Use of Warranties on Highway Projects: A Real Option Perspective

Qingbin Cui[1]; Mehmet Emre Bayraktar[2]; Makarand Hastak[3]; and Issam Minkarah[4]

Abstract: Since the introduction of warranty provisions in federal highway jobs, more and more state departments of transportation (DOTs) have considered the use of such provisions to protect their initial investment. This paper describes the pros and cons of warranty contracting in highway construction based on a survey of warranty practices in the United States. In particular, the need for state DOTs to buy a warranty for a well-built project is questioned. As an alternative, this paper introduces the warranty option, which gives the DOT the right to buy a warranty only if it becomes necessary at the end of construction. This option is exercised if the performance on site warrants it. This paper describes the mechanics of the warranty option and its advantages over the conventional warranty. A bid evaluation model is also developed for the *warranty option* approach.

DOI: 10.1061/(ASCE)0742-597X(2004)20:3(118)

CE Database subject headings: Highway construction; Construction industry; Warranties; Quality control; State government.

Introduction

Since the adoption of warranty provisions on federal highway jobs, more and more state departments of transportation (DOT) have considered the use of warranty provisions to protect their initial investment and to encourage innovations and quality improvement. Eleven states participated in the warranty experiment under Special Experiment Project Number 14, referred to as SEP-14, which was created by the Federal Highway Administration (FHWA) to study the effects of innovative contracting techniques (Hancher 1994). By 1999, more than 21 states had applied warranty provisions and finished about 240 warranted highway construction projects (Russell et al. 1999). By the end of 2002, more than 25 states had adopted warranty provisions in highway construction, but only a limited number of these projects have so far used up their warranty periods.

The warranty approach in highway construction contrasts sharply with traditional highway contracting practices. Under the standard contracting option, the state DOTs provide a detailed design and decide on the construction processes and materials to be used. Contractors perform the construction and bear no responsibility for future repairs once the project is accepted. Stringent quality control and inspection are necessary to make sure that contractors are complying with the specifications and the design. The warranty approach, usually used with performance-based specifications, changes almost every step in the standard contracting system. The changes go beyond the manner in which projects are bid, awarded, and constructed. Most important, contractors are bound by the warranty and are required to come back to repair and maintain the highway whenever certain threshold values are exceeded. In return for the shift in responsibility, contractors are given the freedom to select construction materials, methods, and mix designs.

This paper describes the pros and cons of warranty practices in the United States and questions the need for state DOTs to buy a warranty for a project that is well executed. Instead, the paper introduces a possible solution, the *warranty option*, which is a right but not an obligation to buy a warranty only if the need arises at the end of construction.

Warranty Contracting

Warranty use on federal highway projects was prohibited until the passage of the Intermodal Surface Transportation Efficiency Act in 1991 because warranty provisions could indirectly result in federal aid participation in maintenance costs, which at that time were a federal aid nonparticipating item (FHWA 2000). Under the warranty Interim Final Rule published April 19, 1996, the FHWA allowed warranty provisions to be applied only to items considered to be within the control of contractors. Ordinary wear and tear, damage caused by others, and routine maintenance remained the responsibility of the state DOTs (AASHTO 2001).

A warranty in highway construction, like warranties for manufactured products, is a guarantee that holds the contractor accountable for the repair and replacement of deficiencies under his or her control for a given period of time. Warranty provisions are widely used in highway construction contracts throughout Europe but are still regarded as an innovative concept in the United States (Hancher 1994; Anderson and Russell 2001).

In the United States, North Carolina first used the warranty approach on a pavement marking project in 1987 (Russell et al.

[1]Graduate Student, Div. of Construction Engineering and Management, School of Civil Engineering, Purdue Univ., West Lafayette, IN 47907-2051. E-mail: qcui@purdue.edu

[2]Graduate Student, Div. of Construction Engineering and Management, School of Civil Engineering, Purdue Univ., West Lafayette, IN 47907-2051. E-mail: mbayrakt@purdue.edu

[3]Assistant Professor, Div. of Construction Engineering and Management, School of Civil Engineering, Purdue Univ., West Lafayette, IN 47907-2051. E-mail: hastak@ecn.purdue.edu

[4]Professor Emeritus, Dept. of Civil and Environmental Engineering, Univ. of Cincinnati, Cincinnati, OH 45221-0071. E-mail: minkari@ucmail.uc.edu

Note. Discussion open until December 1, 2004. Separate discussions must be submitted for individual papers. To extend the closing date by one month, a written request must be filed with the ASCE Managing Editor. The manuscript for this paper was submitted for review and possible publication on May 8, 2003; approved on November 25, 2003. This paper is part of the ***Journal of Management in Engineering***, Vol. 20, No. 3, July 1, 2004. ©ASCE, ISSN 0742-597X/2004/3-118–125/$18.00.

1999). Soon after, warranty provisions were adopted by other state DOTs and implemented on all kinds of highway projects, including pavements, bridge decking, bridge painting, preventive maintenance jobs, intelligent traffic systems, and so on. The warranty approach requires more general specifications than does standard contracting. Rather than defining how to construct a project, a warranty specification would describe the performance of the project. Some of the identical elements in a warranted specification include warranty terms, performance criteria (indicators) and threshold values, bonding requirement, conflict resolution team, control methods, and remedial actions, as well as measurement and payment (Anderson and Russell 2001).

Most state DOTs consider calendar time as the unique warranty term that governs a warranty period. A few states (New Mexico, Colorado, and so on) use two-dimension warranty terms—calendar time and traffic load—whichever comes first (Abbey 1999; Ashenbrener and DeDios 2001). Contractors are required to guarantee that the warranted project works well for a specified period without exceeding threshold values. If the project fails during the warranty period, contractors would come back to repair or replace the item at no cost to the state agency. Once the warranty period expires, the contractor is relieved from the warranty. In the time and usage scenario, the warranty expires when the time is met or the usage exceeds the design value, whichever comes first. This is similar to the 5-year or 50,000-m warranty in the automobile industry. The warranty could expire earlier than the specified period if the real traffic load exceeds the design value.

In a warranted project, the contractor provides a guarantee for the performance of the project. In return, he or she is allowed to select construction materials, processes, and methods, which is impossible in the standard system. In a design/build warranty project, the contractor would provide a detailed design for the whole project. Instead of a tight quality control program, warranty provisions require that state DOTs only evaluate and accept the warranted item based on performance criteria. Indicators such as cracking, rutting, bleeding/flushing, raveling, and roughness are widely used by many states in evaluating asphalt pavement projects, while scaling, spalling, and cracking are the indicators used in decking projects. State DOTs set up threshold values for these performance criteria in accordance with average historical data from similar projects. The threshold value could be adjusted a little higher or lower based on performance expectations in a warranted project.

Most states require contractors to follow a standard remedial action whenever a threshold value is exceeded. The contractor is required to obtain a warranty bond from a surety company as a guarantee against default during the warranty period. It could be a single-term warranty bond or a renewable performance bond. The face value of the bond is set as either a total sum or a percentage of the contract price to cover the worst-case scenario for maintenance costs when the warranted item fails. Since disagreements may arise with regard to the possible causes for failure of some warranted items in the project, there is a need for an independent entity empowered to resolve these disputes and assign responsibilities. This task is entrusted to the conflict resolution team, which is formed from representatives of the state DOT, the contractor, and a third party.

Warranty contracting is primarily classified as a workmanship and material warranty or as a performance warranty (Aschenbrener and DeDios 2001). A workmanship and material warranty holds a contractor responsible for correcting deficiencies caused by bad workmanship and material but exempts the contractor from deficiencies caused by design and other reasons beyond the contractor's control. The state DOTs are still responsible for deficiencies that are design related. The workmanship and material warranty is compatible with the low-bid system and usually has a short-term period, from a few months to 7 years. The contractor is given the responsibility for material selection and undertakes the risk for bad workmanship and early failure of the selected material.

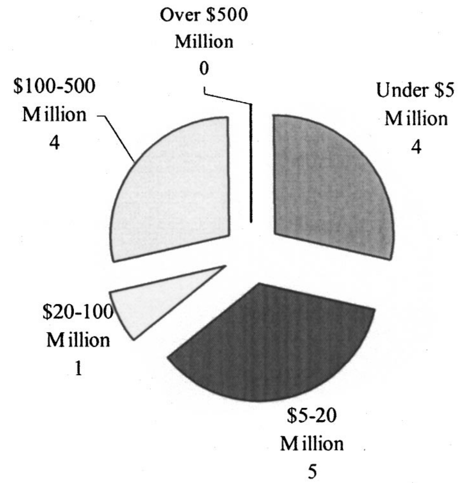

Fig. 1. Annual sale of warranty projects in 14 states surveyed

In the performance warranty approach, the contractor is given flexibility to design and even modify contract details, in addition to material selection and workmanship. Thus he or she assumes the responsibility for correcting defects caused by workmanship and material as well as design. The contractor may also choose a rehabilitation strategy or undertake preventive maintenance during the warranty period. To provide adequate protection from design defects, the performance warranty usually has a longer period, from 5 to 20 years, which under certain conditions may also be a biddable item (Russell et al. 1999).

Warranty Practices: Pros and Cons

Among the states that have applied warranty provisions in highway construction, Michigan, Ohio, Wisconsin, and New Mexico are considered the current frontrunners in highway warranty use. Implementation of warranty provisions in construction contracts is considered an innovative contracting practice that is expected to provide many benefits. However, many challenges are associated with its use nationally, and research on its evaluation in highway construction is limited.

A questionnaire survey and follow-up interviews were conducted to compare warranty projects to nonwarranty projects with regard to cost, time, quality, bonding, risk, and dispute. The survey covers the warranty experience in 14 states: California, Colorado, Florida, Indiana, Michigan, Minnesota, Mississippi, Ohio, Oregon, Pennsylvania, South Carolina, Texas, West Virginia, and Wiconsin. Fig. 1 shows the annual sales of warranty projects in these 14 states. Based on the survey results, the following sections describe the advantages and disadvantages of warranty provisions.

Advantages of Warranty Provisions

State DOTs and contractors both believe that warranty provisions lead to higher quality on site. The survey confirms this belief, although only a slight improvement in quality was observed in most states.

J. Manage. Eng. 2004.20:118-125.

One important result obtained from the use of performance-based specifications in highway construction projects is the development of contractor-funded internal innovations. As judged by contractors, quality-conscious construction, better workmanship, and more design input are the most attractive features of warranty projects. A few contractors differentiate themselves from their competitors by providing new materials and innovative technologies that will need less maintenance and fewer repairs in the future. State DOTs are still protected by the warranty provisions in the event of early failures of these innovative, unproven products and techniques. In this sense, state DOTs therefore are purchasing not only labor, equipment, and materials from the contractor, but also innovation and expertise.

Warranty requirements release state DOTs from stringent inspection. Under a performance-based specification, contractors are responsible for the design of the construction process as well as the selection of the materials used in the project. Therefore, there is no need for state agencies to follow standard inspection procedures on warranted projects. In addition, contractors are responsible for the performance of the finished project during the warranty period. Early failures caused by a contractor's bad performance will be corrected at the contractor's expense.

Another advantage of warranty requirements is that liability is transferred from state DOTs to contractors. In standard contracting, the contractor's responsibility for the project ceases once the project is handed over to the state. If early failures occur, state DOTs would have to make the repairs with public funding. Warranties provide an assurance to state DOTs that the contractor will correct failures that occur during the warranty period. The risk of early failures within the contractor's control is thus transferred from state DOTs to contractors.

Disadvantages of Warranty Provisions

Warranty provisions increase the initial bid price, especially for long-term warranty projects, because of the risk of potential liability. The more the risk, the more the bid price increases. In a typical 5 to 7 year warranty pavement project, the bid price increases by 5 to 15% on average; however, if the warranty term is less than 3 years, the price increase is barely noticeable. The increase in the initial price varies with the type of warranted project. In Ohio, an average increase in the bid price of 90% on pavement-marking projects led to a phase-out in the use of warranty provisions on such projects. Although warranty provisions are expected to yield savings in project delivery and maintenance costs, the survey does not support the view that warranties reduce life-cycle costs by spreading the initial investment over the entire warranty period. Most states do not have sufficient information on the change in maintenance costs due to warranty provisions. However, the data obtained from the survey indicate that 8 states that have used warranty provisions have experienced a slight saving (under 10%) in maintenance costs for warranty projects. The potential change in maintenance costs after the warranty expires is expected to be minimal as compared to nonwarranty projects. With regard to the project life cycle cost, 6 out of 12 respondents stated that they expected a little increase due to warranty provisions. Only the state of Wisconsin expects a substantial saving in the project life-cycle cost. Considering that the probability of an early failure is quite low, state DOTs are paying extra money on warranty projects to get contractors to do what they are supposed to do anyway, that is, provide a quality product that meets all performance requirements.

Surety companies are uncomfortable with issuing a long-term warranty bond, and small contractors find it difficult to get a warranty bond. Even some large contractors have difficulty getting a warranty bond if the warranty term goes beyond 7 or 10 years. Companies that do not have problems in getting warranty bonds might later find that warranty projects could hinder them from bidding new contracts by using up the companies' bonding capacity.

A warranty is only as good as the contractor and the surety company involved. The concern is whether the contractor and the surety company still remain in business for the duration of the warranty period and whether the companies will honor the warranty bond if a project failure occurs.

The use of warranties may not always improve overall quality. In a low-bid contracting environment, with or without warranties, the tendency will be for the contractor to try to cut costs wherever possible while barely meeting quality requirements.

The warranty approach has raised some concerns regarding bid competition. Although warranty provisions do not cause an observable change in the number of bidders, some smaller contractors may already have dropped out of the bidding due to their inability to obtain a warranty bond for the project. This somewhat supports the concern that smaller companies might get eliminated from warranty projects since they have more difficulty obtaining and carrying long-term bonds compared to larger companies.

The potential for an increase in litigation can also be expected due to the difficulty in identifying the real reason for a failure. A project failure could be caused by many factors beyond the control of a contractor, such as subsurface conditions, weather, and traffic load. Although litigation has not increased in current warranty practice, many state agencies have expressed concern that this may happen in the future.

Warranty Provisions: Best Value to State Agencies?

Many uncertainties are involved in highway construction, including variables such as quality, cost, and time. The warranty approach provides state DOTs with a method to lock in these uncertainties through a warranty agreement at the time the contract is awarded. This is an early decision, before state DOTs have the opportunity to observe the performance of the contractor on site. The assumption behind this approach is that the warranty purchase decision could not be delayed, or at least a delay would not add value to the project. However, this assumption is not always true. Since the warranty period starts after the project is accepted, the warranty buy-in decision could always be delayed till the end of construction. Is this delay of the decision valuable? The answer is definitely yes. Because of the uncertainty involved, delaying this decision until the end of the project makes it possible for the owner to gather more information that could be used to improve the decision.

A warranty does not add value to a well-performed project since the project is expected to finish the warranty period without major problems. This situation is shown in Fig. 2(a), where project quality is described using a normal distribution. Project quality, which is affected by construction performance, is uncertain before the start of construction. It might go above the average level, called favorable uncertainty, or stay at an average level. In these cases the project is expected to perform well during the warranty period. A warranty buy-in decision under this scenario will then become a bonus for contractors to do what they are supposed to do. On the other hand, construction quality could go below the average level or even below the acceptable level, which

J. Manage. Eng. 2004.20:118-125.

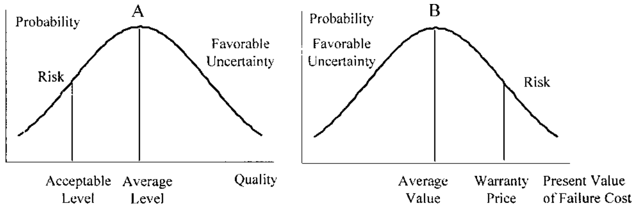

Fig. 2. Uncertainty in warranted project

would result in a project that will not perform well during the warranty period. This constitutes a performance risk, which warranty provisions try to eliminate. But under the current warranty approach, a warranty is bought before the start of construction, thereby eliminating the contribution of performance to the decision.

With regard to cost, the warranty approach is reasonable only if the present value of the failure cost during the warranty period is higher than the price of the warranty [Fig. 2(b)]. The warranty price in this figure is a little higher than the present value of average failure cost to account for a contractor's profit and a reduction in the state delivery cost. The failure cost here refers to maintenance and other related costs when a failure occurs within the warranty period. User costs could be estimated and factored into the failure cost. However, the failure cost is not known before the contract is sold. The state DOT estimates the failure cost based on typical projects rather than real information from the project under construction. The discounted failure cost could fall below the warranty price or even below the average failure cost. These situations are favorable for the state DOT and make the warranty an unnecessary investment. In a bad scenario, the present value of the failure cost could be higher than the warranty price. In such a situation the warranty provision would benefit the state DOT and save on potential maintenance costs. However, the warranty approach also eliminates the possibility of a good scenario, as discussed earlier. In the conventional warranty approach the state DOT pays for the warranty in both cases, favorable or unfavorable.

Under the conventional warranty approach, the state DOT gets protection for early failures, but a potential favorable uncertainty is not considered. The state DOT has no flexibility to buy a warranty based on observed performance during construction. This information is not considered in the buy-in warranty decision. Thus, the best value is not achieved. Since the warranty starts after the construction is completed, a possible solution is to delay the warranty purchase decision until the end of construction. In this scenario, the contractor is required to provide a price for the warranty while bidding a project. The state DOT will then decide on the need for a warranty after construction is complete and would buy a warranty only for projects with a high probability of failure. This method is based on an important analogy to financial options, which will be presented in the following section.

Financial Options and Real Options

An option is a right, but not an obligation, to take an action in the future. In financial markets, the most common types of options are a call option and a put option. A call option gives the owner the right to buy a stock at a predetermined exercise price on a specified maturity date. The option is exercised only when the price of the stock on that date exceeds the exercise price. If the stock price on the maturity date is below the exercise price, the option can be ignored. A put option can be viewed as the opposite of a call option. A put option gives its owner the right to sell the stock at a fixed exercise price. Stock prices are notorious for their volatility. The stock price on the maturity date might be above or below the exercise price. An option gives its owner an opportunity to exercise it and make a profit if a favorable uncertainty unfolds. On the maturity date, the value of an option depends on the difference between the stock price and the exercise price. Before an option expires, the value of an option is a function of five variables: the current price of the stock, the exercise price, the time to maturity date, the variability of the stock, and the risk-free rate. The most famous quantitative model, the Black-Scholes Model, was developed by Fischer Black, Myron Scholes, and Robert Merton, whose Nobel prize-winning work puts a value on a call option by duplicating the call over an infinitesimal time horizon (Hull 1997).

Many corporate decisions can be thought of as options on the underlying value of the risky asset. Those options are called real options. Like financial options, the value of real options depends on five variables: the value of the underlying risky asset, the exercise price, the time to expiration of the option, the variation of the value of the underlying risky asset, and the risk-free rate. The value of underlying risky assets is the stream of cash flow at a discounted value generated from the risky asset. The exercise price is the money invested in getting the risky asset. The fundamental insight of the real option theory is to view opportunities as options—rights but not obligations to take actions in the future. A deferral option is a call option in most projects where one has the right to delay the start of a project. This opportunity to delay the investment allows the owner to start the project if it is advantageous to do so.

When one exercises a deferral option by making an irreversible investment, he or she effectively gives up the possibility of waiting for new information that might affect the desirability and timing of the investment. The net present value rule assumes a noncontingency scenario in which one can start and complete a project. No opportunity to delay or abandon the investment is anticipated if market conditions turn sour. The real option method makes a more useful comparison. Several possibilities, such as invest today or wait for one year or longer, are examined to make a right and timely decision. The option value is an opportunity cost that should be included in the capital investment. An option is valuable when there is uncertainty. The more uncertain the underlying asset is, the more valuable the option (Trigeorgis 1996; Amram and Kulatilaka 1999).

Warranty Option: Possible Alternative to Warranty Approach

Similar to a financial option, a warranty option is a right but not an obligation to buy a warranty. It is a contingent decision, an opportunity to delay the warranty buy-in decision until the state DOT sees how events unfold. On the expiration date, if events turn out to be favorable, the state DOT will make one decision—give up the warranty option. But if events turn out to be unfavorable, the state DOT will buy a warranty protection. This means that the payoff to a warranty option is nonlinear—it changes with the decision. Fixed (noncontingent) decisions have linear payoffs because no matter what happens, the same decision is made. The warranty option has the potential to benefit state DOTs by providing managerial flexibility.

Under the option approach, the value of the warranty option is impounded into the evaluation of the bids, and the warranty pur-

J. Manage. Eng. 2004.20:118-125.

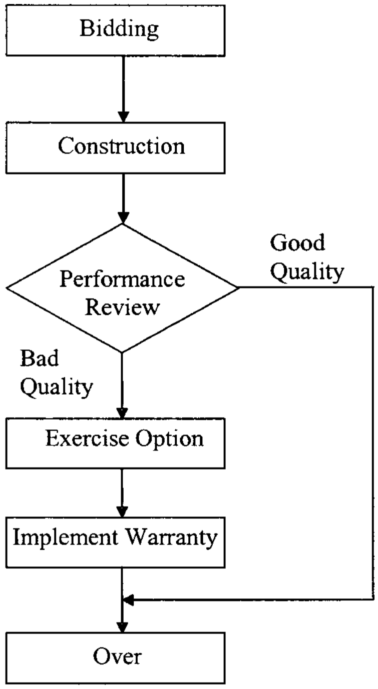

Fig. 3. Workflow of warranty option contracting

chase decision is delayed until the end of construction. Fig. 3 presents the workflow in the warranty option approach. The project is bid the same way as in a traditional low-bid system, but contactors are required to submit the price of the warranty with their bids. The state agency does not need to make the decision on the purchase of the warranty during the bidding phase. To evaluate the bids under the warranty option approach, the total price of the warranty should not be included in the bid since the state DOT might not exercise the option at the end of construction. Only part of the warranty price, called the value of the warranty option, should be considered when evaluating the bids. The value of a warranty option is then deducted from the bid to determine the lowest bidder. After the project is completed, all information gathered during construction is considered to evaluate performance. The potential failure cost will be predicted, discounted, and compared to the warranty price to make a decision on exercising the warranty option. Thus, information on project construction is gathered and used to improve the decision process. If the quality of construction is considered to be good and the warranty price is higher than expected discounted failure costs, the state DOT will not exercise the warranty option. But if a high probability of failure is predicted, the state DOT can exercise the option and bind the contractor into project maintenance. If contractors are allowed to provide multiple warranty terms, a derivative warranty term option is created.

Comparison of Warranty Option versus Conventional Warranty

The current warranty approach ignores the value of waiting, and the decision is made before actual performance during construction unfolds. Instead of making a decision beforehand, the warranty option delays the decision until the end of construction, when more information is available and future performance can be better predicted. Warranty option contracting is superior to conventional warranty contracting from the point of view of bidding, flexibility, risk, bonding, and incentive (Table 1). The option concept has the potential to provide a great benefit to the construction industry. These benefits are discussed below.

Table 1. Comparison of Conventional Warranty versus Warranty Option

Category	Conventional warranty	Warranty option
Bid price	High	Low
Flexibility for DOTs	Low	High
Risk for contractor and surety	High	Low
Bonding	Difficult	Possibly easy
Incentive	High	High
Warranted projects	Less	More

- Bidding: As compared to conventional warranty contracting, the warranty option delays the decision on the purchase of a warranty until the end of construction. Thus, the initial bid price will not increase much. Since the price of the warranty is not included in the evaluation of the bids, contractors will submit bids that are not too dissimilar to regular nonwarranted contracts.
- Flexibility: Instead of buying a warranty before construction begins, the warranty option makes it possible to delay that decision. More information is gathered as the project is constructed. The new information could be used to make a much more accurate prediction of the future performance of the project. Compared to current warranty practice, the warranty option allows state DOTs to buy warranties only for those projects that have a high probability of failure within the warranty period. This managerial flexibility benefits state DOTs by allowing them to buy the right warranties for the right projects.
- Risk: The warranty option changes risk allocation among project participants. Under current warranty contracting, contractors and surety companies are exposed to default risk within the period of the term of the warranty. The risk is not related to the performance of the project. The warranty option will lower the risk for a high-quality contractor but increase the risk for a poor-quality contractor because the state DOT might give up the option if a well-performed project is observed.
- Bonding: A long-term warranty puts surety companies in a risky situation if contractors default. Surety companies are not comfortable issuing long-term warranty bonds. Under warranty option contracting, the warranty liability might be waived if the contractor provides high-quality work. Although many surety companies evaluate the worst-case scenario when issuing a warranty bond, the reduced risk involved in warranty option contracting could make them lower the cost of the warranty. Covering smaller construction films that provide high-quality work is no more risky than for the same companies in the conventional warranty environment.
- Incentive: The warranty option gives contractors an additional incentive to produce higher-quality work since the DOTs may not exercise the purchase of the warranty after the project is over. After all, many of them have limited bonding capacity.
- Warranted projects: The warranty option gives the state DOT a right to delay the warranty decision until the completion of construction. Thus, state DOTs would be able to cover more projects, which would greatly benefit them if they were under a tight warranty budget.

J. Manage. Eng. 2004.20:118-125.

Table 2. Key Elements of Warranty Option

Underlying asset	= Warranty
Value of underlying asset	= Expected failure cost within warranty period (present value)
Exercise price	= Warranty price in bid
Time to expiration	= Construction period
Volatility	= Construction performance uncertainty
Risk-free rate	= Interest rate of U.S. treasury bond

Evaluation of Warranty Option

Since the state DOT has managerial flexibility to exercise or give up a warranty option, the total warranty price should not be added up in the evaluation of the bids. On the other hand, the warranty price does affect project cost if the state DOT decides to exercise the option. Therefore, a model is needed for calculating the value of the warranty option so as to include it in the bids. This paper presents a quantitative model for calculating the value of the warranty option.

The value of managerial flexibility is believed greatest when (1) high volatility is expected in the future; (2) there is more room for flexibility; and (3) net present value (NPV) is near zero (Copeland and Antikarov 2001). As discussed earlier, the warranty option, like a stock option, has five key components: value of underlying asset, exercise price, time to expiration, volatility, and risk-free rate. The explanations of these components with respect to the warranty option are listed in Table 2. The value of the underlying asset is defined as the present value of the expected failure cost during the warranty period. The warranty price in the bid is the exercise price when the state DOT decides to buy the warranty. The failure cost varies according to the contractor's performance on the site and the materials used during construction. If the contractor uses good-quality material on the project and is generally quality conscious, the project will likely last longer without a failure. Therefore, future maintenance on the project will be less expensive. This suggests that the present value of the failure cost within the warranty period (the value of the underlying asset) will be less. At the end of construction, the warranty option is valued as the difference between the present value of the failure cost within the warranty period and the listed price of the warranty in the bid. The payoff of the warranty option at the expiration date is then

$$WO_T = \mathrm{MAX}(C_T - P, 0) \quad (1)$$

where T = time of end of construction; WO_T = value of warranty option at time T; C_T = estimated present value of failure cost at time T based on information on construction performance; and P = warranty exercise price in bid. If the present value of the failure cost were greater than the warranty exercise price in the bid, the state DOT would buy the warranty at the predetermined price P. The added value of the warranty option at that time would be $C_T - P$. If the present value of the expected failure cost were less than the warranty exercise price, the warranty option would be worthless; the state DOT would have no reason to buy a warranty at such a price. With the value of the warranty option known at the time of completion of the project (or time T), the following assumptions are needed for calculating the value of the warranty option at the time of bidding (time 0).

1. The risk-free interest rate is known and constant throughout the construction period;
2. No structural maintenance funded by the state DOT occurs during the warranty period; and
3. In a continuous time frame over period $[0,T]$, where $T>0$, the perception of project quality (measured via the predicted failure cost) follows a stochastic differential equation:

$$dC = \mu C dt + \sigma C dZ \quad (2)$$

where μ and σ are the mean and standard deviation of percentage changes in the failure cost C, and dZ follows a standard Wiener process in the probability space. The Wiener process describes a particular type of stochastic process where only the present state of the process (the current quality level) is relevant for predicting the future. The past history of the process is irrelevant because all historical behavior has been impounded into the current quality level. In other words, the current quality state contains all information needed to predict future deterioration. This assumption is fairly standard in finance (Hull 1997) and construction research on deterioration modeling (Livneh 1996). This assumption makes it possible to duplicate a warranty option over an infinitesimal time period.

Modeling project quality in this fashion allows the use of standard option-pricing models. With the assumptions discussed above, the warranty option could be evaluated by the classic Black-Scholes equation (Hull 1997)

$$WO_0 = C_0 N(d_1) - Pe^{-rt} N(d_2) \quad (3)$$

where

$$d_1 = [\ln(C_0/P) + (r + 1/2\sigma^2)t] / \sqrt{\sigma^2 t} \quad (4)$$

$$d_2 = d_1 - \sqrt{\sigma^2 t} \quad (5)$$

$$N(d) = \int_{-\infty}^{d} \frac{1}{\sqrt{2\pi}} e^{-x^2/2} dx \quad (6)$$

The equations indicate that the value of the warranty option at the time of bidding WO_0 is determined by five parameters listed in Table 2: C_0 = engineer-estimated present value of failure cost within warranty period at time 0 (time of bidding); P = exercise price of warranty option predetermined in bid; σ = annualized compounded standard deviation of percentage changes in present value of failure cost within warranty period (C); r = risk-free interest rate based on treasury bond or treasury bill with same time period as construction period; and t = time to expiration or whole construction period. In addition, $N(d)$ = probability that a standardized, normally distributed, random variable will be less than or equal to d.

The model can be divided into two parts. The first calculates the expected benefit from acquiring the warranty option, and the second gives the present value of paying the exercise price on the expiration day. The value of the warranty option is then calculated by taking the difference between these two parts (Hull 1997). The volatility of the failure cost σ is an unobservable variable that could be very challenging to estimate. However, the state DOTs could estimate this variable from historical data.

Warranty Option Approach: Hypothetical Case

By calculating and using the value of the warranty option at the time of bidding, state DOTs can evaluate bids with different warranty exercise prices. The following example illustrates how the warranty option for a hypothetical pavement project can be incorporated in bid evaluations during the bidding stage.

J. Manage. Eng. 2004.20:118-125.

Table 3. Bid Evaluation in Warranty Option Contracting: Example (in Millions of Dollars)

Contractor	A	B	C	D
Construction contract ($)	94	95	98	97
Warranty price ($)	NA	8	7	5
d_1 [Eq. (4)]	NA	1.58	2.91	6.28
d_2 [Eq. (5)]	NA	1.48	2.81	6.81
Value of warranty option ($)	NA	1.30	2.24	4.17
Bid value ($)	94	93.70	95.76	92.83
				Best value

Note: Assumption: (1) Engineer's estimate of warranty price = $9,000,000; (2) risk-free interest rate = 3.5%; (3) standard deviation of performance = 10%; and (4) construction period = 1 year.

Evaluation of bid of contractor B is

$$d_1 = \left[\ln\left(\frac{9{,}000{,}000}{8{,}000{,}000}\right) + (3.5\% + 1/2 \cdot 10\%^2) \cdot 1\right] \Big/ \sqrt{10\%^2 \cdot 1}$$

$$= (0.1178 + 0.04)/0.1 = 1.578 \quad d_2 = d_1 - \sqrt{\sigma^2 t} = 1.478$$

$$WO_0 = C_0 N(d_1) - Pe^{-rt} N(d_2)$$

$$= (\$9{,}000{,}000 \cdot 0.9427) - (\$8{,}000{,}000 \cdot e^{-0.035} \cdot 0.9304)$$

$$= \$1{,}297{,}146$$

Bid value of contractor B

$$= (\text{Construction contract}) - (\text{Value of warranty option})$$

$$= (\$95{,}000{,}000 - \$1{,}297{,}146) = \$93{,}702{,}854$$

Assume that a state DOT plans to build a new asphalt pavement. The state is considering a 7-year warranty for the pavement to guarantee quality and pavement performance. The warranty is expected to be about 9% of the total contact price, estimated to be about $9 million. Under the conventional warranty approach, the cost of the warranty becomes a part of the bid that will have to be paid by the DOT irrespective of the quality of construction and an assessment of the probability of failure during the warranty period. If the project is well built, the pavement will quite possibly last through the 7-year warranty period without any major failure that is expensive to repair. The taxpayer's money could be used more effectively by the state DOT if this decision is delayed until the quality of construction is known. In the proposed warranty option method, the project can still be bid under the traditional lowest-bid system. To keep the choice of the warranty open, the state asks contractors to provide warranty exercise prices in their bids.

Four bids are received for the pavement project (Table 3). Contractor A does not qualify because a warranty option is not offered. With different expectations of project failure risk, the remaining contractors B, C, and D provide different quotes for the 7-year warranty. These quotes now have to be incorporated in the bids by calculating the value of the warranty options using Eqs. (1) through (5). The warranty option is valuable to the DOT since it gives the state an opportunity to save on warranty costs. Therefore, this value should be credited to the bid (deducted from the bid amount when evaluating the bids, as shown in the example below). From historical data, the state DOT assumes that the standard deviation of construction performance is about 10%. The time to expiration of the warranty option is the same as the construction period, assumed to be 1 year. With a risk-free rate of 3.5%, the value of the warranty option can be calculated using the above evaluation equations.

The value of the warranty option is considered a credit for bid evaluations, which means the warranty option is a deductible item in the bids. Although contractor B submitted the lowest bid for construction, the warranty option gives him or her only $1.3 million credit. Contractor D quoted a much lower warranty exercise price that generated a $4.2 million bid value. The final corrected bids for contractors B, C, and D are $93.7 million, $95.8 million, and $92.8 million, respectively. Therefore contractor D is the successful bidder, giving the state the best value for the project.

Conclusions

The warranty option concept suggests a new development in construction research. The warranty option, as a derivative of the conventional warranty approach, is a better concept in that it gives state DOTs managerial flexibility. While maintaining the lowest-bidder approach to contracting, it delays the decision on buying the warranty until the end of construction when more information is available on the quality of the end product, and the need for a warranty to cover future maintenance can be better assessed. A decision is made on exercising the warranty option only after comparing the cost of possible future maintenance to the cost of purchasing the warranty. The costs of future failures can then be assessed from information gathered during the construction of the project rather than using average values from past projects.

Acknowledgments

This research was supported by the Ohio Department of Transportation (ODOT), whose support is gratefully acknowledged. The opinions and findings expressed here, however, are those of the writers alone and not necessarily the views or positions of ODOT.

References

AASHTO. (2001). *Primer on contracting for the twenty-first century*, 4th Ed., Washington, D.C.

Abbey, D. (1999). "Review of statewide transportation improvement plan and related topics." *Technique Rep.*, State Highway and Transportation Dept., Santa Fe, N.M.

Amram, M., and Kulatilaka, N. (1999). *Real options: Managing strategic investment in an uncertain world*, Harvard Business School Press, Watertown, Mass.

Anderson, S. D., and Russell, J. S. (2001). *NCHRP Rep. 451 guidelines for warranty, multi-parameter, and best value contracting*, Transportation Research Board, National Academy Press, Washington, D.C.

Aschenbrener, T., and DeDios, R. (2001). "Materials and workmanship warranties for hot bituminous pavement." *Technique Rep. No. CDOTS-DTD-2001-18*. Colorado DOT.

Copeland, T., and Antikarov, V. (2001). *Real options: A practitioner's guide*, TEXERE Publishing Limited, London.

Federal Highway Administration (FHWA). (2000). "Warranty clauses in federal-aid highway contracts." *FHWA Briefing*, December 7, Washington, D.C.

Hancher, D. E. (1994). *NCHRP synthesis 19: Use of warranties in road*

J. Manage. Eng. 2004.20:118-125.

construction, Transportation Research Board, National Academy Press, Washington, D.C.
Hull, J. C. (1997). *Options, futures, and other derivatives*, Prentice-Hall, Upper Saddle River, N.J.
Livneh, M. (1996). ''Deterioration modeling for life cycle cost analysis.'' *Transportation Research Record 1524*, Transportation Research Board, Washington, D.C.
Russell, J. S., Hanna, A. S., Anderson, S. D., Wiseley, P. W., and Smith, R. J. (1999). ''The warranty alternative.'' *Civ. Eng.*, 69(5), 60–63.
Trigeorgis L. (1996). *Real options: Managerial flexibility and strategy in resource allocation*, MIT Press, Cambridge, Mass.

J. Manage. Eng. 2004.20:118-125.