WARRANTY PRACTICE IN PAVEMENT CONSTRUCTION
– AN ASSESSMENT OF THE COSTS AND BENEFITS

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ABSTRACT: The concept of warranties involves an increased shift of the burden of construction quality control, product performance and maintenance from the owner to the contractor. The expected benefits of warranty projects such as enhanced product quality and service life could be offset by their higher construction costs. Using data from a state highway agency, this paper evaluates the costs and benefits of pavement projects undertaken through warranty and traditional contracts in order to identify the more cost-effective practice. Effectiveness was measured in terms of average pavement condition and service life. On the basis of inflation-adjusted costs and other data, it was determined that warranty contracts generally have higher agency cost but lower user cost and superior pavements compared to their traditional counterparts. Also, over a relatively short analysis period of five years, the warranty contracts are 27-30% less cost-effective than their traditional counterparts. However, in the long term, the warranty projects were found to be 70-90% more cost-effective on the basis of service life, and 58-65% more cost-effective on the basis of both service life and pavement condition. The study results suggest that the higher cost-effectiveness of warranty over traditional projects is more discernible when both cost and effectiveness are viewed over the entire treatment life rather than only a part thereof, and when both agency and user cost are used in the analysis. The paper identifies certain areas of the study methodology that could lead to bias in the conclusions and advocates for caution in selecting warranty/traditional contract comparison pairs.
BACKGROUND AND PROBLEM STATEMENT

In the current era of increased travel demand, higher user expectations, greater preservation needs, and uncertainty of sustained funding, the pursuit of innovative and cost-effective contracting practices for enhanced highway project delivery is one of the most important and challenging tasks facing highway agencies. Developments in construction and material technology have provided greater opportunities for increased contractor innovation and enhanced overall product delivery. As such, highway agencies are showing great interest in non-traditional contracting systems and practices such as warranties.

A warranty is defined as a guarantee of the integrity of a product and of the maker’s responsibility for defects repair or product replacement \( (1) \). The product manufacturer (in this case, the highway project contractor) takes responsibility for the product performance over a specified time period. Under most pavement warranty contracts, the contractor is liable for pavement defects and deficiencies arising from improper materials or workmanship and is also responsible for pavement maintenance throughout the warranty period. Although warranties typically have higher initial costs, it has been hypothesized that they yield pavements of higher quality and that they consequently provide a product with lower overall life-cycle costs compared to traditional contracts \( (2) \). It may be true that warranties generally yield superior products – this could be attributed to the warranty contractors’ aversion of having to replace the work in case of failure and consequently, their greater incentive to produce a high quality product \( (3) \). However, it could be argued that spending millions of dollars to gain benefits (higher quality and longer life) may not be justified in view of existing budgetary constraints at most highway agencies. Another perspective to the issue is the fact that pavement managers are increasingly going beyond just agency costs but are also considering user perspectives (often reflected through user costs) and facility condition. It is therefore clear that consideration of both costs and benefits is therefore necessary in evaluating warranty projects.

The use of warranties is widespread in Europe where contractors are generally required to provide post-construction quality assurance and satisfactory product performance over a rather extended time period. In the USA, the use of warranties in highway contracting saw an upsurge in the beginning of the last decade with the experimentation of innovative and best value contracting practices as an alternative to (or as a complement to) traditional contracting methods \( (4, 5) \). Several key states have taken the initiative in warranty contracting and have sought to develop guidelines for such practice \( (1, 6, 7, 8, 9) \). In the state of Indiana, the first project constructed to warranty contract specifications is a section of Interstate 70 near Indianapolis, in 1996 \( (10) \).

In practice, there is a great deal of circumspection among highway agencies in adopting warranty projects partly because relatively little research on cost-effectiveness assessment on these types of projects has been carried out with field data. It has been suggested that the increasing shift of quality control responsibility from the agency to the contractor results in better product performance and longer service life. Furthermore, it has been hypothesized that the reallocation of responsibility between the agency and the contractor decreases the overall level of agency resources required for project delivery. On the other hand, warranty contracts are perceived to have higher initial contract costs due to the purchase of the performance bond and extra efforts towards compliance with material and workmanship quality specifications. In this respect, the current apprehension of highway agencies could be assuaged by appropriate research that investigates whether benefits of warranties are worth their costs.

The purpose of this paper, therefore, is to develop an analytical methodology to evaluate the medium-term and long-term cost-effectiveness of highway warranty contracts using selected measures of effectiveness. For purposes of this paper, the terms “non-warranty”, “control”, and “traditional” all have the same meaning and refer to contracts given under the traditional contracting process. Also, the terms “project’ and “contract” have the same meaning in this paper and therefore are used interchangeably.
ASSESSMENT PROCEDURE

Assessment of the cost-effectiveness of contracting practices involves several steps that are summarized as follows: First, pavement sections constructed using warranty specifications and traditional bidding processes are established to form comparison sets. Second, agency and user costs are estimated for each warranty and traditional project in a comparison set. Third, effectiveness (or, benefit) is estimated in terms of service life and average pavement performance for each warranty and traditional project in a comparison set. Finally, using the costs and benefits, the medium- and long-term cost-effectiveness of warranty and traditional sections in each comparison set are determined. Details of each step are provided in the next section.

Establishing Warranty/Traditional Comparison Sets
In this step, highway warranty projects are identified and appropriate traditional projects are selected for comparison with each warranty project. To minimize bias in the analysis, the constituent projects in each comparison set were selected on the basis of their similarity in terms of traffic loading, project type, geographical (climatic) location, contract length, and construction year. In most cases, characteristics were similar but not necessarily identical. Five comparison sets were established.

Estimating Agency and User Cost
In estimating the costs for each project, a real discount rate was used to bring all inflation-adjusted agency and user cost components to their present worth and then to their equivalent uniform annual costs (EUAC) over the analysis period as follows:

\[
\text{Present Value (dollars)} = \text{Nominal Value (dollars)} \times \left( \frac{1}{(1+i)^n} \right)
\]

\[
\text{EUAC} = \text{Present Value} \times \left( \frac{1(1+i)^n}{(1+i)^n - 1} \right)
\]

where \(i\) = discount rate, 4\%, and \(n\) = year at which the cost was incurred.

Agency Cost
The two major components comprising agency costs are initial construction costs and maintenance costs. Maintenance costs may be routine or periodic, may have a preventive or corrective role, or may be done in-house or by contract. In the case of traditional projects, the maintenance responsibility of the contractor is terminated shortly after project completion. For warranty projects on the other hand, the contractor bears the cost of maintenance for a specified length of time following construction (defined as the “warranty period”). In the computation of agency costs therefore, only the initial construction cost and post-warranty period maintenance costs are considered for warranty project agency costs, while both construction and maintenance costs are considered for the traditional projects. The maintenance costs for the traditional projects (and also for the warranty projects after expiration of the warranty period) were determined using existing models that estimate the average annual level of maintenance that a pavement section is expected to receive over a period of time, based on pavement age, surface type, and other factors (11).

To ensure an unbiased analysis, the effects of inflation due to differences in construction dates of the warranty and traditional projects were duly accounted for – agency costs were converted to Year 2000 constant dollar using the FHWA Construction Price Index (12). With regard to economy of scale, it is known for example, that long sections generally have smaller unit costs ($ per lane-mile) compared to short sections; and thicker pavements have lower unit costs ($ per inch-mile) compared to thin pavements. To avoid any analytical bias and erroneous inferences about relative costs of warranty and traditional projects, pavements in each comparison set had, as much as possible, similar contract lengths, number of lanes, and pavement thickness.
User Cost
User costs in road construction are mostly due to queuing delays experienced during the work-zone duration and are influenced by the timing and duration of the roadwork, the volume of traffic disrupted due to the work-zone, and predetermined cost rates (13). User costs of selected projects were estimated using historical traffic volume and classification data at the construction year. Monetary values of travel time, used were $11.58/hr for Passenger Cars, $18.54/hr for Single Unit Trucks, and $22.31/hr for Combination Trucks (13), and were duly adjusted for inflation. Speed reduction in work-zones was duly considered – speed limits of 65 mph and 45 mph were assumed for normal operating conditions and work-zones, respectively. Due to lack of observed work-zone speed data, work-zone speed limits were used. All the project sections have two lanes in each direction during normal operating conditions, and closure of one lane in each direction was considered for work-zones. The durations of work-zones were duly considered in the computation of total user cost and was estimated using procedures developed in past research (14).

Estimating Effectiveness
The time scope for evaluating the effectiveness or cost-effectiveness of pavement treatments could be any of three time frames – short-term, medium-term, and long-term. Short-term evaluation, which involves the immediate performance jump upon pavement treatment, was not considered in the present paper.

- **Medium-term** evaluation of effectiveness can be described as the actual performance exhibited by the pavements relative to the agency and user costs over a fraction of the treatment life (in this study, 5 years was used).
- **Long-term** evaluation involves the actual (or projected) performance and costs over the entire treatment life. Treatment life is determined either directly (using the difference in dates between consecutive treatments) or indirectly (by measuring the time taken for a performance curve to reach a specified performance threshold).

Units of Performance Effectiveness – The International Roughness Index
The various measures of pavement treatment effectiveness (treatment life, area under curve, etc.) are typically expressed in terms of the units of effectiveness or the performance indicators such as International Roughness Index (IRI), Pavement Condition (PCR), Rut, etc. For warranty projects, the contractual threshold of performance indicators have been established by most agencies to reflect minimum acceptable pavement serviceability over the warranty period and the Contractor is obligated to carry out remedial work if the thresholds are violated at any time during that period. It should be noted that such warranty serviceability compliance specifications is not necessarily the same as the minimum serviceability for rehabilitation or replacement. Given the minimum rehabilitation threshold and the performance curve for each performance indicator, the service life of each indicator can be determined, thus yielding several service lives depending on the performance indicator used.

In this study, IRI was used because it serves as an important basis upon which INDOT makes pavement preservation decisions, and because of data availability. Furthermore, the overall service life is typically determined on the basis of IRI.

IRI is a measure of pavement surface roughness (a common indicator of pavement condition that directly reflects pavement ride quality). For purposes of this paper, service life was measured on the basis of when the rehabilitation threshold IRI is exceeded. This is different from the warranty thresholds (maximum IRI values). The warranty thresholds are as follows: average IRI in any 100-meter segment which is established at 2.1 m/km (133 in/mi) in any 100-meter segment for “crack-and-seat” overlay projects, and 1.9 m/km (120 in/mi) for “rubblized” overlay projects (15).
Estimating Medium-Term Cost-effectiveness
In this study, the medium term was taken as a five year period. In the medium term, effectiveness was measured in terms of (i) the area enclosed by the pavement performance curve and the threshold line, (ii) the average pavement condition, as explained below.

Area Enclosed by the Pavement Performance Curve
This was determined first by finding the area under the curve (integral of the performance function with respect to age, from limits of 0 and 5 years) and subtracting such area from the total area of the rectangle OADE (Figure 1) to yield the area shown as Area I.

Over a 5-year period, therefore, the area enclosed by the IRI curve is given by: Area of the rectangular region OADE - \( \int_{0}^{5} f(x)dx \)

where \( f(x) \) is the pavement performance curve and \( x \) is the pavement age.

In Figure 1, the indicated threshold IRI value (Line E-C) is the threshold IRI value for rehabilitation. The medium-term cost-effectiveness is calculated as the area enclosed by the IRI-Age Curve)/EUAC, where EUAC is the equivalent uniform annual cost over the 5-year period. It may be noted that because the analysis period was the same for both alternative (5 years), the net present value (NPV) could be used in place of EUAC. The alternative with a higher Area/EUAC or Area/NPV value is considered more cost-effective.

Average Pavement Condition
The two-sample paired \( t \)-test was carried out for each comparison set of warranty and traditional contracts to ascertain whether any significant statistical differences exist in the performance levels exhibited by pavements constructed using the two alternative contracting practices. It is based on the null hypothesis that the population means of the paired differences of the two samples is zero. This is equivalent to performing a one-sample \( t \)-test on the paired differences. An advantage of this test is that the variation in the data is reduced by considering the mean differences. The test assumes that the paired differences are independent and normally distributed, but does not necessarily assume that both population variances are equal.

Estimating Long-Term Effectiveness
The methodology for evaluating the long-term effectiveness and cost-effectiveness was similar to that for the medium term as described above. An exception was that for the long term, the analysis period is not just five years but the entire treatment service life. In the long term, effectiveness was measured in terms of (i) the treatment service life, (ii) the area enclosed by the performance curve and the threshold line.

Treatment Service Life
For purposes of this paper, service life is defined as the time interval between initial construction and the point where the rehabilitation performance threshold is reached. This point was determined by extrapolating available observed performance data points. An important assumption made in establishing the performance curves is that the performance trend of the warranty pavements beyond the warranty period is a continuation of the functional trend of performance exhibited during the warranty period. It is worth noting that most of the warranty pavements are still in their early years and that as time goes on, more performance data would become available to enable more reliable projections of pavement performance and consequently greater certainty of service life predictions.

Area Enclosed (Bounded) by the Performance Curve
The area enclosed or bounded by the performance curve represents the dual benefits of increased pavement life and average pavement condition, and was determined after extrapolating IRI trends up to the terminal serviceability (rehabilitation threshold) level. This was done for each warranty and corresponding traditional project. The area enclosed by the IRI-age curve is illustrated in Figure 1 as
(Area I + Area II) and was determined as the difference between the area of rectangle OBCE and the area under the curve (integral of the performance function with respect to age from limits of 0 and the service life).

**Estimating Long-term Cost-effectiveness**

For purposes of the present paper, long-term cost-effectiveness ($CE$) is defined as the additional pavement life per dollar and the area enclosed by the performance curve per dollar. The cost-effectiveness expressions with respect to treatment service life ($CE_{TSL}$) and area enclosed by the curve ($CE_{AEC}$), are given as Equations (3) and (4), respectively.

$$CE_{TSL} = \frac{(Treatment \ Service \ Life)}{EUAC}, \quad (3)$$

$$CE_{AEC} = \frac{(Area \ enclosed \ by \ the \ IRI-Age \ Curve)}{EUAC} \quad (4)$$

where $EUAC = Equivalent \ Uniform \ Annual \ Cost$ over treatment service life and comprises the agency and user cost or the agency cost only, from time of construction to end of service life (see Equation (2)). Computation details are similar to that discussed for medium-term evaluation. The alternative with a higher $CE_{TSL}$ or $CE_{AEC}$ value is considered more cost-effective.

**DATA COLLECTION AND PROCESSING**

In order to assess selected five comparison sets based on the evaluation process described above, relevant data including costs information and performance index were collected. The main source of data was the INDOT Pavement Management System, Research Division, and Contract Division.

*Pavement Condition Data:* The source of IRI data was INDOT’s Pavement Management System database.

*Operating Characteristics Data:* Data on traffic volumes (Annual Average Daily Traffic, AADT) were obtained from INDOT Interstate traffic flow maps. Traffic data is important because the traffic characteristics of a facility greatly influence the user costs of construction workzones.

*Agency Cost and Contracts Data:* Data on the cost of each warranty and traditional project were obtained from INDOT Divisions of Program Development and Contracts and Construction. The data also includes the final as-built cost incurred by the agency for each project as well as a description of work done and number of construction days. The maintenance costs are incurred by the agency for all activities done between periods of construction and resurfacing or between successive treatments to maintain the pavement within acceptable levels of performance. For warranty projects, there is no direct maintenance expenditure incurred by INDOT during the warranty period. After the expiration of the warranty period, maintenance costs for both project types are borne by INDOT. Estimates of annual maintenance costs for the projects were obtained using Average Annual Maintenance Expenditure (AAMEX) models (11). AAMEX models estimate the level of maintenance that a pavement section is expected to receive at any given age.

*User Cost Data:* User costs largely involve queuing costs that reflect the delay experienced by the motorists due to reduction of roadway capacity (resulting, in turn, from the placement of work-zones) and are associated with the value of travel time. Values of time were obtained from FHWA LCCA Technical Bulletin (13) and updated. All costs were expressed in their Year 2000 values.
EVALUATION RESULTS – COMPARISON SET 1

For purposes of a detailed discussion, this section focuses on the evaluation results for comparison set 1, while another section discusses the collective results for the remaining comparison sets. The first comparison set includes the first project implemented under Indiana’s warranty program, Contract R-22232, which involved pavement rehabilitation. The project is located on I-70 in the Greenfield district of Indiana and its five year warranty period expired in 2001. The selected traditional project for comparison is Contract R-21607, located on I-69 also in the Greenfield district.

Medium-term Effectiveness Analysis

IRI based Performance Comparison

Plots of average IRI values of two projects as a function of age show that the warranty pavement performed considerably better than the traditional pavement in terms of surface roughness (Figure 2). The statistical t-test result indicated that at 95% confidence, the warranty pavement has significantly lower IRI values compared with the traditional pavement.

Medium-Term Cost-Effectiveness Analysis

Costs Assessment

The agency cost of the warranty project, per lane-mile, was found to be significantly higher than that of the corresponding traditional project. To estimate user costs due to work-zone delay, similar levels of traffic volume and classification were used for both warranty and traditional projects. It was found that the warranty pavement has lower user costs and this can be attributed to its shorter work-zone duration.

Medium-term Effectiveness

The effectiveness values (that is, areas enclosed by the curves) were determined by using fitted values of the performance models developed for each of the warranty and traditional pavements. The performance models were of the exponential form with pavement age as the explanatory variable.

Medium-term Cost-effectiveness

Analysis results, summarized in the second row of Table 1, addresses cost-effectiveness in two ways, first on the basis of agency cost only, and then on the basis of both agency and user costs. In the medium term, it can be noticed that the warranty project in comparison set 1 is 30% less cost-effective than the traditional project when only agency cost is considered in the analysis, and is 27% less cost-effective than the traditional project when both agency and user costs are considered in the analysis. When both agency and user costs are considered, it is assumed that they have the same weight – in other words, a dollar of agency cost is assumed to be equal to a dollar of user cost, so their overall cost is simply the sum of the two.

Long-Term Cost-Effectiveness Evaluation

Long-term cost-effectiveness, taken over the projected treatment life of the pavement, showed some interesting results. First, on the basis of projections of field data, the treatment lives for the warranty and traditional pavements were determined to be 25 and 15 years, respectively. Then, it was determined that the long-term agency cost of the warranty project exceeds that of the traditional project.

The overall cost-effectiveness was estimated first on the basis of agency costs only, and then on the basis of both agency and user costs. Measures of effectiveness were the average projected treatment life and the area bounded by the IRI performance curve and threshold line. In contrast to that of medium-term, the long-term analysis results suggest that the warranty project is the more cost-effective of the two, for comparison set 1. It is seen that on the basis of service life, the warranty project is 39% more cost-effective than the traditional project when only agency cost is considered in the analysis, and is 56% more cost-effective when both agency and user costs are considered in the analysis. On the basis of area bounded by the curve, which reflects effectiveness in terms of both service life and pavement condition, the warranty project is 29% more cost-effective than the traditional project when only agency cost is
considered in the analysis, and is 48% more cost-effective when both agency and user costs are considered in the analysis.

**Overall Discussion for Comparison Set 1**

From the comparative analysis on the first comparison set, it can be noted that the warranty pavement has higher cost but exhibits higher effectiveness than the traditional projects. The warranty contract has lower cost-effectiveness in medium-term, but higher cost-effectiveness than the traditional project in the long term.

**EVALUATION RESULTS – COMPARISON SETS 2-5**

Table 1 presents the details of the cost-effectiveness analysis in the medium and long terms, respectively, for each comparison set. The background project information and results for each set are then discussed.

**Comparison Set 2**

This pair comprises the warranty project involving Contract R-22854, an Interstate pavement reconstruction in Seymour District of Indiana, and had completed its warranty period as at the time of writing. The matching traditional project is Contract R-21602, located in the Fort Wayne district of Indiana.

On the basis of performance only, the warranty project pavement was analyzed to exhibit better pavement performance in terms of IRI. The warranty project was found to have lower user cost and higher initial agency costs compared to the traditional project. Overall, it was found that in the medium term, the warranty project is 46% less cost-effective when only the agency cost is considered and 42% less cost-effective when both agency and user costs are considered, compared to the traditional project.

In the long-term analysis (with respect to service life), the warranty project was found to be 17% more cost-effective based on agency cost, and is 33% more cost-effective based both on agency and user costs. In the long-term analysis (with respect to area-bounded-by-the-curve), it was determined that the warranty project is 17% more cost-effective than the traditional project when only agency cost is considered in the analysis, and is 33% more cost-effective than the traditional project when both agency and user costs are considered.

**Comparison Set 3**

The third warranty project, Contract R-22925, involved crack-and-seat treatment of an existing PCC pavement and hot-mix asphalt overlay at an I-69 section in the Fort Wayne District of Indiana. The warranty period ended in 2002. Its traditional counterpart, Contract R-22912, is located in the same district.

The pair-wise comparison indicated that warranty pavement exhibited better pavement performance due to lower IRI values. The warranty pavement had agency costs that were higher than that of the traditional pavement, but had lower user costs.

The medium-term analysis showed that the warranty project, compared to its traditional counterpart, is 21% less cost-effective when only agency cost was considered and 15% less cost-effective when both agency and user costs were considered.

For long-term evaluation involving service life as a measure of effectiveness, the warranty project was found to exhibit 75% higher cost-effectiveness when only agency cost was considered in the analysis, and 87% higher cost-effectiveness when both agency and user costs were considered. For long-term evaluation involving the area enclosed by the performance curve, it was found that the warranty project is 41% more cost-effective than the traditional project when only agency cost is considered in the analysis, and is 50% more cost-effective when both agency and user costs are considered.

**Comparison Set 4**

The fourth set involves the warranty pavement rehabilitation project, Contract R-23390 that was completed in June 1999. This project was evaluated based on data that was available at the time of the
study (four years after construction). The project is located on I-74 in the Greenfield district of Indiana. The corresponding traditional pavement is Contract R-22923.

It was determined that the warranty pavement exhibited superior pavement performance in terms of IRI. The user cost of the warranty pavement was also found to be lower than that of the traditional project. However, on the basis of agency costs, the warranty project had a higher cost.

In the medium term, the warranty project exhibited 39% less cost-effectiveness when only agency cost was considered and 35% less cost-effectiveness when both agency and user costs were considered.

On the basis of long-term evaluation expressed in terms of service life, the warranty project was found to be 96% more cost-effective when only agency cost is considered in the analysis, and is 163% more cost-effective when both agency and user costs are considered. On the basis of long-term effectiveness expressed in terms of area enclosed by the curve, it was determined that the warranty project is only 10% more cost-effective than the traditional project when only agency cost is considered in the analysis, and is 2% more cost-effective when both agency and user costs are considered.

Comparison Set 5
The fifth warranty project involved pavement rehabilitation at Interstate 74 in the Crawfordsville district of Indiana, and was completed in 1999, and was evaluated on the basis of available data for the first three years of its warranty period. The traditional project, R-22923, is located in the Greenfield district.

In the medium term, the warranty project was found to be 5% less cost-effective than the traditional project when only agency cost was considered and 4% less cost-effective when both agency and user costs were considered.

On the basis of long-term effectiveness represented by service life, the warranty project exhibited 119% higher cost-effectiveness when only agency cost is considered in the analysis, and is 100% higher cost-effectiveness when both agency and user costs are considered. In long-term evaluation involving effectiveness measured in terms of the area enclosed by the performance curve, the warranty project was found to be 136% more cost-effective than the traditional project when only agency cost is considered in the analysis, and 123% more cost-effective than the traditional project when both agency and user costs are considered.

Overall Discussion for Comparison Sets 2-5
Pavement performance values in terms of IRI suggest that the warranty projects in this study generally performed significantly better than their traditional counterparts.

When IRI performance trend lines were fitted and extrapolated to the point of age zero (that is, immediately after construction), as seen in Figure 2, it can be seen that the warranty pavements show much higher initial performance (lower initial IRI) than the traditional pavement. In past research, it has been observed that initial smoothness is often a reliable predictor of subsequent pavement life (16), this may explain for the relatively greater (projected) service life and superior subsequent performance over the period exhibited by the warranty contract compared to their traditional counterparts.

The major disbenefit of the warranty projects is their higher initial construction costs compared with those of the traditional projects. However, agency maintenance costs for the warranty pavement were relatively lower because the Contractor is responsible for the pavement upkeep during the warranty period. Furthermore, the user cost during the construction phase was estimated to be much lower for warranty projects than the traditional projects due to the shorter contract duration and work-zone duration which, in turn, could probably be attributed to incentives typically included in warranty contracts to reward early project completion.

As the medium-term evaluation results indicated, over a relatively short period of 5-years, the warranty pavement contracts are 27-30% less cost-effective than their traditional counterparts. However, when the analysis is carried out over the long term (treatment service life), the warranty contracts are found to be approximately 70 to 90% more cost-effective on the basis of service life, and 58 to 65% more cost-effective on the basis of both service life and pavement condition. The study results suggest that the superiority of warranty projects over traditional projects is more discernible when both cost and
effectiveness are viewed over the entire life of the pavement treatment rather than the short-term. Also, the superior long-term cost-effectiveness of warranty projects is more manifest when both agency and user cost are used in the analysis rather when only agency cost is used.

**SUMMARY OF FINDINGS AND CONCLUSIONS**

In this paper, pairs of warranty and traditional contracts were compared to assess their relative costs, effectiveness, and cost-effectiveness over the medium and long-term. Each comparison set was carefully selected such that the constituent projects had similar characteristics in terms of work type, surface type, functional class, and other features, in order to minimize bias.

Statistical analysis of field data showed that the warranty pavements performed significantly better than the pavements built under the traditional contracting system.

The warranty periods of the warranty contracts evaluated in the paper are of relatively short term (5-years) compared to European warranties. However, the evaluation was carried out both in the medium term and long term. The results of the medium-term analysis indicated that warranty projects were less cost-effective than the traditional projects in the medium term. In the case of long-term cost effectiveness, effectiveness was measured in terms of the average service life and area under the performance curve. Service lives were estimated from the performance models based on the pavement condition during the warranty period and established thresholds. The effectiveness analysis showed that the warranty and traditional pavements had average treatment service lives of 25 and 15 years, respectively. These service lives are estimated on the basis of projections of available data, and could be revised as more performance data become available over the years. The long-term analysis also showed that the warranty projects are more cost-effective than similar traditional projects, thereby indicating that the “worthwhileness” of warranty projects is more perceptible when viewed over a longer period of time such as the entire life of the pavement treatment.

It is expected that the results of this study can influence future decision criteria for selecting warranty projects and may also influence the selection of criteria for post-implementation evaluation of warranty projects and innovative contracting systems in general. The study shows that the cost category considerations (that is, “agency costs only” versus “both agency and user costs”) considered in the analysis can affect the outcome of the comparative analysis between the two alternative contracting systems. Other important analytical aspects that may affect the evaluation outcome include the temporal scope of the analysis (medium-term vs. long-term), and the measure of effectiveness used (service life vs. average pavement condition vs. both). As with any life cycle based analysis, the discount rate could also affect the outcome of the comparison process. These considerations confirm (or could supplement) general guidelines and considerations that have been discussed in previous research (3,4,5,7,8,9).

The current study involved only 5 different comparison sets. As more and more warranty projects reach their warranty expiration dates, a plethora of data is expected to become available to enable more insightful investigations of the costs and effectiveness of warranty projects. Future research in this area could examine the cost-effectiveness of warranty projects on the basis of accumulated traffic loading rather than passage of time. Also, other performance indicators specific to states’ PMS databases could be used for the analysis. Recent surveys suggest that the 5-year warranty period is perceived by the Owners (agency engineers) as being too short but is seen as being too long by the contractors (6). As such, research could be carried out to identify the Pareto optimal warranty period for each contract type and facility type, such that all parties to the warranty process would achieve maximum possible benefit at minimal overall cost. Furthermore, future studies may examine the impacts of uncertainty of the input variables such as the discount rate and pavement service life. Such probabilistic analysis may throw more light on the sensitivity of the choice of the best contracting system with respect to various evaluation factors and criteria, for a given contract type and facility type.

There is also the issue of possible bias in selecting projects for warranty implementation. The integrity of any comparative evaluation could be seriously jeopardized if selectivity bias exists in the assessment. For example, in a bid to minimize the risk of structural failure unrelated to the warranty
provisions and accompanying contractor/owner conflict, agencies may tend to implement warranty projects only at carefully chosen sections with no known structural problems. On the other hand, there is no such restriction on the implementation of traditional projects. As such, the traditional component of an evaluation comparison pair may be plagued with historically problematic subgrades, high water table, and other adverse factors associated with the natural project environment, and may consequently exhibit relatively poor performance. Carrying out evaluation in such cases, even with the statistical control of pavement thickness and traffic, is likely to weigh (unfairly) the results in favor of warranty projects. As such, future studies of this kind could investigate the geotechnical characteristics of the selected traditional and warranty projects in greater detail to ascertain that they do not differ in these respects. This could include reviewing past deflection measurements, interviews of local engineers about any known (persistent, occasional, or one-time) structural problems attributed to the subgrade, unusually short service lives of previous pavement repairs, etc.

The issue of selectivity bias also arises in the case of agency incentives for early completion and contractor selection. If there are incentives for quick completion in warranty and none for traditional contracts, warranty projects would have a shorter contract period and thus, a shorter work-zone duration that would translate into lower user costs of delay. This would unfairly weigh the evaluation outcome in favor of warranty projects. Also, an agency, through warranty provisions, may selectively attract relatively outstanding, high class contractors for warranty work (because the agency wishes to avoid poor work and subsequent conflict, among other reasons), while they may not be as selective for traditional projects. In such a case, the warranty project would have a higher product quality and shorter construction duration, both of which would translate into higher cost-effectiveness than the traditional project, even if all other factors are the same. Future studies of this kind could therefore include the class of contractor as a factor in selecting the constituent warranty/traditional projects for comparison.

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Table 1  Medium- and Long-term Cost-effectiveness Evaluation by Comparison Set
FIGURE 1 Measures of medium-term and long-term treatment effectiveness.
FIGURE 2 IRI trends for the warranty and traditional pavements in comparison set 1.
## TABLE 1  Medium- and Long-term Cost-effectiveness Evaluation by Comparison Set

<table>
<thead>
<tr>
<th>Temporal Scope of the Analysis and Measure of Cost-Effectiveness</th>
<th>Comparison Sets (Warranty project / Traditional project)</th>
<th>Agency Cost only</th>
<th>Agency Cost + User Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Warranty</td>
<td>Traditional</td>
</tr>
<tr>
<td><strong>Medium-Term</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area enclosed by the IRI-Age curve/EUAC</td>
<td>#1 (R-22232 / R-21607)</td>
<td>4.47</td>
<td>6.70</td>
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<tr>
<td></td>
<td>#2 (R-22854 / R-21602)</td>
<td>3.21</td>
<td>5.41</td>
</tr>
<tr>
<td></td>
<td>#3 (R-22925 / R-22912)</td>
<td>4.87</td>
<td>6.25</td>
</tr>
<tr>
<td></td>
<td>#4 (R-23390 / R-21607)</td>
<td>4.58</td>
<td>4.87</td>
</tr>
<tr>
<td></td>
<td>#5 (R-23898 / R-22923)</td>
<td>1.64</td>
<td>1.58</td>
</tr>
<tr>
<td><strong>Long-Term</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Service life/EUAC (Years per $1000)</td>
<td>#1 (R-22232 / R-21607)</td>
<td>0.69</td>
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<tr>
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<td>#2 (R-22854 / R-21602)</td>
<td>0.54</td>
<td>0.46</td>
</tr>
<tr>
<td></td>
<td>#3 (R-22925 / R-22912)</td>
<td>0.91</td>
<td>0.52</td>
</tr>
<tr>
<td></td>
<td>#4 (R-23390 / R-21607)</td>
<td>0.98</td>
<td>0.50</td>
</tr>
<tr>
<td></td>
<td>#5 (R-23898 / R-22923)</td>
<td>0.46</td>
<td>0.21</td>
</tr>
<tr>
<td><strong>Long-Term</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area enclosed by the IRI-Age curve/EUAC (IRI-Years per $1000)</td>
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<td>78.05</td>
<td>60.60</td>
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<td>84.62</td>
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<td>94.52</td>
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<td>51.27</td>
<td>46.65</td>
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<tr>
<td></td>
<td>#5 (R-23898 / R-22923)</td>
<td>82.31</td>
<td>34.91</td>
</tr>
</tbody>
</table>

Areas are expressed in units of IRI-years/$1000