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Comparative Economic Analysis of Asphalt and Concrete Pavements

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ABSTRACT

A comparative economic analysis of alternative asphalt and concrete pavement design is presented in this paper. Both a life-cycle cost comparison and an economic impact analysis were conducted. In this study, using specific designs for a hypothetical rural Florida project and 1983 Florida estimated costs, the asphalt pavement design was the clear and unambiguous economic choice at 5, 7, and 10 percent discount rates and for both 30- and 40-year project lives. A sensitivity analysis of energy price impacts was conducted by assigning asphalt material prices a 2.6 percent differential inflation rate. The asphalt pavement design was again the economic choice in all comparisons. A comparative life-cycle cost analysis should be conducted routinely. It has great potential for resolving ambiguous public debate as well as maximizing the economic efficiency of public expenditures. An economic impact analysis, which consisted of an assessment of the earnings and employment effects of each design, was accomplished by applying an input-output model, RIMS II, to industry-specific input costs. The study found an employment benefit in the use of concrete; however, the interpretation of this advantage must be left to the decision maker. Further research is recommended.

The literature consistently recommends the use of life-cycle cost analysis in evaluating alternative pavement designs; however, there are few articles that discuss the application of this technique to a practical case study. Practical examples can be very useful for exploring how sensitive the outcome of an analysis is to different and often controversial parameter assumptions such as the discount rate, the treatment of inflation, and the economic life of a project.

In 1983 the Florida Department of Transportation (FDOT) completed a study, A Comparative Analysis of Asphalt and Cement Concrete (1), on the relative

merits of the use of these two products for highway construction. The portion of that study concerned with conducting a life-cycle cost analysis is discussed in this paper. The following issues are specifically addressed.

1. Is the initially higher construction cost of cement concrete pavements mitigated by reduced future maintenance costs and longer facility life?
2. Will the future price of asphalt, as a scarce natural resource, further erode the initial cost advantage of asphalt pavement?

The employment impact of a public investment decision is often considered more important by policy makers than minimizing the cost of an investment, especially during periods of economic contraction. Despite the apparent interest of elected officials in the economic impact of a project, the issue has seldom been the subject of empirical research. For this reason the FDOT study was broadened to include an assessment of the earnings and employment effects of each pavement design using Florida-specific multipliers from the Regional Input-Output Modeling System (RIMS II) developed by the U.S. Bureau of Economic Analysis.

The focus of this paper is on the analytic approach rather than the results of this Florida-specific case. Although other designs in other regions may produce different outcomes, the same principles and techniques of economic analysis should still be applicable.

PROJECT DESCRIPTION

For cost comparison purposes we selected a typical rural four-lane Interstate project designed to provide adequate capacity and structural strength for the estimated traffic volume for 20 years. It was assumed that after this period traffic would increase through the 30th year until the carrying capacity of the roadway was exceeded and the roadway required major widening and reworking, ending the economic life of the initial roadway. Using current FDOT design procedures, the two pavement designs (asphalt and nonreinforced concrete) shown in Figure 1 were prepared based on the assumption that during the 20-year design period there would be 10 million 18-kip equivalent single axle loads in the design lane. The asphalt pavement design uses a stage construction concept that provides an initial pavement and base thickness sufficient for the first 10-year loadings with a planned second stage pavement layer to be added after the tenth year. The combination of the first and second stage construction provides an asphalt pavement design equivalent to the concrete pavement design.

Based on these designs the quantity of materials required to construct a 1-mile section of Interstate was calculated for each pavement type. Design component costs, given in Table 1, were then estimated based on 1983 prices for similar new Interstate construction projects in Florida.

To determine the total life-cycle cost of equivalent pavement sections, it was assumed that 30 years represents the economic life of a successful project and is an appropriate period of analysis. All major rehabilitative activities and annual routine pavement maintenance expenditures were then estimated as well as the salvage value of the pavement materials in place at the end of the 30-year period. Estimates of the annual expenditures for routine maintenance on each pavement type for the hypothetical 1-mile section were $528 for asphalt and $1,044 for concrete. These estimates were based

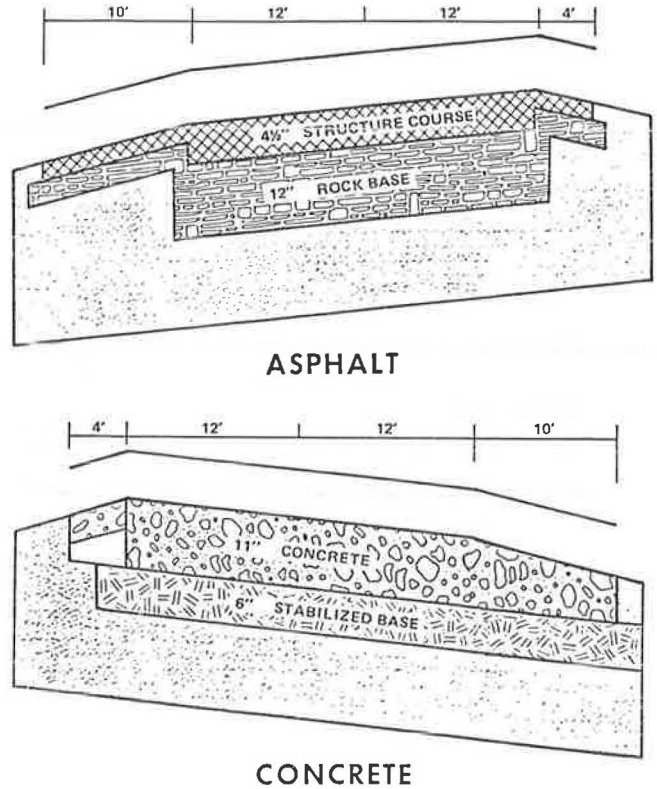

FIGURE 1 Typical sections of alternate pavement designs for initial construction.

on the historic expenditure experience of the FDOT for asphalt and concrete Interstate roadways. Terminal values were also estimated using $0 per ton for concrete pavement and $8 per ton for asphalt pavement. These figures are the estimated differences in the cost to salvage old pavements in rural settings and the market value of the recycled material to be used on other projects. Table 1 gives the life-cycle components and their cost estimates in 1983 dollars.

LIFE-CYCLE COST ANALYSIS

This study provides a description of the economic principles, analytic techniques, and primary conclusions reached in performing a life-cycle cost (LCC) analysis of asphalt and concrete pavement designs for a typical rural highway section. Maximizing economic efficiency is the decision criterion implicit in this technique. Therefore, even though other factors may also be important, the pavement design with the lowest LCC would be the most economically efficient choice.

Discounting and Opportunity Cost of Capital

The concept of LCC should be understood to represent an economic assessment of competing design alternatives, considering all significant costs over the life of each alternative, expressed in equivalent dollars (2). A key to LCC is economic assessment using equivalent dollars. For example, assume one person has $1,000 on hand, another has $1,000 promised 10 years from now, and a third is collecting $100 a year for 10 years. Each has assets of $1,000. However, are the assets equivalent? The answer is

TABLE 1 Life-Cycle Components and Cost[a]

Design Element	Asphalt	Cost ($)	Concrete	Cost ($)
Initial construction				
Surface	4½ in. (stage 1)	346,041	11 in. concrete	673,016
Base	12 in. rock	198,940	6 in. sand and stone	92,712
Major maintenance				
10 years	2 in. (stage 2)	219,890	Reseal joints	33,131
20 years	Recycle	179,018	Reseal joints	33,131
Routine annual maintenance		528		1,044
Terminal	7½ in. pavement	94,336	11 in. pavement	0

[a]1983 dollars.

not simple because the assets are spread across different points in time. To determine whose assets are worth most, a baseline time reference must first be established. All dollar values are then brought back to the baseline, using proper economic procedures to develop an equivalent dollar value. Given the time value of money, today's dollar is simply not equal to tomorrow's dollar. Money invested in any form earns, or has the capacity to earn, interest so that a dollar today is worth more than the prospect of a dollar at some future time. The same principle applies when comparing the cost of various pavement design alternatives over time.

Each alternative may have a different stream of costs that must be transformed into a single equivalent dollar value before a meaningful comparison can be made. The rate at which these alternative cost streams are converted into a single equivalent dollar value is referred to as the discount rate.

The time value of money concept applies far beyond the financial aspects of interest paid on borrowed money. First, money is only a medium of exchange that represents ownership of real resources--land, labor, raw materials, plant and equipment--that are diverted from one use to another. Second, the most important concept in the use of a discount rate is the opportunity cost of capital (3-7). The funds expended for a government project are not funds that would otherwise stand idle. They are obtained by the government from the private sector, either by taxation or by borrowing, or from the government itself by diverting funds from other purposes. If left in the private sector, such funds will be put to use there, and in that use will earn a return that measures the value society places on the use of funds. If the funds are diverted to government use, the true cost of the diversion is the return that would otherwise have been earned. The cost is the opportunity cost of capital and is the correct discount rate to use in calculating the LCC of various pavement design alternatives.

Inflation

The issue of how to deal with inflation in LCC studies is important because the procedure adopted for the treatment of inflation can have a decided effect on the results of an analysis. First, the difference between two types of price changes must be carefully identified: general inflation and differential price changes. The former may be defined as an increase in the general level of prices and income throughout the economy. Differential price change means the difference between the price trend of the goods and services being analyzed and the general price trend. During the period of analysis some prices may decline whereas others may remain fairly constant, keep pace with, or exceed the general trend in prices.

Distortions in the analysis caused by general inflation can be avoided by making appropriate decisions regarding the discount rate and the treatment of future costs. The discount rate for performing present-value calculations on public projects should represent the opportunity cost of capital to the taxpayer as reflected by the average market rate of return. However, the market or nominal rate of interest includes an allowance for expected inflation as well as a return that represents the real cost of capital. For example, a current market rate of interest of 12 percent may well represent a 7 percent opportunity cost component and a 5 percent inflation component. The practice of expressing future costs in constant dollars and then discounting these costs using the market, or nominal, rate of interest is in error and will understate the LCC of an alternative. Similarly, the practice of expressing future costs in inflated, or current, dollars and then discounting the costs using the real cost of capital would overstate the LCC of an alternative.

The distortion caused by general inflation may be neutralized in two ways. One is to use the nominal rate of interest (including its inflation premium) for discounting, while all costs are projected in inflated or current dollars. The other is to adjust the nominal rate of interest for inflation, discounting with the real rate component only, while measuring the cost stream in constant dollars. Because of the uncertainty associated with predicting future rates of inflation and in view of the similar results achieved by following either method, a discount rate has been used that represents the real cost of capital while calculating LCC in constant dollars. Because it avoids the need for speculation about inflation in arriving at the economic merit of a project, this procedure is generally accepted in the engineering profession (2,3,6) and is recommended by the U.S. Office of Management and Budget (8).

Although the distortions caused by general price inflation can be easily neutralized, the issue of incorporating differential, or real, price changes into an economic analysis is an extremely complex matter. Authorities such as Winfrey (9,pp.247-248), Lee, and Grant (10,p.253;11) have recommended the use of differential prices only when there is overwhelming or substantial evidence that certain inputs, such as land, are expected to experience significant price changes relative to the general price level. It is the preferred practice, and the one followed in this study, to incorporate differential prices in a separate sensitivity analysis. At the point where a decision is reversed, the differential prices can be carefully examined to determine if there is a high probability that they will prevail.

Comparative Analysis

This section provides a comparative LCC analysis of

an asphalt and a concrete pavement design. In line with the previous discussion, differential prices were not included in this phase of the analysis but are fully considered in a separate sensitivity analysis.

Both the expected physical life and the possibility of technological obsolescence serve as upper limit parameters in estimating the life of a project. The critical determinant, however, will be the economic life of the project. The latter is that estimated period of time extending from the date the project is complete and service actually begins to the date when the project is no longer economically viable. With this in mind, 30 years has been selected as the most appropriate period of analysis. However, for comparative purposes a 40-year analysis period is also included.

Selection of a discount rate can be a crucial parameter in LCC analysis. A high discount rate means a lower life-cycle cost for those design alternatives the costs of which are incurred late in their economic life. Similarly, a low discount rate means a much higher life-cycle cost for these same design alternatives. It is believed that the true social opportunity cost of capital, before taxes and after inflation, is approximately 7 percent and this is the correct discount rate to use in an LCC analysis. Predictably, the selection of a discount rate has generated a diversity of opinion (3,8,12,13). Because the results of this analysis may be sensitive to the discount rate used, calculations will be performed at two additional discount rates (5 and 10 percent), which represent the extreme upper and lower range of current opinion.

Computational Formulas

$$PV = IC + (P/F,r,N_2)(STG2) + (P/F,r,N_3)(STG3) + \ldots (P/F,r,N)(STGN) + (P/A,r,N)(AMC) - (P/F,r,N)(TSV)$$

where

PV = present-value cost per mile of concrete or asphalt pavement;
IC = initial cost per mile of concrete or asphalt pavement;
N_i = analysis period (yr);
r = discount rate (5%, 7%, 10%);
STG2 = stage 2 cost per mile, overlay for asphalt pavement, joint resealing for concrete pavement;
STG3 = stage 3 cost per mile recycling for asphalt pavement, joint resealing for concrete pavement;
STGN = final stage cost per mile, recycling for asphalt pavement, joint resealing for concrete pavement;
AMC = annual maintenance cost per mile of either concrete or asphalt pavement; and
TSV = terminal salvage value of asphalt pavement.

$(P/F,r,N_i)$ = Single Payment Present-Worth Factor = $1/(1 + r)^{N_i}$

where

r = discount rate and
$N_i = N_2, N_3, \ldots N_n$.

$(P/A,r,N)$ = Uniform Series Present-Worth Factor = $[(1 + r)^N - 1]/r(1 + r)^N$

where

r = discount rate and
N = analysis period.

Results of Comparative Analysis

The results of the comparative LCC analysis are provided in Table 2 for the two alternative pavement designs. To test the sensitivity of these results to changes in certain key parameters, two additional discount rates are considered and a 40-year analysis period is included.

TABLE 2 Total Life-Cycle Present-Worth Cost Comparison

Alternative	Discount Rate (%) 5	7	10
30-year life-cycle cost ($)			
Concrete pavement	814,603	804,087	793,268
Asphalt pavement	733,734	697,182	655,939
40-year life-cycle cost ($)			
Concrete pavement	824,134	809,402	795,534
Asphalt pavement	782,925	726,527	670,048

Largely because of the use of stage construction, the results indicate a clear and decisive advantage of asphalt over concrete pavement. Note that these results are not sensitive to changes in key parameters. The life-cycle cost of the asphalt pavement design is significantly lower regardless of the discount rate or period of analysis chosen.

Sensitivity Analysis

The issue of incorporating differential, or real, price changes in an LCC analysis is an extremely complex matter. Authorities have recommended the use of differential prices only when there is overwhelming or substantial evidence that certain inputs are expected to experience significant price changes relative to the general price level. The key question is what constitutes "overwhelming evidence"? Overwhelming evidence is interpreted here to mean long-term historic experience, based on an economic phenomenon that is clearly understood and reasonably predictable. There are few examples where there is an indication that the real price of some input is likely to increase over a 30- to 40-year period. It is important to remember that real price increases represent those increases in excess of the general inflation rate.

It is often argued that the real price of land, especially in highly congested areas, has increased over the long term. This is because there is an absolutely fixed supply of land and therefore each successive use intensifies a scarcity problem. Real prices are thus forced up by rising demand.

Another argument is frequently made that energy, in particular petroleum, is a scarce natural resource, limited in supply, that will exhibit real price increases in the future. In addition, the activities of the Organization of Petroleum Exporting Countries (OPEC) cartel, it is believed, will lead to price increases above those expected for a scarce natural resource. Although these arguments provide compelling examples, a closer examination of the energy issue reveals the complexity of trying to anticipate what may happen to the long-term price of petroleum.

First, cartels have historically experienced only short-term success. The prevailing view of OPEC is that it has not yet demonstrated its ability to control prices over a long period of time. Second, although petroleum is recognized as a scarce natural resource, there are mitigating factors, such as new discoveries, technological change, substitution, and conservation (14,pp.129-147) that may moderate price

increases. These factors cannot be ruled out on the basis of our recent energy experience.

Although the scarcity argument provides a strong case for believing that the real price of petroleum will increase over the long run, a closer examination of these issues reveals that, given the previous discussion, this may not occur. Even if real price increases for petroleum do occur, predicting their timing and magnitude would be highly speculative.

The case for incorporating differential price changes in a comparative analysis of asphalt and concrete pavements is even weaker and more ambiguous. Certainly the same criterion should be required: long-term historic experience based on a phenomenon that is clearly understood and reasonably predictable. Unfortunately, this criterion presents several problems such as which price index and time period to use as a historic guide. Which period is most appropriate? A variety of different and probably erroneous assumptions about the future is possible depending on the historic period selected.

There are also other problems. The criterion that requires overwhelming evidence before differential prices can be used in LCC analysis still applies. A history of real price changes must be based on an economic phenomenon that is clearly understood before one can reasonably predict that these trends will continue over a 30-year period. Historic price trends, unsupported by an underlying economic rationale, may merely reflect a statistical artifact. Is the underlying basis for real price changes in both asphalt and concrete pavements clearly understood? Certainly the cost of both is inseparably linked to the price of energy, and the price of energy has experienced unprecedented instability during the past decade. Other factors such as demand, industrial structure, and the cost of labor are also important but have obscure and uncertain impacts. All of these conditions make it extremely difficult to predict future price trends; consequently, the criteria for establishing overwhelming or substantial evidence have not been met.

Nevertheless, the purpose of a sensitivity analysis is to determine how sensitive results may be to variations in uncertain parameters. How would differential prices, even if incorporated in this analysis, alter the results? Instead of arbitrarily selecting a historic period as a guide to the future, it was decided to use an established econometric model, Data Resources, Inc. (DRI), to forecast real price trends (15). This approach is more rigorous in that it relies on a model that explicitly contains an underlying economic rationale that can be tested statistically.

Although the DRI forecast does not provide a prediction of the real price changes in asphalt and concrete, the costs of both are inseparably linked to the price of energy. According to Data Resources, the real price of U.S. oil, which will be used as a surrogate for the future price of asphalt, is expected to increase at a compound annual rate of 2.6 percent (15,p.1.118).

The sensitivity analysis was conducted by applying the 2.6 percent escalator to the estimated cost of the asphalt material contained in the stage 2 and the recycling elements of the asphalt pavement design. Of the stage 2 costs ($219,890), $78,840 is asphalt material. Of the recycling costs ($179,018), $14,250 is asphalt material (see Table 1).

Although a real price increase of 2.6 percent may seem small, it is important to remember that real price increases represent those increases in excess of the general inflation rate. Further, the compounding effect of such a price increase over a 30-year period would have a significant effect on the real cost of highway construction. Such a growth rate would provide ample incentive for technological change and substitution. However, the sensitivity analysis has been conducted as if the 2.6 percent real growth rate held over the entire analysis period, 30 and 40 years, and no technological breakthroughs or substitutions occurred to reduce asphalt consumption. Recent studies of the use of sulphur as an asphalt extender or substitute are examples of how technological progress often makes long-term projections based on current technology difficult (16).

Results of Sensitivity Analysis

The results of the sensitivity analysis are presented in Table 3. The purpose of a sensitivity analysis is to identify the turning points in a decision. In particular, the sensitivity analysis should indicate whether the strongest argument for the highest cost alternative is sufficient to change the results of the comparative analysis. In this case the comparative analysis (Table 2) and the sensitivity analysis (Table 3) are in agreement. This strengthens confidence in the results of the comparative analysis.

Both Tables 2 and 3 should be interpreted as efforts to depict the relative confidence that could be placed in making a decision based on a 7 percent discount rate at 30 years. Table 2 indicates that widening the discount range or the project life does not affect the choice. The results indicate a clear and decisive economic advantage to asphalt pavement over concrete pavement in this case study. In Table 3 the life-cycle cost of the concrete pavement alternative is higher under the most extreme parametric assumptions--a 5 percent discount rate at 40 years with a projected 2.6 percent real increase in the price of asphalt material. The results of the sensitivity analysis further confirm the outcome of the comparative analysis.

TABLE 3 Total Life-Cycle Present-Worth Cost Comparison with Escalator

	Discount Rate (%)		
Alternative	5	7	10
30-year life-cycle cost ($)			
Concrete pavement	814,604	804,087	793,268
Asphalt pavement	750,603	710,637	665,691
40-year life-cycle cost ($)			
Concrete pavement	824,135	809,402	795,534
Asphalt pavement	803,618	742,153	680,157

ECONOMIC IMPACT ANALYSIS

An implicit assertion, on behalf of the cement and concrete industry, is that the use of concrete pavement in highway construction generates a significantly greater local earnings and employment impact than does the use of asphalt (1). Two lines of reasoning are generally offered in support of this assertion. First, concrete highway construction is more labor intensive than asphalt construction. Second, whereas asphalt is an essential component of imported petroleum, all cement and concrete products are locally produced and therefore their use has a greater economic impact.

Elected officials often find these assertions compelling because the employment impact of public

investment may be considered more important than achieving economic efficiency, especially during periods of economic contraction. Unfortunately, the issue is seldom approached quantitatively except in the most casual manner. An empirical evaluation of the earnings and employment impact of these two designs could substantially improve public decision making by removing some of the ambiguity surrounding this issue.

Regional Input-Output Modeling System

This type of economic assessment has previously required the development of an input-output model that was complex, time consuming, and expensive to construct. Recently these problems have been overcome with the development of the Regional Input-Output Modeling System (RIMS II) by the Regional Economic Analysis Division of the Bureau of Economic Analysis (BEA), U.S. Department of Commerce (17). The RIMS II provides region-specific multipliers for a single county or groups of counties and industry-specific multipliers for any of the 496 industrial sectors contained in the 1972 BEA national input-output table. These multipliers are obtained by a standard and consistent methodology at reasonable cost and permit the estimation of the relative impact of investing in either asphalt or concrete highway construction projects.

RIMS II provides earnings multipliers that may be used to estimate the employment impact of projects. The model also provides a table of direct coefficients and a table from which output multipliers can be calculated for each industry. However, for public decision purposes, earnings and employment effects are the most appropriate indicator of economic activity.

Methodology and Results of Impact Analysis

There are computational problems associated with the application of the RIMS II input-output model to this public investment issue. The two industries involved are not separate and uniquely defined industries in the RIMS II model. Consequently steps had to be taken to differentiate asphalt highway construction from cement concrete highway construction because each type of construction activity represents unique goods and services.

To account for these differences, the construction cost of each design was disaggregated into various input cost categories based on the FDOT contract estimating system (CES). This computerized system estimates material, equipment quantities, and prices and establishes task and crew configurations, providing the scope of work and production rate for each item (18). It provides the data a hypothetical contractor would need to bid each potential construction contract. Based on information from the CES, the estimated cost of each design (see Table 1) was disaggregated into the following broad input categories consistent with the RIMS II model: highway construction labor cost; the cost of highway construction equipment; and the cost of asphalt, lime rock, and portland cement concrete.

The following step-by-step procedure was used to estimate the earnings and employment impact of the two pavement designs for the 30-year analysis period.

1. Because of its uncertain geographical distribution, and estimated profit/overhead margin of 25 percent embedded in the cost of construction (Table 1) was viewed as a leak from the Florida expenditure-earnings stream and was therefore removed. It should be noted that this adjustment affects all input categories equally; therefore the outcome of the comparative analysis of the two industries is not affected. Because the cost of annual routine maintenance was inconsequential, it was excluded from the impact analysis.
2. The adjusted cost of construction for each pavement design was distributed among the five input cost categories. In terms of input-output analysis the expenditures in each category represent a change in final demand.
3. The adjusted cost of each category was deflated to 1972 dollars (using implicit price deflators for Gross National Product). This step is necessary because the RIMS II model is based on the 1972 National Input-Output model and the various activities under study may have experienced different price changes during that period. To use 1983 dollars could introduce a systematic error into the computations.
4. The cost of each category (1972 dollars) was multiplied by the corresponding RIMS II earnings multiplier and then summed to yield an estimated total earnings impact for each pavement design and for each year in which the expenditure would be made (years 1, 10, and 20).
5. Using BEA personal income data, employment effects were estimated by dividing the total earnings impact for each pavement design (in the year expenditures were made) by the 1972 Florida average annual earnings per employee ($7,385).

The outcome of these calculations is given in Table 4. The cost of construction (1983 dollars); earnings (1972 dollars); and number of persons employed for a 1-year period, full-time equivalent employment (FTE), are reported for each pavement design. In the first year, the concrete pavement design has a greater absolute employment impact (30.9 versus 18.7) and a 17.6 percent greater employment impact per $10,000 of construction cost. During the total 20-year construction period, concrete pavement has a much smaller absolute employment advantage (34.3 versus 31.4) but a slightly larger employment impact (24 percent) per $10,000 of construction cost. To a public decision maker interested in employment impacts, the short-run, first-year impact would be more significant.

TABLE 4 Estimation of the Earnings and Employment Impact of the Two Pavement Designs

Pavement Type	Cost ($)[a]	Earnings ($)[b]	FTE Employment	FTE Employment Cost (per $10,000 construction)
Year 1				
Asphalt	544,981	137,966	18.7	3.4
Concrete	765,728	228,411	30.9	4.0
Year 10				
Asphalt	219,890	47,151	6.4	2.9
Concrete	33,131	12,734	1.7	5.1
Year 20				
Asphalt	179,018	46,824	6.3	3.5
Concrete	33,131	12,734	1.7	5.1
Total				
Asphalt	943,889	231,941	31.4	3.3
Concrete	831,990	253,879	34.3	4.1

[a]Cost in 1983 dollars.
[b]Earnings in 1972 dollars.

There are, however, several important limitations in using this type of model to determine the impact of construction expenditures during a 20-year period. Input-output models, such as RIMS II, are unable to adequately handle substitution effects. Although Conway (19) has demonstrated that changes

in technical coefficients during 5- to 10-year time periods are small, the reliability of these coefficients when used over much longer time periods must be viewed with caution. In addition, unlike LCC analysis, input-output models do not account for society's collective rate of time preference that relates the value of some future benefit to the value of an equivalent benefit available today. Consequently there is uncertainty about what value to place on future earnings and employment. Therefore Table 4 must be viewed from an interpretive, judgmental perspective. The missing concept, which is captured by LCC analysis through discounting, must be supplied subjectively by the reader.

Despite these limitations, input-output models are appropriate tools for this type of analysis. They allow the analyst to focus on one particular economic activity and capture the fully multiplied impact of alternative public spending decisions on a regional economy.

Nevertheless, there are several unresolved problems in interpreting the outcome of this analysis. First, the model employed does not distinguish directly between these two pavement designs. The process of interpreting data and assigning cost estimates to given industries is a source of imprecision. Second, the data used are estimates and are a second source of imprecision. Third, although the outcome of the analysis favors concrete, there is no decision rule in impact analysis comparable to that of LCC analysis where the lowest cost pavement design is considered the most economically efficient choice. Therefore, decision makers must apply interpretive judgment to the value of these conclusions.

Although the model and analytic approach have the capacity to discriminate between two products, the results are not entirely conclusive because of these problems. Nevertheless, these results are useful for dismissing the argument that either product has a significantly larger economic impact than does the other.

This has been a limited analysis. A larger research effort, beyond the scope of this paper, may find this analysis more useful when balanced among a wider range of topics such as business-cycle policy, economic efficiency arguments, and agency budget constraints.

CONCLUSIONS

In this particular study, using specific designs for a hypothetical rural Florida project and 1983 Florida estimated costs, the asphalt pavement design was the clear and unambiguous economic choice at 5, 7, and 10 percent discount rates and for both 30- and 40-year project lives. A sensitivity analysis of energy price impacts was conducted by assigning asphalt material prices a 2.6 percent differential inflation rate. The asphalt pavement design was again the economic choice in all comparisons.

An economic impact analysis, which consisted of an assessment of the earnings and employment effects of each design, was accomplished by applying an input-output model, RIMS II, to industry-specific input costs. The study found an employment benefit in the use of concrete; however, the interpretation of this advantage must be left to the decision maker. Further research is recommended.

A comparative life-cycle cost analysis should be conducted routinely. It has great potential for resolving ambiguous public debate as well as for maximizing the economic efficiency of public expenditures.

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The contents of this paper 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 of the Florida Department of Transportation.

Discussion

Robert Roy and Gordon K. Ray*

The paper by Sandler, Denham, and Trickey of the Florida Department of Transportation is an example of how life-cycle cost analysis can be applied to the evaluation of alternate pavement types, namely asphalt and concrete. Unfortunately, although they have correctly applied the life-cycle cost technique in a technical sense, several of their assumptions that are critical to the whole analysis are subjective and far removed from economic or engineering reality. This discussion will focus on three assumptions:

1. The choice of the appropriate real discount rate,
2. The choice of the appropriate time span between resurfacings of asphalt pavements, and
3. The choice of a salvage value for concrete pavements.

The word "choice" is stressed because there are no fixed, immutable assumptions in life-cycle cost analysis. Alternative calculations will be presented later using different assumptions than those used by Sander et al. The outcomes are substantially different--the life-cycle cost of the concrete pavement design is lower than asphalt in virtually every instance.

THE "REAL" REAL DISCOUNT RATE

Sandler et al. have not considered actual real interest rates (i.e., adjusted for inflation) at all in their paper, let alone real interest rate trends over the past three or four decades. They assume a real discount rate (or a range of real rates) with no empirical justification. Considering the actual course of inflation and interest rates during the past 30 years, the conclusion is clear--the "real" real discount rate is much lower than Sandler et al. assume.

Although there is some controversy among monetary economists about whether real interest rates are constant over time, there is almost total agreement among them that the expected real rate of interest

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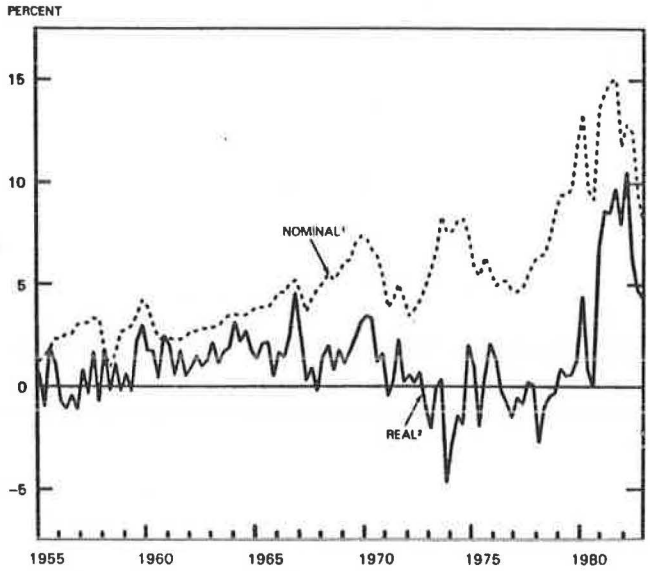
virtually always falls between 0 and 4.5 percent, with a typical value somewhere between 1 and 2.5 percent. This range holds regardless of how inflation is measured, of which particular interest rate is chosen, or of whether current inflation is compared with future or current interest rates. It holds regardless of the time period under consideration--before World War I, between the Wars, after World War II, or since 1970.

Real interest rates have been negative at times in the past, and, of course, they have been quite high recently, but these are temporary phenomena resulting from the sluggish adjustment of market interest rates to a lasting change in inflation. After a period, if a change in the inflation rate proves to be permanent, market interest rates adjust along with inflationary expectations. The real interest rate reverts back to its longstanding historical range.

EXAMPLE

In this example the real interest rate has been calculated by subtracting the price deflator for personal consumption expenditures from the 91-day U.S. Treasury bill (T-bill) rate (see Figure 2). The data are reported on a quarterly basis at a compound annual rate. This measure of inflation comes from the GNP accounts computed by the U.S. Department of Commerce and is widely considered to be one of the



¹CONVERTED TO EFFECTIVE ANNUAL YIELD FROM DISCOUNT BASIS.

²EQUALS NOMINAL YIELD LESS ACTUAL RATE OF INFLATION, DEFINED BY PERSONAL CONSUMPTION DEFLATOR, OVER THE PERIOD TO MATURITY. DEFLATOR FOR FIRST QUARTER 1983 FORECAST BY COUNCIL OF ECONOMIC ADVISERS.

SOURCES: DEPARTMENT OF COMMERCE, BOARD OF GOVERNORS OF THE FEDERAL RESERVE SYSTEM, AND COUNCIL OF ECONOMIC ADVISERS.

FIGURE 2 Nominal and real 3-month Treasury bill yield.

best overall measures of inflation. The 91-day T-bill rate is used because of its quarterly maturity. Data were collected from the first quarter of 1956 to the first quarter of 1983, or 112 quarters (28 years).

The real T-bill interest rate as calculated here ranged from a low of negative 4.7 percent in the first quarter of 1974 to a high of 8.4 percent in the second quarter of 1982. The average real T-bill rate was 1.2 percent in this 28-year period with a standard deviation of 2.2 percentage points. The real T-bill rate had no statistically significant trend either upward or downward. Standard confidence tests indicate that the following outcomes could be expected:

	Number of Quarters the Real T-Bill Rate Is Expected to Exceed			
Future Time Frame	4.1%	4.9%	6.4%	7%
100 quarters or 25 yr	10	5	1	0.5
120 quarters or 30 yr	12	6	1.2	0.6
160 quarters or 40 yr	16	8	1.6	0.8

Thus, from the standpoint of probability, one would expect the real T-bill rate to exceed 4.1 percent only 16 times in the next 160 quarters (or 40 yr) and to exceed 6.4 percent only once or twice. One would expect the real T-bill rate to surpass 7 percent only one quarter every 50 years. This example and common sense indicate that current real interest rates will not and cannot persist for long. Yet, Sandler et al., without any empirical prototype use real discount rates of 5, 7, and 10 percent.

It might be argued that past economic relationships give no guide to the future, but this is a faulty assumption. There are fundamental inconsistencies in today's economy that cannot continue unresolved. The economy cannot keep expanding with abnormally high real interest rates. Either market interest rates must decline or inflation must increase, and, if the latter were to occur, the expansion still would not last. In either case real interest rates will decline to their historical range of 0-4.5 percent. Certainly, when evaluating a public project with an expected life of 30-40 yr, it would not be appropriate to challenge an empirical relationship that has been validated as far back as the nineteenth century just because of a few abnormal quarters in 1981 and 1982.

TIME INTERVAL TO FUTURE EXPENDITURES

A second factor that can distort life-cycle costs is the assumption of unrealistic time intervals until future expenditures are made. Because the effect of applying a discount rate is to reduce the present value of future costs, the longer costs are deferred, the lower the discounted present value.

Sandler et al. assume that flexible pavement will have a second stage applied in 10 yr and be recycled at 20 and 30 yr. This assumption greatly understates the cost of these future expenditures. In a communication to the Legislative Transportation Committee, the Florida Department of Transportation documented that the weighted average age to second stage for Florida Interstate flexible pavements was 6.3 yr. Confirming this was a study conducted by the Portland Cement Association in 1983 of all Interstate highways in Florida, both flexible and rigid, showing that the weighted average interval of flexible pavements to overlay (either second-stage or major maintenance resurfacing) was 6.4 yr.

TERMINAL VALUES

Also significant in the life-cycle cost analysis are the estimates by Sandler et al. of terminal values of material for recycling of $8 per ton for asphalt pavement and $0 per ton for concrete pavement. Both airport and highway concrete recycling projects throughout the nation indicate that $4 per ton for old concrete would be more realistic.

NEW RESULTS

Table 5 has been prepared to correspond with Table 2

TABLE 5 Alternative Total Life-Cycle Present-Worth Cost Comparison

Alternative	Discount Rate (%) 7		3		0	
	FDOT Analysis[a]	Revised Analysis[b]	FDOT Analysis	Revised Analysis	FDOT Analysis	Revised Analysis
30-year life-cycle cost ($)						
Concrete pavement	804,087	804,087	829,265	790,790	863,310	769,922
Asphalt pavement	697,182	826,042	779,160	975,091	865,403	1,154,919
40-year life-cycle cost ($)						
Concrete pavement	809,402	803,166	846,506	817,877	906,881	813,493
Asphalt pavement	726,527	865,649	860,900	1,076,322	1,037,000	1,414,609

[a]10-yr flexible major maintenance cycle, $0/ton for recycled concrete.

[b]6.4-yr flexible major maintenance cycle, $4/ton for recycled concrete.

in the Sandler et al. paper. The real discount rate selected by Sandler et al. of 7 percent is shown, but rates of 3 and 0 percent are also shown. The 3 percent real discount rate represents the upper limit based on the historical record even when risk factors and administrative costs are added. The 0 percent real rate represents the rate selected by many state highway departments that use neither imputed interest nor inflation; the figures shown for 0 percent are simply the undiscounted, estimated dollar expenditures over the analysis period.

Under each discount rate in Table 5, column 1 is calculated using the same assumptions for all costs and time periods that were used by Sandler et al. With the 7 percent discount rate chosen by Sandler et al., the asphalt pavement design is shown to have the lower life-cycle cost. However, when a more realistic 3 percent real discount rate is used, the 40-yr analysis favors the selection of concrete. When a 0 percent real discount rate is used, both the 30- and 40-yr analyses favor concrete.

When a more realistic overlay cycle of 6.4 yr is used for asphalt and a recycling value of $4 per ton is attributed to old concrete, the figures in column 2 are derived. Although the routine maintenance costs used by Sandler et al. are questionable, they have been used again. The Sandler, Denham, and Trickey paper states that annual routine maintenance expenditure by Florida DOT for asphalt is $528 per mile and $1,044 for concrete "based on historical expenditure experience." In contrast, a 1984 Florida DOT letter in response to a Legislative Transportation Committee inquiry stated: "In regard to your request we have been reviewing cost data available in the department with respect to asphalt pavement and cement concrete pavement maintenance... I regret to say the systems currently in place in the department do not collect data to the detail necessary to determine life-cycle costs of pavements on a statewide basis." Under circumstances similar to these, it appears that a better procedure may be to avoid using undocumented maintenance costs. In this case, concrete becomes the preferred selection for both the 30- and 40-yr analyses, not only for 0 and 3 percent real discount rates, but even for 7 percent.

CONCLUSION

Life-cycle cost analysis is an excellent way to evaluate alternative public investments or available options for a particular public investment. However, this technique is highly sensitive to the assumptions that are made. The analysis of alternative pavement designs--concrete versus asphalt--by Sandler et al. is one example of the pitfalls of calculating life-cycle costs using inappropriate assumptions for real discount rates, costs (e.g., value of material for recycling and routine maintenance), and time intervals to future expenditures. Only if reasonable, well-documented, and empirically valid assumptions are made can the procedure maximize the economic efficiency of public investments.

Authors' Closure

The purpose of our paper was to demonstrate, within the context of a practical case study, how a life-cycle cost (LCC) comparison of alternative pavement designs should be conducted. Although Robert Roy and Gordon Ray acknowledge that LCC analysis is an excellent technique to apply to questions of pavement design and selection, they take issue with several critically sensitive arguments in our example. They are correct in highlighting the importance of choice in the assumptions used in our model, but the burden of proof is a two-edged sword that applies to their arguments as well as ours. We appreciate the opportunity to extend this discussion and thereby demonstrate that our assumptions were, in fact, reasonable, well documented, and empirically valid.

APPROPRIATE REAL DISCOUNT RATE

Despite the extensive literature on the subject, the comments of Roy and Ray on the discount rates we used in our analysis dramatically illustrate the confusion that still exists about the selection of an appropriate rate. To shed light on this issue, it may be useful to restate what the discount rate represents.

The funds expended for government projects are not funds that would otherwise stand idle. They are obtained by the government from the private sector. If left in the private sector, they will earn a return that measures the value society places on the funds. If the funds are diverted to government use, the true cost of the diversion is the return that would otherwise have been earned. This is the opportunity cost of capital and is the correct rate to use in life-cycle cost analysis.

The critical question is what market rate (or rates) of return on investment in the private sector best measures the opportunity cost of capital to be used in evaluating public projects. This is a complex issue because it involves market imperfections, risk, and the distortion arising from the corporate income tax. All of these considerations should be taken into account in determining the cost of capital.

In our view, the real interest rate suggested by

Roy and Ray, which is frequently calculated by subtacting the rate of inflation from the yield on some short-term security, is not appropriate because it does not, in any sense, represent an average rate of return on private investment. A better measure would be some weighted average yield on private claims against physical assets. This weighted estimate should include a mix of debt and stockholders' equity, including proprietorships and owner-occupied housing.

We were criticized for using a range of discount rates (5, 7, and 10 percent) without supporting empirical evidence. Although it is quite difficult, in practice, to estimate the average rate of return on private investment, an abundance of such evidence does exist. J. Stockfisch not only offers empirical evidence but also includes an excellent discussion of the theoretical issues (20). Gorman (21), Holland and Myers (22,p.151) provide additional empirical work. All of their estimates are close to the upper range of rates we used and are also consistent with those discount rates used by many federal agencies to evaluate public projects (8;13;23;24,p.A-4).

TIME INTERVAL TO FUTURE EXPENDITURES

The purpose of our study was to undertake an economic comparison of candidate pavement designs, not an economic analysis of the outcome of previous pavement design decisions. We were not concerned so much with measuring how well the FDOT had done, as with predicting the relative impact of current decisions. The FDOT's historical experience with pavement types was reflected in our candidate design standards, which were intended to improve on and not repeat the historical experience.

If, however, historical data had been used for asphalt, they should also have been used for concrete. Unfortunately, an excessive reliance on historical performance can often bias the outcome of an analysis. Florida has had only limited experience with designs using concrete pavement on rural highways. Such pavements have exhibited a great deal of variation in performance; consequently, any measure of average performance would have been unduly influenced by such major projects as Interstate 10, which is currently experiencing premature distress. If we had used the historical performance for both designs, the concrete alternative would have been dramatically penalized. For these reasons, we used asphalt resurfacing periods and concrete pavement life periods consistent with the best current design standards.

TERMINAL VALUES

At the time of our analysis, we were unable to establish a market value for recycled concrete. Because of changing technology there may now be recycling projects throughout the nation where, because of local circumstances, a market value for concrete can be established. Certainly, the parameters used in our analysis will be subject to changes over time. For example, we now understand that the value of recycled asphalt may be much higher than the $8 per ton we used in the original analysis. A far more important point is that, given the other assumptions that are much more critical, the outcome of this comparative analysis is not sensitive to the $4 per ton change in terminal value proposed by Roy and Ray.

In conclusion, our original purpose was to encourage consideration and application of life-cycle costing in questions of pavement design selection. We hope we have achieved that intent. We also appreciate the fact that our stated purpose and space constraints did not provide an opportunity for a full presentation of all the supporting empirical evidence, arguments, interpretations, and assumptions of the larger study. The issues raised by Roy and Ray are certainly relevant to the application of the life-cycle cost technique, and we hope that this extended discussion has demonstrated that the assumptions made in this particular case study were reasonable, can be well documented, and are empirically valid.

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Abridgment

Economic Analysis of Highway Investment: Recent Developments in Great Britain

A. D. PEARMAN and K. J. BUTTON

ABSTRACT

The problem of evaluating and assigning priority to proposed highway investments continues to pose difficulties, especially in an era of constrained highway budgets and increasing environmental awareness. In this paper recent developments in the economic analysis of highway investment in Great Britain are described. In Great Britain in the late 1970s, a major government inquiry (the Leitch Committee) criticized several elements of the Department of Transport's investment evaluation procedures. Particular attention was given to traffic forecasting methods, the treatment of uncertainty, the use of design standards, and the balance between economic and environmental impacts. The nature of these criticisms is described together with changes they have induced.

Formal economic analysis has for some time been an important input to the decision-making process for highway investment decisions in Great Britain. It has not, however, been without its critics, and in the late 1970s the pressure of criticism grew so great that the government was forced to institute a committee of inquiry into the procedures adopted for assessing major highway proposals. The committee, chaired by Sir George Leitch and usually referred to as the Leitch Committee, has now published its findings (1). The purpose of this paper is to outline the questions asked by the Leitch Committee, to summarize the conclusions it reached, and to assess present British practice in light of the committee's views.

HIGHWAY INVESTMENT APPRAISAL BEFORE THE LEITCH REPORT

Since 1973 COBA, a computer software package for highway cost-benefit analysis, has formed the main underpinning of official appraisal procedures in Great Britain. COBA uses discounted traffic costs and benefits and probably represents the major regular application of cost-benefit techniques for public policy making in any sector in Great Britain. Despite its widespread use, COBA is by no means a comprehensive evaluation tool, a weakness that was particularly germane to the Leitch Committee's deliberations and to the continuing debate on highway appraisal procedures.

Within the framework of Department of Transport (D. Tp.) appraisal procedures, it is useful to identify two components: the inputs to the economic appraisal and the appraisal itself.

Inputs to the Economic Appraisal

There are two particularly influential inputs to the economic appraisal--forecasts of traffic levels and the specification of the scale and detailed design of the proposed highway. The latter depended at the time of the Leitch Committee's investigations on sets of design standards. D. Tp. policy was to plan for the forecast traffic levels 15 years after the opening of a scheme. Some changes have subsequently been made in the specification and use of design standards. These will be discussed in the third section.

The primary input to the economic appraisal is