—	469,972	
	PORTLAND CEMENT	5%	4.00							419,510							419,510	1.2766
	ASPHALTIC CONCRETE			6	11.46	15.41	—	—	—	316,043	35,718	29,468	25,719	—	—	—	406,948	
	PORTLAND CEMENT	10%	4.00							419,510							419,510	1.1568
	ASPHALTIC CONCRETE			6	11.46	15.41	—	—	—	316,043	27,021	17,266	12,570	—	—	—	372,900	
6	PORTLAND CEMENT	0	4.25							419,510							419,510	1.6711
	ASPHALTIC CONCRETE			6	11.46	15.41	19.17	—	—	316,043	47,867	51,527	54,535	14,540	—	—	484,512	
	PORTLAND CEMENT	5%	4.25							419,510							419,510	1.3010
	ASPHALTIC CONCRETE			6	11.46	15.41	19.17	—	—	316,043	35,718	29,468	25,719	6,163	—	—	413,111	
	PORTLAND CEMENT	10%	4.25							419,510							419,510	1.1643
	ASPHALTIC CONCRETE			6	11.46	15.41	19.17	—	—	316,043	27,021	17,266	12,570	2,341			375,241	

TABLE IV (Continued)

LIFE RATIO NO.	SURFACE	INTEREST RATE	RESURFACE RATIO	n_1	n_2	n_3	n_4	n_5	n_6	1st COSTS	s_1	s_2	s_3	s_4	s_5	s_6	PRESENT WORTH	RATIO OF 1st COSTS TO BRING TO EQUIVALENCE
				(N_i = Years to Resurfacing i)														
7	PORTLAND CEMENT	0	4.50							$ 419,510							419,510	1.7738
	ASPHALTIC CONCRETE			6	11.46	15.71	19.17	--	--	316,043	47,867	51,527	54,535	29,080	--	--	499,052	
	PORTLAND CEMENT	5%	4.50							419,510							419,510	1.3264
	ASPHALTIC CONCRETE			6	11.46	15.71	19.17	--	--	316,043	35,718	29,468	25,719	12,326	--	--	419,274	
	PORTLAND CEMENT	10%	4.50							419,510							419,510	1.1719
	ASPHALTIC CONCRETE			6	11.46	15.71	19.17	--	--	316,043	27,021	17,266	12,570	4,682	--	--	377,582	
8	PORTLAND CEMENT	0	4.75							419,510							419,510	1.8900
	ASPHALTIC CONCRETE			6	11.46	15.71	19.17	--	--	316,043	47,867	51,527	54,535	43,620	--	--	513,592	
	PORTLAND CEMENT	5%	4.75							419,510							419,510	1.3528
	ASPHALTIC CONCRETE			6	11.46	15.71	19.17	--	--	316,043	35,718	29,468	25,719	18,489	--	--	425,437	
	PORTLAND CEMENT	10%	4.75							419,510							419,510	1.1796
	ASPHALTIC CONCRETE			6	11.46	15.71	19.17	--	--	316,043	27,021	17,266	12,570	7,623	--	--	379,923	
9	PORTLAND CEMENT	0	5.00							419,510							419,510	2.0225
	ASPHALTIC CONCRETE			6	11.46	15.71	19.17	--	--	316,043	47,867	51,527	54,535	58,161	--	--	528,132	
	PORTLAND CEMENT	5%	5.00							419,510							419,510	1.3802
	ASPHALTIC CONCRETE			6	11.46	15.71	19.17	--	--	316,043	35,718	29,468	25,719	24,652	--	--	431,600	
	PORTLAND CEMENT	10%	5.00							419,510							419,510	1.1874
	ASPHALTIC CONCRETE			6	11.46	15.71	19.17	--	--	316,043	27,021	17,266	12,570	9,364	--	--	382,264	
10	PORTLAND CEMENT	0	5.25							419,510							419,510	2.1825
	ASPHALTIC CONCRETE			6	11.46	15.41	19.17	22.70		316,043	47,867	51,527	54,535	58,161	15,212	--	543,344	
	PORTLAND CEMENT	5%	5.25							419,510							419,510	1.4125
	ASPHALTIC CONCRETE			6	11.46	15.41	19.17	22.70	--	316,043	35,718	29,468	25,719	24,652	6,945	--	438,545	
	PORTLAND CEMENT	10%	5.25							419,510							419,510	1.1933
	ASPHALTIC CONCRETE			6	11.46	15.41	19.17	22.70	--	316,043	27,021	17,266	12,570	9,364	1,749	--	384,013	
11	PORTLAND CEMENT	0	5.50							419,510							419,510	2.3702
	ASPHALTIC CONCRETE			6	11.46	15.41	19.17	22.70	--	316,043	47,867	51,527	54,535	58,161	30,424	--	558,556	
	PORTLAND CEMENT	5%	5.50							419,510							419,510	1.4463
	ASPHALTIC CONCRETE			6	11.46	15.41	19.17	22.70	--	316,043	35,718	29,468	25,719	24,652	13,890	--	445,490	
	PORTLAND CEMENT	10%	5.50							419,510							419,510	1.1993
	ASPHALTIC CONCRETE			6	11.46	15.41	19.17	22.70	--	316,043	27,021	17,266	12,570	9,364	3,498	--	385,762	
12	PORTLAND CEMENT	0	5.75							419,510							419,510	2.5930
	ASPHALTIC CONCRETE			6	11.46	15.41	19.17	22.70	--	316,043	47,867	51,527	54,535	58,161	45,636	--	573,768	
	PORTLAND CEMENT	5%	5.75							419,510							419,510	1.4817
	ASPHALTIC CONCRETE			6	11.46	15.41	19.17	22.70	--	316,043	35,718	29,468	25,719	24,652	20,835	--	452,435	
	PORTLAND CEMENT	10%	5.75							419,510							419,510	1.2053
	ASPHALTIC CONCRETE			6	11.46	15.41	19.17	22.70	--	316,043	27,021	17,266	12,570	9,364	5,248	--	387,511	

TABLE IV (Continued)

LIFE RATIO NO.	SURFACE	INTEREST RATE	RESURFACE RATIO	n_1	n_2	n_3	n_4	n_5	n_6	1st COSTS	s_1	s_2	s_3	s_4	s_5	s_6	PRESENT WORTH	RATIO OF 1st COSTS TO BRING TO EQUIVALENCE
				(N_i = Years to Resurfacing i)														
	PORTLAND CEMENT	0	6.00							$ 419,510							419,510	2.8621
	ASPHALTIC CONCRETE			6	11.46	15.71	19.17	22.70	--	316,043	47,867	51,527	54,535	58,161	60,849	--	588,980	
13	PORTLAND CEMENT	5%	6.00							419,510							419,510	1.5135
	ASPHALTIC CONCRETE			6	11.46	15.71	19.17	22.70	--	316,043	35,718	29,468	25,719	24,652	22,383	--	458,380	
	PORTLAND CEMENT	10%	6.00							419,510							419,510	1.2114
	ASPHALTIC CONCRETE			6	11.46	15.71	19.17	22.70	--	316,043	27,021	17,266	12,570	9,364	6,997	--	389,261	
	PORTLAND CEMENT	0	6.25							419,510							419,510	3.2102
	ASPHALTIC CONCRETE			6	11.46	15.71	19.17	22.70	26.28	316,043	47,867	51,527	54,535	58,161	60,849	15,894	604,874	
14	PORTLAND CEMENT	5%	6.25							419,510							419,510	1.5393
	ASPHALTIC CONCRETE			6	11.46	15.71	19.17	22.70	26.28	316,043	35,718	29,468	25,719	24,652	22,983	4,643	463,023	
	PORTLAND CEMENT	10%	6.25							419,510							419,510	1.2160
	ASPHALTIC CONCRETE			6	11.46	15.71	19.17	22.70	26.28	316,043	27,021	17,266	12,570	9,364	6,997	1,300	390,561	
	PORTLAND CEMENT	0	6.50							419,510							419,510	3.6547
	ASPHALTIC CONCRETE			6	11.46	15.71	19.17	22.70	26.28	316,043	47,867	51,527	54,535	58,161	60,849	31,788	620,768	
15	PORTLAND CEMENT	5%	6.50							419,510							419,510	1.5660
	ASPHALTIC CONCRETE			6	11.46	15.71	19.17	22.70	26.28	316,043	35,718	27,468	25,719	24,652	22,983	9,285	467,666	
	PORTLAND CEMENT	10%	6.50							419,510							419,510	1.2206
	ASPHALTIC CONCRETE			6	11.46	15.71	19.17	22.70	26.28	316,043	27,021	17,266	12,570	9,364	6,997	2,600	391,861	
	PORTLAND CEMENT	0	6.75							419,510							419,510	4.2421
	ASPHALTIC CONCRETE			6	11.46	15.71	19.17	22.70	26.28	316,043	47,867	51,527	54,535	58,161	60,849	47,682	636,662	
16	PORTLAND CEMENT	5%	6.75							419,510							419,510	1.5936
	ASPHALTIC CONCRETE			6	11.46	15.71	19.17	22.70	26.28	316,043	35,718	29,468	25,719	24,652	22,983	13,927	472,308	
	PORTLAND CEMENT	10%	6.75							419,510							419,510	1.2252
	ASPHALTIC CONCRETE			6	11.46	15.71	19.17	22.70	26.28	316,043	27,021	17,266	12,570	9,364	6.997	3,900	393,161	
	PORTLAND CEMENT	0	7.00							419,510							419,510	5.0545
	ASPHALTIC CONCRETE			6	11.46	15.71	19.17	22.70	26.28	316,043	47,867	51,527	54,535	58,161	60,849	63,575	652,556	
17	PORTLAND CEMENT	5%	7.00							419,510							419,510	1.6220
	ASPHALTIC CONCRETE			6	11.46	15.71	19.17	22.70	26.28	316,043	35,718	29,468	25,719	24,652	22,983	18,570	476,951	
	PORTLAND CEMENT	10%	7.00							419,510							419,510	1.2299
	ASPHALTIC CONCRETE			6	11.46	15.71	19.17	22.70	26.28	316,043	27,021	17,266	12,570	9,364	6,997	5,200	394,461	

later in this chapter may be used to calculate the critical ratio of 1st costs.

The Effect of Inflation and the Time Value of Money

Inflation, as it is evidenced in rising highway construction costs, is a real factor in an accurate comparison of Portland Cement and asphaltic concrete. This is because of the basic difference in the manner in which costs are incurred with the two materials. Portland Cement is characterized by a high initial investment followed by a slight but relatively constant maintenance cost. Asphaltic concrete, on the other hand, is characterized by a lower initial cost, followed by a relatively stable maintenance cost similar to that found on Portland Cement, but periodically broken by large resurfacing costs. Since costs to be incurred in the future, under the present economic conditions, can be expected to be substantially higher than those associated with the same work today, it is necessary to take this into consideration in any economic evaluation.

For the above reason, a linear regression analysis was performed on data provided by the Bureau of Public Roads (10) surface cost index and the costs, indicated by this analysis, to be associated with resurfacing at the estimated times of resurfacing were used to compile Table IV. (These estimated resurfacing costs are displayed in

TABLE V

ESTIMATED RESURFACING COST

Year	Index Value	Cost	Year	Index Value	Cost
1955	86.459	43,564	1976	118.194	59,552
1956	87.970	44,325	1977	119.705	60,314
1957	89.481	45,087	1978	121.216	61,075
1958	90.992	45,848	1979	122.728	61,837
1959	92.503	46,609	1980	124.239	62,598
1960	94.014	47,370	1981	125.750	63,359
1961	95.526	48,131	1982	127,261	64,121
1962	97.037	48,893	1983	128.772	64,882
1963	98.548	49,654	1984	130.284	65,644
1964	100.059	50,416	1985	131.795	66,405
1965	101.571	51,177	1986	133.306	67,166
1966	103.082	51,938	1987	134.172	67,728
1967	104.593	52,670	1988	136.328	68,689
1968	106.104	53,461	1989	137.840	69,451
1969	107.616	54,223	1990	139.351	70,212
1970	109.127	54,984	1991	140.862	70,973
1971	110.638	55,745	1992	142.373	71,735
1972	112.149	56,507	1993	143.884	72,496
1973	113.660	57,268	1994	145.396	73,258
1974	115.172	58,030	1995	146.907	74,019
1975	116.683	58,791			

Table V.) This regression line, which is super-imposed on the surfacing cost index graph (Figure 5), was found to be of the form $y = 36.596 + 1.5112X$. Y in this case represents the cost index number and X is the variable associated with the time in years since 1922. For an evaluation of this equation to 1995, see Table V (page 41). In regard to Table IV, an index reading of 100 corresponds to a cost of resurfacing the Oklahoma test road of $50,387. In conjunction to this, a correlation analysis was performed to verify the approximation of the cost graph by a straight line and the correlation was determined to be .9515. This indicates almost perfect correlation and the slight deviation is caused by the depression years of the 1930's. If, for some reason, the economic picture should change so that this function no longer represents the true trend, then, as with the traffic, this change may be taken into consideration in the formulas given later and, therefore, give more satisfactory comparisons than Table IV.

The application of the theory of the time value of money, more commonly referred to as interest rates, to a comparison of paving materials is, unlike the effects of inflation, more subject to controversy. In essence, there are three major points of view on this matter which are satisfactory for this comparison.

The first faction advocates that assigning an interest rate to highway appropriations is inappropriate because a state highway department is appropriated a certain sum of

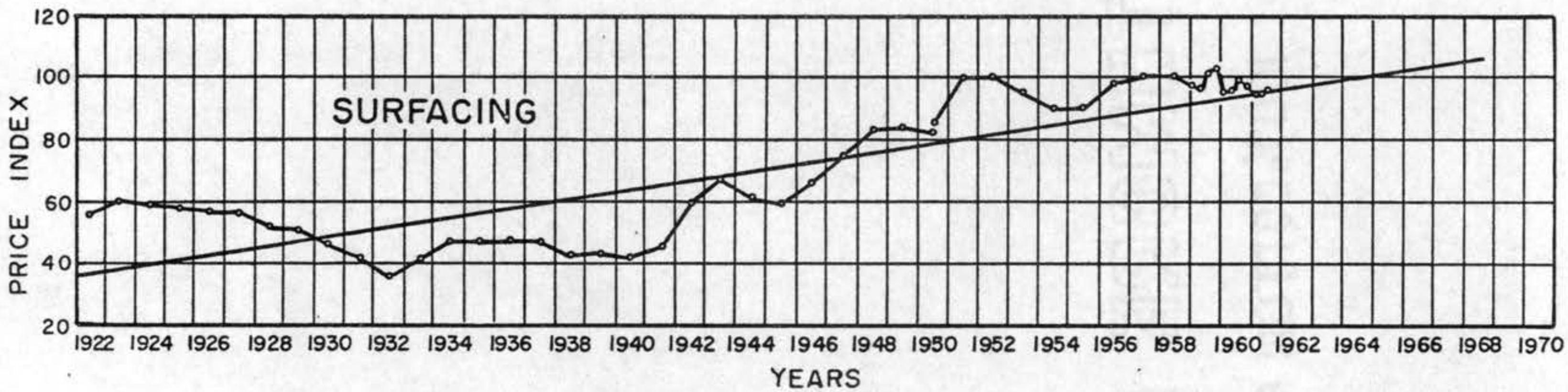


Figure 5. Price Trends for Federal-Aid Highway Construction

money in a given year and does not have the prerogative of either spending that money or reinvesting it. This group states that, should the department show a surplus at the end of the year, the result would simply be a reduction in their appropriation for the next year.

A second school of thought submits that since both states and the Federal Government are large borrowers of money, it is necessary to take into consideration the rates that they have to pay for these funds. This is especially pertinent due to the large amount of Federal aid which is devoted to highway construction. The argument here is that the Government pays approximately 3.5% interest on Federal and municipal bonds, and in addition the revenue on these bonds is not subject to Federal taxation. Since the primary holders of these bonds are either corporations who are subject to a 52% tax or wealthy individuals who are likely to be in the 50% or above tax bracket, this group advocates that it is reasonable to assign a 5% rate to these borrowed funds and to proceed on this basis.

The third point of view argues for the assignment of up to a 10% rate of return to the expenditures for highways. They argue thusly; since, if this money were not spent by the Government, it could be retained, in the form of lower taxes, by the people. The people, they say could receive up to and possibly exceeding 10% for their money from alternative investments. For this reason, they feel that a 10% rate of return is applicable.

In order to appease all of these factions, Table IV is calculated for all of the three rates advocated and factors are given in Appendix C for each, which may be used in the expressions developed in the next section.

Development of Present Worth Formulas and Procedures for Calculation of the Critical Ratio

In an attempt to compare the costs associated with two or more engineering alternatives, it is necessary to bring the costs of each to their equivalent amount at some specified time period. This is easily done by using the concept of present worth as explained by Thuesen (2). In essence, this involves the determination of what amount would need to be invested, at a specified interest rate immediately in order that future expenditures could be met. Thuesen (2) advances certain factors which are useful in this type of analysis. These factors are: (a) The "single payment present-worth factor," called PS i - n, which can be multiplied by an expected expenditure "S", occurring "n" years in the future and this product is the amount "P" which must be presently invested, with a rate of return i, so that the amount "S" will be available, (b) The "equal payment series present-worth factor," called PR i - n, which, when multiplied by an annual payment for a period n gives the present worth of this series of n annual payments, considering a rate of return i, (c) The "equal payment series capital recovery factor," henceforth referred to as RP i - n, is a factor that, when multiplied by an anticipated expenditure P, gives the equivalent annual amount R, which if collected for n years will result in the return of P plus compounded interest of an amount i. Selected tables of these three factors may be found in Appendix C, for i = 5% and 10% and n from 1 to 35 years.

Once this present worth concept is understood, the following formulas suggest themselves. To evaluate the present worth of the expenditures on either surface, it is necessary only to sum the present worths of each individual expenditure. This, of course, involves only the 1st Cost of Portland Cement since the small maintenance cost is held insignificant. For asphaltic concrete, on the other hand, the following relationship results.

$$\text{Present worth} = I + s_1 + s_2 + \ldots s_t$$

where I = 1st Cost

s_1 = The estimated cost of the first resurfacing x PS $i - n_1$

s_2 = The estimated cost of the 2nd resurfacing x PS $i - n_2$

etc.

s_{t-1} = The estimated cost of the t-1 resurfacing x PS $i - n_{t-1}$.

s_t = The estimated cost of the t^{th} resurfacing

x RP i − ($n_{t+1} - n_t$) x PR i − [($n_{t+1} - n_t$)

(The fractional part of the performance ratio)].

x PS i − n_t

n_1 represents the time lapse to the 1^{st} resurfacing.

n_2 represents the time lapse to the 2^{nd} resurfacing.

⋮

n_{t-1} represents the time lapse to the t − 1 resurfacing

n_t represents the time lapse to the t^{th} resurfacing

t = the whole number portion of the performance ratio.

Example:

Given: Performance ratio of 4.25, i = 5%,

Required: Determine a) Present worth of Portland Cement.

b) Present worth of asphaltic concrete.

Solution:

a) Present worth = I = $419,510

b) Step 1: Solve for n_1, n_2, n_3, n_4,

n_1 = 6 years = 5,473,175 vehicle passages (from actual experience).

n_2 = 11.46 years = 6 + 5.46 years = 6 yrs. + time for 5,473,175 additional vehicle passages.

n_3 = 15.41 years.

n_4 = 19.17 years.

n_5 = 22.70.

Step 2: Solve for s_1, s_2, ... s_t

s_1 = Cost of resurfacing at Index level 100%

$$\times \frac{\text{Index level}}{100} \text{ at } 1955 + n_1 \times PS_{s-6}$$

= \$50,387 x .95 x .7462 = \$35,718.

Similarly,

s_2 = \$50,387 x 1.023 x .5719 (Interpolated)

= \$29,468.

$s_3 = s_{t-1}$ = \$50,387 x 1.08 x .4716 (Interpolated) = \$25,719.

$$s_4 = s_t = \$50{,}387 \times 1.15 \times RP_{5-(n_{t+1}-n_t)}$$

$$\times PR_{5-\frac{(n_{t+1}-n_t)}{4}} \times PS_{5-n_t}$$

$$= \$50{,}387 \times 1.15 \times RP_{5-3.57} \times PR_{5-.89}$$

$$\times PS_{5-19.17}$$

$= \$50,387 \times 1.15 \times .31865$ (Interpolated)

$\times .84728$ (Interpolated) $\times .3925$

(Interpolated $= \$6,163$.

Step 3: Solve for present worth.

$$\text{Present worth} = I + s_1 + s_2 - s_{t-1} + s_t$$

$$= \$316,043 + 35,718 + 29,468$$

$$+ 25,719 + 6,163 = \$413,111.$$

Once the present worth of the two surfaces has been calculated, it is a simple matter to compute the critical ratio of 1st Costs. This may be done using the following relationship:

$$\text{Critical Ratio} = \frac{\text{I for Portland Cement}}{\text{I for asphaltic concrete + present worth, Portland Cement - present worth, asphaltic concrete.}}$$

For the above example, this becomes:

$$\text{Critical Ratio} = \frac{419,510}{316,043 + 419,510 - 413,111} = \frac{419,510}{322,442}$$

$$= 1.3010.$$

Comparing this ratio, given that the performance ratio has been experimentally determined to be approximately 4.25, with the ratio of estimated 1st Costs for a proposed roadway, if the estimated 1st Cost ratio exceeds the critical ratio, then asphaltic concrete would appear to be the most desirable material. If, however, the ratio of 1st Cost estimates is smaller than the critical ratio, then Portland Cement would be indicated. It is appropriate to add that there exists limiting regions where one material or another is clearly indicated regardless of 1st Cost ratio. These have been determined to exist as follows:

1. If the initial design considerations, traffic volume and intensity, etc., indicate slab thicknesses less then approximately 6 inches, there is doubt that Portland Cement is a desirable surfacing material. (11).
2. If the design considerations are such that extremely high loads, such as large impact loads, must be handled, there is doubt as to the advisability of using asphaltic concrete. The critical ratio will, however, indicate a preference for Portland Cement prior to this point.

In summary, since most highway designs fall in between these extreme conditions, the critical ratio comparison should prove helpful in deciding between the two materials, as soon as sufficient experimental evidence has been accumulated to reliably indicate performance ratios applicable under various average traffic volumes.

CHAPTER VII

SUMMARY AND CONCLUSIONS

To attempt a direct comparison between asphaltic concrete and Portland Cement as highway paving materials is a difficult, as well as prodigious, undertaking. This is especially true, not only because of the inherent properties of the two, their method of supporting traffic and design characteristics, but also because of the lack of realistic comparative information. Surprisingly enough, notwithstanding the great monetary investments for which this work accounts in this country, only recently have the states embarked on critical evaluational testing programs, such as the Oklahoma test road. The various highway agencies have not, in fact, even made the best use of an available source of information, their road histories and evaluation reports. These remarks are not intended to be unfairly critical, for much work has been done, but only to emphasize the need for additional experimentation under actual field conditions and the maintenance of records of such a form as to shed light on road life characteristics under varied traffic loads. This type of information will enable more detailed economic comparisons of the type found herein, and possibly prove the validity of this approach. In any event, it is hoped that until more comprehensive studies can be conducted, the ratios determined here will provide a significant step forward in proposing reasonable and quantitative criteria for evaluating the two materials prior to their installation.

It would be wrong to leave the impression that economic considerations are the only ones affecting the relative desirability of asphaltic concrete and Portland Cement. Since the ultimate duty of a public highway, whatever the surface material, is to adequately, safely, and comfortably carry the private and commercial traffic load placed upon it by the people who own it, it is desirable to take into consideration all factors which affect the realization of these functions. Other than the economics of highway construction and maintenance, such factors as maintenance of skid-free surfaces in various weather conditions, the effect of surface on vision and mental fatigue under adverse conditions, the contribution to wear on the vehicles traveling the road, more specifically the effect on tire wear of the surface material, and the rideability of smoothness and comfort characteristics of the two surfaces should be taken into consideration. These are some, but not nearly all, of the more or less qualitative variables which affect material desirability. Unfortunately, even less is known about these factors than about those pertinent to a pure economic comparison. This is due, perhaps, to the greater difficulty of data accumulation in conjunction with this area of evaluation. This is not to say, however, that nothing is being done in this regard. The AASHO test effort, for example, conducted extensive tests on the coefficient of friction present on both rigid and flexible pavements under varied weather and wheel load conditions. These tests showed that only slight difference could be detected between the two surfaces. Hopefully, when information is available, correction factors can be introduced into the economic relationships developed here, which will allow recognition of these effects.

Until these intangible variables can be evaluated, it is necessary to be content with simple cost comparisons in order to make decisions relative to the surfacing material to be used on a prospective roadway. It is hoped that the criteria advanced here will aid in this endeavor. While the Oklahoma test road was the one examined, the results and criteria developed should prove valuable in scrutinizing any road which is located in Oklahoma and will be subjected to similar traffic loads. In the event that the conditions are so dissimilar as to make the tabulated critical ratios inapplicable, the method of analysis used in this presentation should prove helpful in projecting the costs to be associated with any highway proposal.

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APPENDIX A

OKLAHOMA COUNTY-TEST ROAD
PROJECT FI-130 (10) ASPHALTIC CONCRETE PAVEMENT

(Letting of August 3, 1954)

Oklahoma Test Road Bid Prices of Metropolitan Paving Co., Oklahoma City, low bidder at $353,007.58 for 3.934 miles, Stabilized Aggregate Base Course with Asphaltic Concrete surface course beginning just North of Witcher Interchange and extending North to just North of Junction of U. S. 66 and U. S. 77 East of Edmond.

PAVING ITEMS

8" X 18" Concrete Curb	10,259.	L. F.	1.50	$ 15,388.50
Subbase (6" X 31'-5½")	29.	Sta.	133.00	3,857.00
Stabilized Aggregate Base Course	39,266.	Ton	2.59	101,698.94
Preparation of Subgrade (B)	269.	Sta.	7.00	1,883.00
Type A Aggregate	12,885.	Ton	5.85	75,377.25
Type B Aggregate	8,437.	Ton	5.80	48,934.60
Asphalt (85-100 pen.)	1,409.	Ton	22.15	31,209.35
Tack Coat (AE-5)	8,638.	Gal.	.13	1,122.94
Prime Material	46,513.	Gal.	.12	5,581.56
Suitable Soil for Asphalt Stabilized Base	9,538.	C. Y.	.40	3,815.20
Manipulation (6" X 10') Asphalt Stab.	374.6	Sta.	15.00	5,619.00
Asphalt for Stabilization	140,258.	Gal.	.12	16,830.96
Rolling (Asph. Stab.)	266.	Hr.	2.00	532.00
Asphalt Binder	15,726.	Gal.	.13	2,044.38
Cover Material	642.	C. Y.	5.50	3,531.00
Hot Plant Mix Soil Asphalt Base	99.13	Sta.	25.00	2,478.25
6" Subbase (6" X39'--4½")	14.	Sta.	161.00	2,254.00
Total, Roadway Section Asphaltic Concrete Paving				$322,157.93

INCIDENTAL CONSTRUCTION

Class D Unclassified Excavation	7,047.	C. Y.	.30	2,114.10
Traffic Bound Surface Course	140.	C. Y.	4.50	630.00
Class A Concrete	16.99	C. Y.	38.00	645.62
Reinforcing Steel	1,441.	Lb.	.12	172.92
Special Inlet Curb	49.	L. F.	2.50	122.50
Inlet Frame and Grate	15.	Ea.	90.00	1,350.00
18" R. C. Pipe Sewer	60.	L. F.	5.40	324.00
Brick, Concrete and Asphalt Pavement Removal	800.	S. Y.	.60	480.00
Metal Plate Guard Rail	2,290.92	L. F.	2.50	5,727.30
Guide Posts	196.	Ea.	4.30	842.80
Reshaping Roadbed	5.613	Mi.	470.00	2,638.11
3" Top Soil	27,168.	S. Y.	.12	3,260.16
Bermuda Slab Sodding	9,056.	S. Y.	.70	6,339.20
Water For Sodding	272.	M-Gal.	2.00	544.00
Fertilizer	0.85	Ton	100.00	85.00
Obliterate Abandoned Road	7.	Sta.	15.00	105.00
Prime Material	470.	Gal.	.12	56.40
Suitable Soil for Asphalt Stabilization	549.	C. Y.	.40	219.60
Manipulation (Asph. Stab.)	21.	Sta.	15.00	315.00
Asphalt for Stabilization	7,906.	Gal.	.12	948.72
Rolling (Asphalt Stabilization)	15.	Hr.	2.00	30.00
Asphalt Binder	790.	Gal.	.13	102.70
Cover Material	32.	C. Y.	5.50	176.00
6" Perforated C. M. Pipe Underdrain	1,215.	L. F.	1.50	1,822.50
Pipe Underdrain Cover Material	450.	C. Y.	3.00	1,350.00
6" P.C. Concrete Paving	16.8	S. Y.	3.90	65.52
6" Non-perforated C. M. Pipe Underdrain	255.	L. F.	1.50	382.50
Total, Incidental Construction (Non-paving Items)				$ 30,849.65
Total, Asphaltic Concrete Paving and Incidental Construction				$353,007.58

Totals of all Bidders on Asphaltic Concrete Section and Incidental Construction on Test Road:

Metropolitan Paving Co., Oklahoma City	$353,007.58
Imperial Paving Co., Oklahoma City	364,854.76
Hunter Construction Co., Ada	366,371.28
Amis Construction Co., Oklahoma City	373,390.66
Dahlgren & Brooks, Oklahoma City	376,323.36
H. D. Youngman, Baxter Springs, Kansas	382,364.90
Layman & Sons, Tulsa	390,072.30
W. E. Steelman, Oklahoma City	397,186.66

APPENDIX A (Continued)

OKLAHOMA COUNTY-TEST ROAD
PROJECT FI-130 (10) P. C. CONCRETE PAVEMENT

(Letting of August 3, 1954)

Oklahoma Test Road Bid Prices of Dohlgren & Brooks, Oklahoma City, low bidder at $444,602.31 for 3.853 miles P. C. Concrete paving beginning just North of Witcher Interchange and extending North to just North of Junctions of U. S. 66 and U. S. 77 East of Edmond.

PAVING ITEMS

Item	Quantity	Unit	Bid Price	Amount
4" Sand Cushion	93,256.	S. Y.	.21	$ 19,583.76
8" P. C. Concrete Paving	81,661.	S. Y.	3.96	323,377.56
6" Integral Curb	10,260.	L. F.	.70	7,182.00
Cement for Stabilization	5,122.	Bbl.	4.70	24,073.40
Suitable Soil for Soil Cement Base	11,804.	C. Y.	.95	11,213.80
Manipulation (7¼" X 13') Soil Cement	289.84	Sta.	68.00	19,709.12
Prime Material (Asphalt Emulsion AE-5)	16,748.	Gal.	.13	2,177.24
Asphalt Binder	30,657.	Gal.	.13	3,985.41
No. 1 Cover Material	657.	C. Y.	5.50	3,613.50
No. 2 Cover Material	602.	C. Y.	6.00	3,612.00
Total, Roadway Section Portland Cement Concrete Pavement				$ 418,527.79

INCIDENTAL CONSTRUCTION

Item	Quantity	Unit	Bid Price	Amount
Class D Unclassified Excavation	3,181.	C. Y.	.30	954.30
Traffic Bound Surface Course	170.	C. Y.	4.00	680.00
Class A Concrete	8.28	C. Y.	40.00	331.20
Reinforcing Steel	1,213.	Lb.	.12	145.56
Special Inlet Curb	49.	L. F.	2.00	98.00
Inlet Frame and Grate	14.	Ea.	80.00	1,120.00
18" R. C. Pipe Sewer	60.	L. F.	4.50	270.00
Metal Plate Guard Rail	1,353.42	L. F.	2.50	3,383.55
Guide Posts	163.	Ea.	4.00	652.00
Reshaping Roadbed	5.926	Mi.	400.00	2,370.40
3" Top Soil	2[illegible],268.	S. Y.	.10	2,326.80
Bermuda Slab Sod	7,756.	S. Y.	.90	6,980.40
Water for Sodding	233.	M-Gal.	2.00	466.00
Fertilizer	0.73	Ton	100.00	73.00
6" Concrete Dividing Strip	111.5	S. Y.	3.50	390.25
Obliterate Abandoned Road	31.	Sta.	15.00	465.00
Cement for Stabilization	69.	Bbl.	4.70	324.30
Suitable Soil for Soil Cement Base	158.	C. Y.	.95	150.10
Manipulation (Soil Cement)	3.9	Sta.	68.00	265.20
Asphalt Binder	412.	Gal.	.13	53.56
No. 1 Cover Material	9.	C. Y.	5.50	49.50
No. 2 Cover Material	8.	C. Y.	6.00	48.00
6" Perforated C. M. Pipe Underdrain	1,315.	L. F.	1.75	2,301.25
Pipe Underdrain Cover Material	487.	C. Y.	3.50	1,704.50
8" P. C. Concrete Pavement	16.8	S. Y.	4.02	67.53
Prime Material (AE-5)	224.	Gal.	.13	29.12
8" Non-perforated C. M. Pipe Underdrain	300.	L. F.	1.25	375.00
Total, Incidental Construction (non-paving items)				$ 26,074.52
Total, Portland Cement Concrete and Incidental Construction				$ 444,802.31

Totals of All Bidders on P. C. C. Section of Test Road:

Dahlgren & [illegible]ooks, Oklahoma City	$ 444,802.31
Imperia[illegible]ing Co., Oklahoma City	447,224.19
Jack Briscoe, Stillwater	447,648.30
Standard Paving Co., Tulsa	449,400.75
Worth Construction Co., Fort Worth, Texas	452,970.05
Amis Construction Co., Oklahoma City	453,862.30
Boecking Construction Co., Oklahoma City	456,549.79

APPENDIX B

STATE OF OKLAHOMA
DEPARTMENT OF HIGHWAYS
COMPTROLLER DIVISION - ACCOUNTS AND BUDGET BRANCH

February 15, 1962

SUBJECT: Maintenance Expenditures on Test Road, Oklahoma County, for period beginning January 1, 1956 to December 31, 1961 (6 years).

Code No.	Type of Operation	Sub-Section No. 66-55-09-W000 66-55-09-E019 (1.9785 Miles) Portland Cement	Sub-Section No. 66-55-09-E000 66-55-09-W019 (1.9785 Miles) Asphaltic Cement
1	Patching, Sanding, Spot Sealing, Etc.	$ 432.99	$ 1,672.25
2	Blading, Scarifying, Reshaping, Etc.	.00	.00
3	Joints and Cracks	289.83	1,153.40
4	Mud-Jacking	.00	186.46
5	Resurfacing	.00	47,867.74
6	Armor Coating	.00	.00
	Total Expenditures on Roadway Surface	722.82	50,879.85
7	Patching, Blading, Reshaping, Etc.	1,370.82	1,384.82
8	Seeding, Sodding, Planting	508.31	386.47
9	Stabilizing soil cement	4,285.57	4,245.92
	Total Expenditures on Shoulders and Side Approaches	6,164.70	6,017.21
10	Repairing Cuts, Fills, Slopes, Drainage	16,035.07	17,183.04
11	Retaining Walls, Rip-Rap, Fences, Etc.	660.93	664.99
12	Mowing	5,345.95	5,859.56
13	Cutting Brush, Removing Trash	2,477.08	1,423.28
14	Heavy Grading	.00	.00
	Total Expenditures on Roadside	24,519.03	25,130.87
15	Traffic Lines	585.69	703.21
16	Signs and Markers	731.09	727.85
17	Guard Rails and Guide Posts	210.92	160.05
18	Roadside Parks	204.82	204.82
19	Watchman, Road Magnet, Detour	77.90	76.39
	Total Expenditures on Traffic Services	1,810.42	1,872.32

APPENDIX B (Continued)

Code No.	Type of Operation	Sub-Section No. 66-55-09-W000 66-55-09-E019 (1.9785 Miles) Portland Cement	Sub-Section No. 66-55-09-E000 66-55-09-W019 (1.9785 Miles) Asphaltic Cement
20	Snow and Ice Removal, Snow Fences, Sanding, Etc.	$ 1,199.13	$ 1,235.14
21	Disaster Work, Storms, Floods, Etc.	80.15	54.85
	Total Expenditures Emergency Repairs	1,279.28	1,289.99
22	Cleaning and Repairing Culverts	2,672.10	1,769.72
23	Installing Culverts	143.20	.00
	Total Expenditures on Structures Under 20 Ft.	2,815.30	1,769.72
27	Total Routine Maintenance	37,311.55	86,959.96
28	Maintenance General Expense	930.93	930.94
	GRAND TOTAL	38,242.48	87,890.90
33	Labor	18,177.94	18,520.04
34	Material	6,546.15	6,841.21
36	Equipment	8,130.83	9,340.35
37	Other Expense	1,017.66	951.66
38	Maintenance Contract	4,369.90	52,237.64
	GRAND TOTAL	38,242.48	87,890.90

ACCOUNTS AND BUDGET BRANCH

APPENDIX C

INTEREST FACTORS TO BE USED IN CALCULATING PRESENT WORTH*

	10% Compound Interest Factors		
	Single Payment	Equal Payment Series	
	Present Worth Factor	Present Worth Factor	Capital Recovery Factor
n	PSi-n (XXXX)	PRi-n (XXXX)	RPi-n (XXXX)
1	0.9091	0.909	1.10000
2	0.8264	1.736	0.57619
3	0.7513	2.487	0.40211
4	0.6830	3.170	0.31547
5	0.6209	3.791	0.26380
6	0.5645	4.355	0.22961
7	0.5132	4.868	0.20541
8	0.4665	5.335	0.18744
9	0.4241	5.759	0.17364
10	0.3855	6.144	0.16275
11	0.3505	6.495	0.15396
12	0.3186	6.814	0.14676
13	0.2897	7.103	0.14078
14	0.2633	7.367	0.13575
15	0.2394	7.606	0.13147
16	0.2176	7.824	0.12782
17	0.1978	8.022	0.12466
18	0.1799	8.201	0.12193
19	0.1635	8.365	0.11955
20	0.1486	8.512	0.11746
21	0.1351	8.649	0.11562
22	0.1228	8.772	0.11401
23	0.1117	8.883	0.11257
24	0.1015	8.985	0.11130
25	0.0923	9.077	0.11017
26	0.0839	9.162	0.10916
27	0.0763	9.237	0.10826
28	0.0693	9.307	0.10745
29	0.0630	9.370	0.10673
30	0.0573	9.427	0.10608
31	0.0521	9.479	0.10550
32	0.0474	9.526	0.10497
33	0.0431	9.569	0.10450
34	0.0391	9.609	0.10407
35	0.0356	9.644	0.10369

*Selected from tables given by Thuesen (2).
Refer to above for other values of n or i.

APPENDIX C (Continued)

5% Compound Interest Factors

	Single Payment	Equal Payment Series	
	Present Worth Factor	Present Worth Factor	Capital Recovery Factor
n	PSi-n (XXXX)	PRi-n (XXXX)	RPi-n (XXXX)
1	0.9524	0.952	1.05000
2	0.9070	1.859	0.53780
3	0.8638	2.723	0.36721
4	0.8227	3.546	0.28201
5	0.7835	4.329	0.23097
6	0.7462	5.076	0.19702
7	0.7107	5.786	0.17282
8	0.6768	6.463	0.15472
9	0.6446	7.108	0.14069
10	0.6139	7.722	0.12950
11	0.5847	8.306	0.12039
12	0.5568	8.863	0.11283
13	0.5303	9.394	0.10646
14	0.5051	9.899	0.10102
15	0.4810	10.380	0.09634
16	0.4581	10.838	0.09227
17	0.4363	11.274	0.08870
18	0.4155	11.690	0.08555
19	0.3957	12.085	0.08275
20	0.3769	12.462	0.08204
21	0.3589	12.821	0.07800
22	0.3418	13.163	0.07597
23	0.3256	13.489	0.07414
24	0.3101	13.799	0.07247
25	0.2953	14.094	0.07095
26	0.2812	14.375	0.06956
27	0.2678	14.643	0.06829
28	0.2551	14.898	0.06712
29	0.2429	15.194	0.06605
30	0.2314	15.372	0.06505
31	0.2204	15.593	0.06413
32	0.2099	15.803	0.06328
33	0.1999	16.003	0.06249
34	0.1904	16.193	0.06176
35	0.1813	16.374	0.06107

VITA

Robert Raymond Tway

Candidate for the Degree of

Master of Science

Thesis: A COMPARATIVE ANALYSIS OF THE ECONOMIC DESIRABILITY OF ASPHALTIC CONCRETE AND PORTLAND CEMENT FOR HIGHWAY CONSTRUCTION

Major Field: Industrial Engineering and Management

Biographical:

Personal Data: Born in Oklahoma City, Oklahoma, September 28, 1939, the son of Robert R. and Margaret Tway.

Education: Attended grade school in Oklahoma City, Oklahoma; graduated from Northwest Classen High School, Oklahoma City, Oklahoma, in 1957; attended the University of Oklahoma, Oklahoma City University, and received the Bachelor of Science degree from the Oklahoma State University, with a major in Industrial Engineering and Management, in August, 1962; completed requirements for the Master of Science degree in May, 1963.

Professional Experience: Was engaged in retail sales work during the period from 1957 through 1960; employed during the Summer of 1962 by Procter and Gamble Manufacturing Company, in the capacity of cost control engineer.