Impact of Pavement Performance Consideration on Economic Evaluation of Pavement Strategies

T. F. FWA AND K. C. SINHA

The conventional practice of economic analysis of pavement strategies does not consider the differences in pavement performance levels among the alternatives analyzed. The impact of incorporating into the analysis pavement performance consideration that explicitly quantifies differences of pavement performance levels in monetary values is examined. Studies have indicated that there exist two components, namely the agency and the user values of pavement performance, that should be included when incorporating pavement performance consideration into economic evaluation of different pavement strategies. On the basis of recently available information and estimates of the agency and user values of pavement performance, it is found that these values are of the same order of importance as the cost items commonly considered in economic evaluation of pavements. Numerical examples illustrate the impact of including pavement performance consideration in the economic analysis. Significant changes to the results of conventional economic analysis are observed for the examples studied.

A common practice among highway agencies is to evaluate the relative merits of different pavement design, construction, and rehabilitation strategies on the basis of engineering economic analysis. Life-cycle cost analysis (*1*) and benefit-cost analysis (*2*) have been the two most widely used procedures for comparing highway pavement alternatives. Both highway agency costs and road user costs are usually considered in such analyses, although the specific cost items included may differ from agency to agency. In general, under the agency cost category, pavement construction, maintenance, and rehabilitation costs are considered. Under the road user cost category, vehicle operating costs and travel and delay time costs are the items most commonly included.

The current practice of economic analysis of pavement alternatives does not take into account differences in pavement performance among the strategies considered. The strategy selected on this basis may not be the most desirable to road users and the highway agency concerned. The need to consider pavement performance in economic analysis of different strategies, together with the usual agency and user considerations, has been discussed in detail by Fwa and Sinha (*3*). They suggested that there existed two distinct components of the value of pavement performance: one related to highway agencies and the other to road users. The order of magnitude of these two values of pavement performance is examined on the basis of the findings of two recently completed surveys. These values are then applied to economic analyses reported in the literature to demonstrate how the outcomes of these analyses would have been affected if pavement performance consideration were to be included.

T. F. Fwa, Department of Civil Engineering, National University of Singapore, Kent Ridge, Singapore 0511. K. C. Sinha, School of Civil Engineering, Purdue University, West Lafayette, Ind. 47907.

MAGNITUDE OF VALUE OF PAVEMENT PERFORMANCE

As the relative level of pavement performance has never been included as a decision parameter in economic analysis of pavements, little is known about the magnitudes and characteristics of agency and user values associated with it. Recently, two studies have been conducted to quantify the value of pavement performance. A study conducted in Indiana by Fwa and Sinha (*4*) was able to express agency and user values of pavement performance in monetary terms. Another study performed by Garg and Horowitz (*5*) in Wisconsin represented the value of pavement serviceability in terms of additional travel time. The findings of these two efforts are discussed in the following sections.

Agency Value of Pavement Performance

The agency value survey in the Indiana study included 30 highway officials whose work involved decision making concerning pavement design, construction, and rehabilitation. There were 9 highway officials from the state, 12 from counties, and 9 from cities. Each of the 30 officials was asked to classify pavement projects into three sizes according to the magnitude of project costs: large, medium, and small. For each project size, an official was to indicate the additional funds he was willing to commit for an alternative with better overall average pavement performance. A detailed description of the survey procedure and results was provided by Fwa and Sinha (*4*).

In analyzing the survey responses, a physical measure known as "pavement performance quality index" (PPQI), was introduced to quantify the overall performance level of a pavement over the entire analysis period. PPQI is defined as

$$(\text{PPQI})_n = \frac{1}{(\text{ESAL})_n}\int_0^{(\text{ESAL})_n} (\text{PSI})\, d(\text{ESAL}) \qquad (1)$$

where

ESAL = equivalent single-axle loads,

PSI = present serviceability index, and
n = analysis period over which the subscripted parameters are computed.

This definition is shown schematically in Figure 1. Each PPQI can be viewed as the overall average PSI level of the pavement performance history represented. Higher PPQI values are associated with better pavement performance.

The following findings were reported in the Indiana study:

1. The agency values of pavement performance differed among highway agency levels. Officials from state highway agencies valued pavement performance more than their counterparts in county and city highway agencies. The agency values awarded by city highway officials were the lowest.
2. The agency values varied with the overall pavement performance level. Higher agency values were associated with higher values of PPQI.
3. The agency values, expressed as percentage of total project cost, were not affected by the size of project.

Figure 2 shows the results of the study. The agency value for a given PPQI can be obtained from the plot for city, county, or state highway agencies. Expressed as a percentage of total project cost, each value represents the average additional fund that highway agencies are willing to spend to

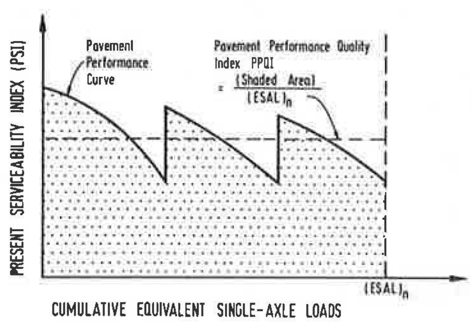

FIGURE 1 Pavement performance quality index as an overall measure of pavement performance (*3*).

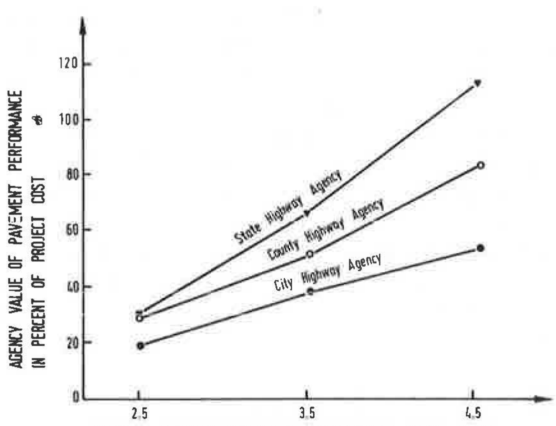

FIGURE 2 Agency value of pavement performance as a function of highway agency level and overall average pavement performance (*4*).

implement a strategy that will improve pavement performance from a PPQI level of 1.5 to the level indicated. In other words, it has been assumed that the agency value for pavement performance is zero at PPQI equal to 1.5. Between PPQI values of 2.5 and 4.5, the agency values ranged from 19 to 114 percent of project costs.

The agency value obtained from a plot such as Figure 2 can be incorporated into economic analysis of pavement alternatives by expressing it either as a form of agency benefits or as extra agency costs. If the benefits approach is adopted, the agency value for a given PPQI is obtained directly from Figure 2. In the extra agency costs approach, it is assumed that there are zero extra agency costs if a pavement strategy produces a PPQI value of 4.5. A PPQI value of 4.5 refers to a hypothetical situation where pavement PSI is maintained at 4.5, which is the PSI level of a newly constructed pavement, throughout the analysis period. Any pavement strategy that has PPQI less than 4.5 would incur an extra agency cost that can be computed from

$$(\Delta P)_k = (P)_{4.5} - (P)_k \tag{2}$$

where

$(\Delta P)_k$ = extra agency costs associated with PPQI value equal to k,
$(P)_{4.5}$ = agency value of pavement performance for PPQI equal to 4.5, and
$(P)_k$ = agency value of pavement performance for PPQI equal to k.

The values of $(P)_{4.5}$ and $(P)_k$ are obtained from Figure 2.

User Value of Pavement Performance

User values of pavement performance were addressed both by the Indiana (*4*) and by the Wisconsin (*5*) studies. Although the latter offered only an indirect assessment of the magnitude of these values, the former has provided monetary evaluation that can be used directly in an economic analyses.

In the Wisconsin study, test road sections with PSI ranging from about 4.0 to less than 1.5 were included. Participating road users were asked to estimate the amount of time they were willing to spend to avoid each test section, assuming they were to make a trip that lasted for 50 min. The survey results shown in Figure 3 are an assessment of user value in

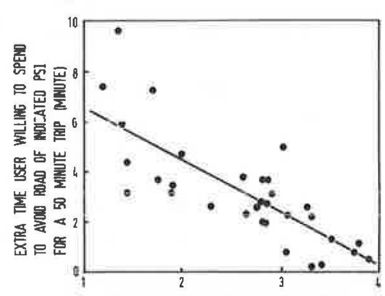

FIGURE 3 Relationship between road PSI and extra time user willing to spend to avoid a given road for a 50-min trip (*5*).

terms of travel time. The likely impact of pavement performance consideration in economic analysis can be judged by considering the expected travel time savings associated with various levels of pavement performance. Travel time savings are computed from estimated traffic speeds, a function of pavement condition. The relationships of PSI to average speed compiled by Haas and Hudson (*6*) are used for this purpose. For easy comparison, extra travel time is computed instead of travel time savings as shown in Figure 4. It is seen that user values of pavement performance are larger than user travel time costs for PSI values higher than 2.0. Because the PSI of typical pavements are higher than 2.0 for practically the entire length of their useful service lives, the comparison suggests that user values of pavement performance would be a significant factor in user costs analysis.

The user value survey of Indiana (*4*) determined how much users were willing to pay to travel on roads with better pavement serviceability. Ninety randomly selected road users of different occupational and educational background from Lafayette, Indiana, were included in the study. The results of the survey are shown in Figure 5. It was found that user values

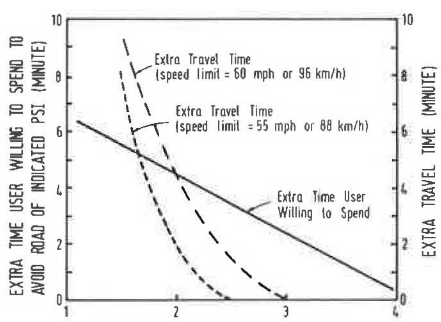

FIGURE 4 Indirect comparison in time between user travel time costs and costs user willing to pay for pavement serviceability.

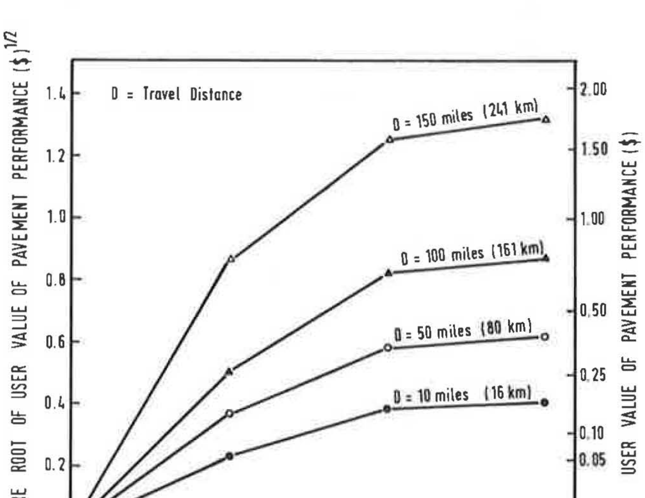

FIGURE 5 User value of pavement performance versus road condition as a function of travel distance (*4*).

varied with both travel distance and road condition. In general, user values increased with travel distance and with better pavement serviceability. The user values reported were obtained by taking the value at PSI = 1.5 as zero reference. The computed user values ranged from \$0.057 for travel distance of 10 mi and PSI of 2.5, to \$1.706 for travel distance of 150 mi and PSI of 4.5. The mean user value, expressed as monetary value per unit distance, ranged from 0.27 to 1.66 cents/mi above the reference value at PSI = 1.5. These values are comparable in their order of magnitude with those of other user cost items, such as vehicle operating costs and travel time saving costs, used in several recent pavement strategy evaluation studies (*7–9*).

For any pavement strategy, the time variation of user value of pavement performance can be derived from its time history of pavement performance. Relationships between PSI and user value of pavement performance such as those shown in Figure 5 provide the necessary information for the derivation. The total present worth of user value of pavement performance may then be calculated as follows:

$$(PW)_B = \int_0^T (S_t)(V_t)(F_t)\,dt \qquad (3)$$

or

$$(PW)_C = \int_0^T (S - S_t)(V_t)(F_t)\,dt \qquad (4)$$

where

$(PW)_B$ = present worth of pavement performance computed as user benefits,
$(PW)_C$ = present worth of pavement performance as extra user costs,
S = user value of pavement performance at PSI equal to 4.5,
S_t = user value of pavement performance at time t,
V_t = traffic volume at time t,
F_t = present worth factor, and
T = length of analysis period.

ECONOMIC ANALYSIS BASED ON AGENCY COSTS

Some highway agencies evaluate pavement alternatives on the basis of agency costs. The reasons for not considering user costs have been found to including the following (*10*): difficulty in obtaining reliable user cost data, lack of information on the relationships between pavement condition and variations of different user cost items, and the fact that user cost consideration does not have a direct link with the funding mechanism of road construction and maintenance. It is therefore relevant to examine how pavement performance consideration would affect the results of those economic analyses that include agency costs only. Two numerical examples from published literature are analyzed for illustration purposes in the following paragraphs.

Agency Cost-Based Analysis—Example 1

Figure 6 shows two design options originally analyzed by Kher et al. (*11*). The two options were compared over an analysis period of 30 years. The initial average daily traffic (ADT) was 10,000 vehicles. It was assumed to increase linearly to a magnitude of 25,000 vehicles per day at the end of the analysis period. Using a discount rate of 7 percent, the present worth of agency costs for Options I and II were computed to be \$291,100 and \$325,250, respectively. These costs included initial capital costs, resurfacing costs, maintenance costs, and salvage return values, but not values of pavement performance.

The PPQI value can be computed from Equation 1 by considering the time growth relationship of traffic loading and time variation of PSI, as follows:

$$(\text{PPQI})_n = \frac{1}{(\text{ESAL})} \int_0^{T_n} \text{PSI}(t)d[\text{ESAL}(t)] \qquad (5)$$

where T_n defines the length of analysis period. Numerical integration may be used in cases where PSI(t) and ESAL(t) cannot be expressed analytically.

Alternatively, a graphical method can be used to compute PPQI. This is achieved by first transforming the PSI-time plots of Figure 6 into PSI–ESAL plots as shown in Figure 1. This transformation can be easily performed because the time growth curve of traffic loading is known. The PPQI value may then be computed in accordance with the definition given in Equation 1.

Assuming that ESAL growth pattern is the same as the given traffic growth pattern, the PPQI values of Options I and II in Figure 6 can be shown to be 3.04 and 3.53, respectively. Using Equation 2 and the state highway agency curve of Figure 2, the extra agency costs for pavement performance are obtained as follows: \$291,000 × (1.14 − .503) = \$185,430 for design Option I, and \$325,250 × (1.14 − .683) = \$148,639 for design Option II. The total agency costs for Options I and II are therefore \$476,530 and \$473,889, respectively. Similar computations can be made if the highway authority were to be county or city highway agency. The results of these calculations are presented in Table 1.

Table 1 indicates that on the basis of conventional agency cost comparison, without considering agency values for pavement performance, Option I would be the preferred alternative. When agency values for pavement performance are included, a different conclusion could be obtained. Option II, instead of Option I, would now be selected by a state highway agency. Although a county or city highway agency would still choose Option I, the margins of difference between the two options have become smaller.

This example clearly illustrates that the outcome of economic analysis is influenced by individual agencies' values for pavement performance. The value a highway agency attaches to pavement performance represents an important feature of its pavement maintenance and management policy. Because pavement design and management policy varies from agency to agency, it is desirable for each agency to conduct its own evaluation to obtain a set of values for pavement performance that reflects its decision making and planning practices.

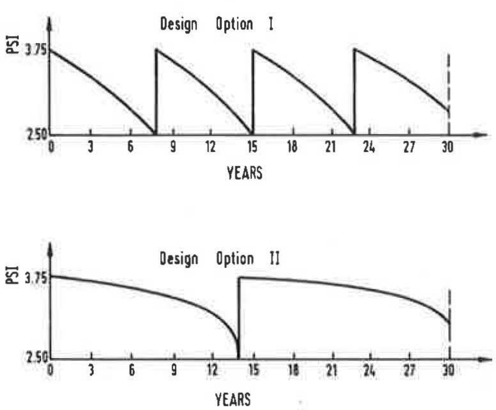

FIGURE 6 PSI versus time histories for design Options I and II considered in Example 1.

Agency Cost-Based Analysis—Example 2

In this example, a four-lane urban highway design analysis by the Maryland State Highway Administration involving comparison of eight strategies (*12*), is considered. The problem is shown graphically in Figure 7. The initial traffic was 12,000 veh/day in both directions with an annual growth rate of 5 percent. The same discount rate of 4 percent used in the original analysis (*12*) is also used in the current example.

Table 2 compares the present worth of agency costs computed with and without pavement performance consideration. The PPQI values have been calculated by assuming an ESAL growth rate equal to the traffic growth rate. Strategy 4 is the preferred choice of conventional analysis that considers construction, maintenance and rehabilitation costs, and salvage value of the pavement. When the extra agency costs associated with pavement performance are included, Strategy 1 becomes the most preferred option.

TABLE 1 SUMMARY OF RESULTS FOR EXAMPLE 1

Design Option	Agency Cost without Pavement Performance Consideration, in Present Worth	Agency Cost with Pavement Performance Consideration, in Present Worth						
		PPQI	State Highway Agency		County Highway Agency		City Highway Agency	
			Extra Cost	Total Cost	Extra Cost	Total Cost	Extra Cost	Total Cost
I	*\$291,100	3.04	\$185,430	\$476,530	\$124,591	*\$415,691	\$69,864	*\$360,964
II	\$325,250	3.53	\$148,639	*\$473,889	\$100,502	\$425,752	\$48,137	\$373,387

Note : Each entry marked with (*) represents the preferred option for the criterion indicated by corresponding column heading.

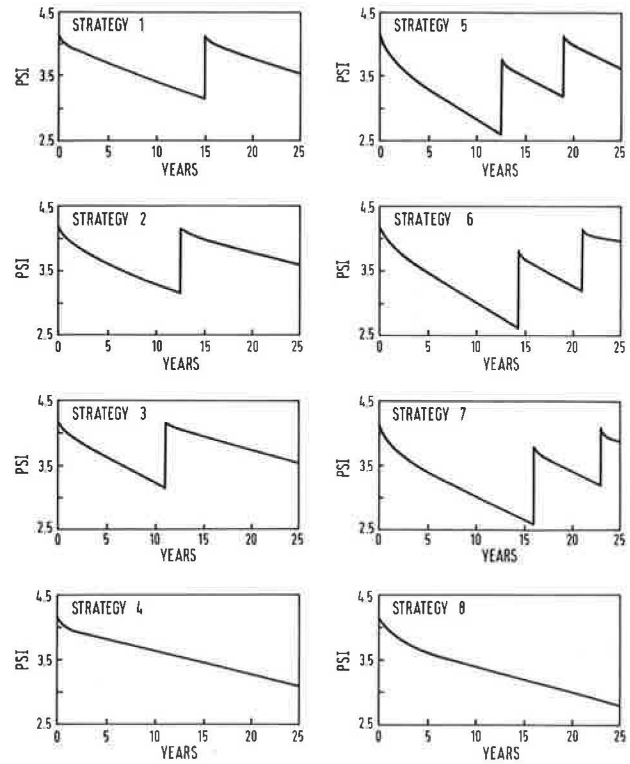

FIGURE 7 PSI versus time histories for different pavement strategies considered in Examples 2 and 4.

An examination of the relative ranking of the eight strategies in each case reveals some interesting trends and provides an insight into the significance of pavement performance consideration. Table 3 presents three lists of ranking in the order of preference according to (a) performance level (i.e., PPQI level); (b) conventional total agency cost without pavement performance consideration; and (c) total agency cost with pavement performance consideration, respectively. The comparison of the first two lists indicates that the relative ranking of Strategies 3, 2, 1, and 4 in List a becomes reversed in List b. The same also happens to Strategies 6, 5, 7, and 8. Strategy 3, which has the highest performance level, ranks last in List b. On the other hand, the strategy with the lowest performance level, Strategy 8, is the second most preferred alternative in List b.

This comparison tends to provide supporting evidence for several observations made by Fwa and Sinha (*3*). By examining the relationships between pavement performance and individual agency cost items, they have stated that (a) with given construction technology and standards, economic analysis based on construction or rehabilitation cost alone would generally favor strategies with lower pavement performance; (b) for a highway agency following a known maintenance policy, a strategy that requires low maintenance expenditure and yet is able to satisfy a minimum serviceability level over the analysis period would be selected on the basis of maintenance cost consideration; and that (c) better engineering and administrative effort helps ensure good pavement performance but requires more monetary imput. A selection criteria based on economy alone would not, therefore, favor a better pavement performance option.

The reasoning appears to be able to explain the ranking in List b of Table 3. However, this tendency to favor lower performance strategies in pavement evaluation may not be known to many engineers who use economic analysis based only on agency costs. Providing pavements with the highest possible performance level within available budget and resources is probably the foremost objective of a pavement engineer. Incorporating pavement performance consideration into economic evaluation of pavement strategies is consistent with this objective. The impact of this can be seen from the ranking in List c of Table 3. Comparison of Lists b and c indicates that some changes have taken place. High-performance strategies, such as Strategies 1, 2, and 3, now receive better preference. The ranking of Strategy 8 dropped from second to sixth position because of the relatively high extra agency costs associated with its low pavement performance level.

COMPARISON BASED ON ROAD USER COSTS

Few highway agencies, if any, would evaluate pavement alternatives on the basis of road user costs alone. However, to investigate how pavement performance consideration would affect the relative magnitude of the user costs under different

TABLE 2 SUMMARY OF RESULTS FOR EXAMPLE 2

Strategy	Agency Cost without Pavement Performance Consideration, in Present Worth	Agency Cost with Pavement Performance consideration, in Present Worth		
		PPQI	Extra agency cost	Total agency cost
1	$178,986	3.66	$70,699	*$249,685
2	$184,443	3.72	$67,322	$251,765
3	$198,566	3.75	$71,682	$270,248
4	*$173,923	3.52	$79,657	$253,580
5	$188,048	3.48	$88,759	$276,807
6	$194,568	3.51	$89,890	$284,458
7	$179,790	3.46	$86,299	$266,089
8	$177,505	3.26	$98,338	$275,843

Note: Each entry marked with (*) represents the preferred strategy for the criterion indicated by corresponding column heading.

TABLE 3 RELATIVE RANKING OF STRATEGIES CONSIDERED IN EXAMPLE 2

Rank	List (a) Ranking by Performance according to PPQI	List (b) Ranking by Agency Cost without Pavement performance consideration	List (c) Ranking by Agency Cost with Pavement performance consideration
1	Strategy 3	Strategy 4	Strategy 1
2	Strategy 2	Strategy 8	Strategy 2
3	Strategy 1	Strategy 1	Strategy 4
4	Strategy 4	Strategy 7	Strategy 7
5	Strategy 6	Strategy 2	Strategy 3
6	Strategy 5	Strategy 5	Strategy 8
7	Strategy 7	Strategy 6	Strategy 5
8	Strategy 8	Strategy 3	Strategy 6

Note : In each list, strategies are ranked in order of decreasing preference i.e. Rank 1 is the most preferred, while rank 8 is the least preferred.

pavement strategies is of interest because user costs often represent a significant share of total pavement costs. Two examples illustrate the impact of pavement performance consideration.

Road User Costs Comparison—Example 3

User costs of the two options shown in Figure 8 were analyzed by Zaniewski et al. (*8*). They reported a difference of only 1.2 percent in the vehicle operating costs of the two options.

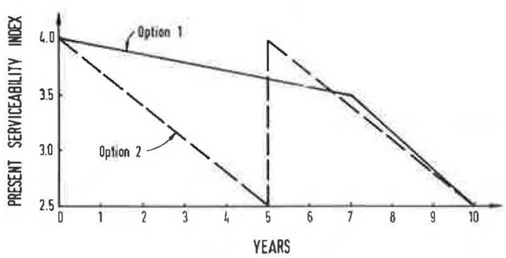

FIGURE 8 Pavement performance versus time relationship for Options 1 and 2 considered in Example 3.

The present worth of vehicle operating costs, including fuel, oil, tires, maintenance, and depreciation costs, was found to be $918,100 for Option I, and $929,200 for Option II. These were computed for an analysis period of 10 years at a discount rate of 3.75 percent, with an assumption that the daily traffic of 2,120 vehicles remained constant over the entire analysis period.

On the basis of the pavement performance data in Figure 8 and the given traffic volume information, the present worth of pavement performance can be derived using either Equations 3 or 4. Assuming the relationship of PSI to user value of pavement performance shown in Figure 5 is applicable, the present worth of pavement performance computed as extra user costs per mile for a 10-mi road segment is found to be $170,278 for Option I, and $353,723 for Option II. The total user costs, inclusive of user values for pavement performance, are $1,088,378 and $1,282,923 for Options I and II, respectively. The results, as presented in Table 4, now indicate a much more substantial difference of about 20 percent between the two options.

It should be noted that Zaniewski et al. (*8*) did not consider travel time and traffic delay costs in their calculations. These two cost items, if included, would have made Option I much more favorable than what they indicated. The inclusion of

TABLE 4 SUMMARY OF RESULTS FOR EXAMPLE 3

Pavement Option	User Costs without Pavement Performance Consideration, in Present Worth	User Costs including Pavement Performance Consideration, in Present Worth	
		Extra User Costs for Pavement performance	Total User Cost
I	*$918,100	$170,278	*$1,088,378
II	$929,200	$353,723	$1,282,923

Note : Entry marked with (*) represents the preferred option for the criterion indicated by corresponding column heading.

the user value of pavement performance, as demonstrated earlier, helps to further confirm the economic desirability of Option I.

Road User Costs Comparison—Example 4

Road user costs of the eight strategies described in Example 2 were also reported by Rada and Witczak (*12*). Two user cost strategies, namely running user costs and added user costs, were considered in the analysis. Running user costs were estimated for different PSI levels as a function of vehicle traveling speed. Added user costs are traffic delay costs caused by rehabilitation activities. The values of these two cost items for all the eight strategies are presented in Table 5. It was concluded that Strategy 1 had the lowest user cost.

Also presented in Table 5 are extra user costs associated with pavement performance levels, and the corresponding total user costs for each of the eight strategies. Strategy 1 is no longer the least cost option. It now falls behind Strategies 2 and 3, the two strategies with the highest PPQI values. The relative preference ranking of the remaining five strategies remains unchanged.

ECONOMIC ANALYSIS ON THE BASIS OF TOTAL COST

Life-Cycle Cost Analysis

The present worth value of agency and user costs, for the eight strategies described in Figure 7, have been computed in Examples 2 and 4, respectively. The life-cycle costs for each of the strategies, with and without pavement performance consideration, are presented in Table 6. Strategy 1 is the best strategy on the basis of the conventional analysis that does not include pavement performance consideration. Strategy 2 becomes slightly better than Strategy 1 in terms of life-cycle cost when agency and user values of pavement performance are included in the analysis.

TABLE 5 SUMMARY OF RESULTS FOR EXAMPLE 4

Strategy	User Cost without Pavement Performance Consideration, in Present Worth			User Cost with Pavement Performance Consideration, in Present Worth	
	Running Cost	Added User Cost	Total User Cost	Extra User Cost for Pavement Performance	Total User Cost
1	$693,356	$1,077	*$694,433	$78,999	$773,432
2	$697,955	$1,068	$699,023	$61,276	*$760,299
3	$707,155	$1,064	$708,219	$56,844	$765,063
4	$958,791	0	$958,791	$92,958	$1,051,749
5	$1,047,741	$1,965	$1,049,706	$127,459	$1,177,165
6	$1,136,997	$1,979	$1,138,976	$118,248	$1,257,224
7	$1,211,709	$1,990	$1,213,699	$129,874	$1,343,573
8	$1,289,186	0	$1,289,186	$147,708	$1,436,894

Note : Entry marked with (*) represents the preferred strategy for the criterion indicated by corresponding column heading

TABLE 6 SUMMARY OF LIFE-CYCLE COST ANALYSIS

Strategy	Life-Cycle Cost without Pavement Performance Consideration, in Present Worth			Life-Cycle Cost with Pavement Performance Consideration, in Present Worth		
	Agency Cost	User Cost	Total Cost	Agency Cost	User Cost	Total Cost
1	$178,986	*$644,433	*$873,419	*$249,685	$773,432	$1,023,117
2	$184,443	$699,023	$883,466	$251,765	*$760,299	*$1,012,064
3	$198,566	$708,219	$906,785	$270,248	$765,063	$1,035,311
4	*$173,923	$958,791	$1,132,714	$253,580	$1,051,749	$1,305,329
5	$188,048	$1,049,706	$1,237,754	$276,807	$1,177,165	$1,453,972
6	$194,568	$1,138,976	$1,333,544	$284,458	$1,257,224	$1,541,682
7	$179,790	$1,213,699	$1,393,489	$266,089	$1,343,573	$1,609,662
8	$177,505	$1,289,186	$1,466,691	$275,843	$1,436,894	$1,712,737

Note: Each Entry marked with (*)represents the preferred strategy for the criterion indicated by corresponding column heading

By arranging the results of Table 6 according to the order of preference, as is done in Table 7, the following observations can be made:

1. In the conventional analysis where pavement performance consideration is not included, drastic differences are found between the ranking list of agency cost-based solutions and that obtained from total cost-based solutions. For the analysis that includes pavement performance consideration, the corresponding differences are much less drastic.

2. User costs have a dominating influence on the results of total cost-based analysis. In the conventional analysis, the total cost-based ranking is identical to the user cost-based ranking. In the case of revised analysis with pavement performance consideration, some differences are found between the two corresponding rankings.

In general, considering agency and user values of pavement performance in project evaluation would achieve better agreement among agency cost-based, user cost-based, and total cost-based decisions. Realizing that "when all things are equal, the preference for better-performance pavements is common to both highway agencies and road users"(*3*), this agreement is not suprising.

Benefit-Cost Ratio Analysis

In this method, the ratio of the present worth of benefits to the corresponding worth of costs is computed to determine the economic desirability of the alternatives on the basis of an incremental pairwise comparison. The pairwise comparison is performed by taking alternatives into consideration in the order of increasing cost. The results of these analyses are presented in Table 8. The final conclusion concerning the most preferred strategy in each case is the same as that in life-cycle cost analysis.

CONCLUSIONS

Making use of recently available estimates of the agency and user values of pavement performance, it has been possible to (a) assess the order of magnitude of these values with respect to the major cost items commonly considered in economic analysis of pavement strategies, and (b) evaluate the impact of incorporating pavement performance consideration into these analyses.

It has been found that the agency and user values of pavement performance are of the same order of importance as the

TABLE 7 RANKING IN ORDER OF PREFERENCE ACCORDING TO LIFE-CYCLE COST ANALYSIS

Ranking in Order of Decreasing Preference	Life-Cycle Cost without Pavement Performance Consideration			Life-Cycle Cost with Pavement Performance Consideration		
	Agency Cost	User Cost	Total Cost	Agency Cost	User Cost	Total Cost
1	Strategy 4	Strategy 1	Strategy 1	Strategy 1	Strategy 2	Strategy 2
2	Strategy 8	Strategy 2	Strategy 2	Strategy 2	Strategy 3	Strategy 1
3	Strategy 1	Strategy 3	Strategy 3	Strategy 4	Strategy 1	Strategy 3
4	Strategy 7	Strategy 4	Strategy 4	Strategy 7	Strategy 4	Strategy 4
5	Strategy 2	Strategy 5	Strategy 5	Strategy 3	Strategy 5	Strategy 5
6	Strategy 5	Strategy 6	Strategy 6	Strategy 8	Strategy 6	Strategy 6
7	Strategy 6	Strategy 7	Strategy 7	Strategy 5	Strategy 7	Strategy 7
8	Strategy 3	Strategy 8	Strategy 8	Strategy 6	Strategy 8	Strategy 8

TABLE 8 SUMMARY OF BENEFIT-COST RATIO ANALYSIS

Analysis without Pavement Performance Consideration			Analysis with Pavement Performance Consideration		
Strategies Compared	Benefit/cost Ratio	Strategy Preferred	Strategies Compared	Benefit/cost Ratio	Strategy Preferred
4 vs. 8	Negative	Strategy 4	4 vs. 8	Negative	Strategy 4
4 vs. 1	Greater than 1	Strategy 1	4 vs. 1	Greater than 1	Strategy 1
1 vs. 7	Negative	Strategy 1	1 vs. 7	Negative	Strategy 1
1 vs 2	Negative	Strategy 1	1 vs. 2	Greater than 1	Strategy 2
1 vs. 5	Negative	Strategy 1	2 vs. 5	Negative	Strategy 2
1 vs. 6	Negative	Strategy 1	2 vs. 6	Negative	Strategy 2
1 vs. 3	Negative	Strategy 1	2 vs. 3	Negative	Strategy 2
Conclusion : Select strategy 1			Conclusion : Select strategy 2		

cost items in economic analysis of pavement. On the basis of the numerical examples presented, the following conclusions can be drawn. Conventional pavement evaluation relying solely on agency cost analysis tends to favor strategies with lower pavement performance levels. This bias can be corrected by including the agency value for pavement performance in the evaluation. Traditionally, very different recommendations could result from agency-cost based and user-cost based analyses. Better agreement would be achieved if both agency and user values for pavement performance are considered. This outcome is logical because good pavement performance is desirable to highway agencies and users alike. Agency and user values of pavement performance are important elements in economic analysis of pavement strategies because they can significantly influence the final outcome of the analysis.

REFERENCES

1. *NCHRP Synthesis 122: Life-Cycle Cost Analysis of Pavement*, TRB, National Research Council, Washington, D.C., 1985.
2. *A Manual on User Benefit Analysis of Highway and Bus Transit Improvements*. AASHTO Washington, D.C., 1977.
3. T. F. Fwa and K. C. Sinha. Pavement Performance and Life Cycle Cost Analysis, *Journal of Transportation Engineering, ASCE*, Vol. 117, No. 1, 1991, pp. 33–46.
4. T. F. Fwa, and K. C. Sinha. *Agency and User Values of Pavement Performance*. School of Civil Engineering, Purdue University, W. Lafayette, Ind., 1989.
5. A. Garg and A. Horowitz. *Establishing Relationships between Pavement Roughness and Perceptions of Ride Quality and Acceptability*. Wisconsin Department of Transportation, Madison, 1987.
6. R. Haas and W. R. Hudson. *Pavement Management System*, McGraw-Hill, New York, 1978.
7. N. J. E. Sheflin. Decision Levels and Issues—A Municipality Perspective. *Proc., North American Pavement Management Conference*, Vol. 1, Toronto, Ontario, March 12–18, 1985, pp. 2.36–2.47.
8. J. P. Zaniewski, G. E. Elkins, and P. R. Flanagan. An Algorithm for User Cost Calculation in a Pavement Management System. *Proc., North American Pavement Management Conference*, Vol. 1, Toronto, Ontario, March 18–21, 1985, pp. 4.72–4.83.
9. W. F. McFarland and M. Chui. The Value of Travel Time: New Elements Developed Using a Speed Choice Model. In *Transportation Research Record 1116*, TRB, National Research Council, Washington, D.C., 1987, pp. 15–21.
10. *Pavement Management Systems*. Road Transport Research Report, Organization for Economic Co-operation and Development, Paris, 1987.
11. R. Kher, W. A. Phang, and R. Haas. Economic Analysis Elements in Pavement Design. In *Transportation Research Record 572*, TRB, National Research Council, Washington, D.C., 1976, pp. 1–14.
12. G. R. Rada and M. W. Witczak. *Project Level PMS Life Cycle Cost Model for Flexible Pavements*. Proc., 6th International Conference on the Structural Design of Asphalt Pavement, Vol. 1, University of Michigan, Ann Arbor, July 1987, pp. 946–957.

Publication of this paper sponsored by Committee on Transportation Economics.