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RESEARCH ARTICLE

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Evaluation of the contract reliability for alternative infrastructure project delivery: a contract engineering method

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Abstract Governments at all levels are increasingly motivating the private sector to participate in infrastructure development using alternative project delivery methods to relieve financial burden. When designing contracts, governments usually offer incentives while requiring cost or time guarantee to balance project attractiveness to the private sector and fair protection of public interest. However, a practical and critical problem is how to properly design these provisions. Although previous studies have investigated the value of these provisions, a knowledge gap still exists with respect to methods of fairly and effectively designing such provisions. This study fills this gap by developing a methodology that analyzes the appropriateness of guarantee or warranty provisions for contracts. In this study, a contract reliability index is constructed, and a process of evaluating contract reliability is proposed. The New Mexico Highway 44 project, in which three warranty provision arrangements are investigated, is used as a case study to illustrate the analysis process. Results show that although a ceiling clause can effectively motivate the private sector to participate in the project, it sacrifices a significant amount of public benefits. By contrast, although a warranty option can protect public benefits, it cannot effectively incentivize the private sector. A combination of the ceiling clause and the warranty option will therefore result in improved contract provision design. The proposed methodology in this study is especially useful for governments in properly determining contract clauses in infrastructure development.

Keywords infrastructure development, contract design, contract reliability, guarantee provision, contract engineering

1 Introduction

Infrastructure development is an important engine for economic development, given the aim of developed and developing countries to upgrade their infrastructure systems (Verhoest et al., 2015; Zhang et al., 2015; Wang et al., 2018a). In the project delivery method of traditional infrastructure, namely, design-bid-build, the government (owner) designs the project and subcontracts the construction and operation to different private firms. In this method, the private sector solely manages the project according to the description of the contract and has little motivation to make innovations and quality improvement (Cui et al., 2004). Moreover, given that infrastructure development requires a large amount of money, the government finds that it is difficult to meet the demand of infrastructure by solely relying on governmental financial budgets (Sharma et al., 2010; Chan et al., 2018).

Some new project delivery methods, such as build-operate-ransfer (BOT), design-finance-build-operation, and design-build-operate-maintain (Park et al., 2013; Van Den Hurk and Verhoest, 2016; Wang et al., 2018a), have been promoted to improve the managerial efficiency of infrastructure and release the financial burden of governments. With these new project delivery methods, a government can sign a long-term concession contract

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with the private sector, which allows the private sector to design, build, and operate the infrastructure based on their own professional knowledge (Park et al., 2013; Van Den Hurk and Verhoest, 2016; Wang et al., 2018a). However, unlike in traditional project delivery methods, the private sector must bear some additional risks, such as the design defect and operating risks, which may deter them from implementing the new project delivery methods. A government usually provides governmental support, such as subsidies and guarantees, to share risk with the private sector (Brandão et al., 2012; Park et al., 2013; Soumaré, 2016) and motivate private firms to participate in these new project delivery methods. The guarantee clause in a contract must be properly arranged; otherwise, it may help the private sector earn sizable profits, thereby potentially reducing public benefits (Gordon et al., 2013; Van Den Hurk and Verhoest, 2016; Wu et al., 2018). Although some remedial measures can be used in the event that an original guarantee clause is improperly designed, several renegotiations will be needed, and such activities will cost a considerable amount of time and money. Renegotiation may also present an undesirable image to the industry, thus possibly affecting the enthusiasm of the private sector about participating in infrastructure development. Therefore, ensuring proper arrangement of a guarantee clause is important during the design of a contract. However, although many studies have evaluated the value of these guarantee or warranty provisions (Cui et al., 2008; Kokkaew and Chiara, 2013; Sun and Zhang, 2015; Carbonara and Pellegrino, 2018; Wang et al., 2018a), a knowledge gap remains with respect to methods of fairly and effectively designing such provisions. Compared with previous studies, the current work fills this gap by developing a methodology of analyzing the accuracy of guarantee or warranty provisions in contracts.

The original idea comes from engineering design, in which the guarantee contract may be designed similar to how engineers design bridges, that is, contract engineering. In engineering design, before a novel idea is added to the design of a bridge, engineers must usually test the reliability of the bridge via simulation. Some reliability indexes that can help engineers determine the appropriateness of adding an idea into the design of the bridge are available. In this manner, engineers can find the potential design defects of the bridge beforehand and fix them in time, thereby helping prevent tragedies. Similarly, the existence of a reliability index, which can help the government determine the appropriateness of providing some guarantee clauses in the contract to reduce the probability of contract renegotiation ex ante, is better. The main contribution of this study is the construction of a contract reliability index and proposal of a process for evaluating the reliability of the contract, which can provide guidelines for the government regarding the guarantee contract design. As shown in the case analysis section, by calculating the contract reliability index, compared with the warranty provision combined with the ceiling clause and that combined with the warranty option, the warranty provision combined with the ceiling clause and the warranty option can generate an improved guarantee contract. Therefore, with the contract reliability index, a government can have better knowledge regarding the guarantee contract similar to engineers designing a bridge.

This paper comprises four sections apart from the introduction. In the next (second) section, a brief literature review regarding the evaluation of the governmental guarantee and warranty is conducted. The contract reliability index was constructed, and a proposed corresponding analysis process is presented in the third section. In a case study in the fourth section, The New Mexico Highway 44 project was used to illustrate the analysis process of contract reliability. Finally, the final section explain the conclusions and limitations of this study, respectively.

2 Literature review

Infrastructure development usually involves large sunk investments, and the context is of considerable uncertainty (Cruz and Marques, 2013; Soumaré and Lai 2016). The government usually provides some governmental support to promote the participation of the private sector in infrastructure development (Brandão et al., 2012; Park et al., 2013; Soumaré and Lai, 2016). The support from the government has also been recognized as a critical factor that influences the success of public-private partnership (PPP) projects because it affects the enthusiasm and the investment decision of the private sector. However, the good intention of governmental support may become a tool for the private sector to increase profits at the expense of public benefits (Cruz and Marques, 2013; Gordon et al., 2013). Some scholars have attempted to evaluate governmental support from different aspects to prevent such abuse.

Researchers have focused their attention on the minimum revenue guarantee. Brandão and Saraiva (2008) studied the option value of the minimum traffic guarantee in infrastructure projects and concluded that the minimum traffic guarantee can effectively attract the private sector to invest in high-risk public infrastructure projects. Ashuri et al. (2012) proposed a risk-neutral pricing approach to evaluate the value of the minimum revenue guarantee in BOT highway projects. Brandão et al. (2012) investigated the minimum demand guarantee in Metro Line 4 of the São Paulo subway system and found that this governmental incentive can effectively increase the net value of the project at a small cost to the government. Hawas and Cifuentes (2017) recently developed a Gaussian copula-based simulation method, which can improve the evaluation accuracy of the minimum revenue guarantee. However, although the minimum revenue guarantee can incentivize the private sector and increase project value, this method is a contingent liability for the government. Park et al. (2013) suggested that the government should establish some complementary agreements to counterbalance the effect of the guarantee and introduced a combination of the maximum revenue limit and the maximum expense limit to stimulate the participation of private entities in the construction of water sewer systems. Chiara and Kokkaew (2013) presented a dynamic revenue insurance contract that can serve a similar role of the government guarantee while reducing the guarantee cost of the government. Sun and Zhang (2015) established an adjustment mechanism through the minimum revenue guarantee and the royalty fee to balance the benefits of the government and the private sector. Chen et al. (2018) investigated the toll-adjustment mechanism, an alternative for the guarantee arrangement that can ensure the private investor a reasonable rate of return while reducing the fiscal burden of the government. Li et al. (2017) argued that the government should charge the project company for a credit default swap (CDS) and proposed a risk-neutral valuation method to price the CDS. Wang et al. (2018b) claimed that the minimum revenue guarantee value should be shared between the government and the private sector and derived the optimal distribution ratio to satisfy both parties.

The government may also provide some warranty provisions in the contract for the private sector to promote innovations and quality improvement. While providing guarantees increases the latent liability of the government, warranty provisions transfer the liability of the government to the private sector. Cui et al. (2004) analyzed the advantages and disadvantages of warranty provisions and proposed a warranty option approach that increases the value of warranty provisions. Furthermore, Cui et al. (2008) investigated the value of the warranty ceiling clause in the New Mexico Highway 44 project using a binomial lattice model. They found that the expenditure ceiling clause is costly and suggested that the government should determine a favorable ceiling value before including a ceiling clause in the warranty.

Some scholars have also investigated the influence of government incentives on the investment behavior of the private sector. Feng et al. (2015) studied the impact of three types of government incentives, namely, minimum traffic guarantee, minimum revenue guarantee, and price compensation guarantee, on the investment behavior of the private sector, including the toll rate, road quality, and road capacity. Shi et al. (2016) supposed that the government guarantee can serve as an instrument that encourages the private sector to reveal the true cost information under asymmetric information conditions. Li and Cai (2017) investigated the impact of government incentives on the investment behavior of the private sector under demand uncertainty. Wang et al. (2018c) studied the impact of government subsidy on the design of BOT contract, including price, demand, and concession period.

From the aforementioned literature analyses, current studies mainly focus on the evaluation of the value of governmental guarantees and warranties and the influence of these government incentives on the investment behavior of the private sector. However, the issues regarding the appropriateness of adding certain guarantee or warranty provision in the contract and the better arrangement of provision remain unsolved. This study developed a methodology to evaluate the appropriateness of including the governmental guarantee and warranty provisions in PPP contracts, which can lay a foundation for the research that intends to investigate the influence of these government incentives on the investment behavior of the private sector. Therefore, the first step is to ensure the appropriateness of adding a certain guarantee into the contract. Moreover, studying the influence of the guarantee in the investment behavior of the private sector is significant.

3 Contract reliability analysis

In this section, an evaluation process for the reliability of a contract, which mainly comprises six steps, is proposed.

The first step of the procedure is to identify the key clause of warranty or guarantee provisions. For example, in a warranty provision, the key clause includes the price of the warranty, the duration of the warranty, and related ceiling clauses.

The second step of the procedure is to forecast the cash flow or cost of the project based on historical data. Some simulation methods, such as Monte Carlo simulation, can be used in this section, and three cash flow or cost scenarios of the project can be realized: the best, the moderate, and the worst scenario. The guarantee and some ceiling clauses may take effect in the best or worst scenarios depending on the specific type of the clause. For example, the maximum revenue limit may have effects when the cash flow of the project is under the best scenario, whereas the expenditure limit may have effects when the cost of the project confronts the worst scenario.

The third step of the procedure is to evaluate the value of warranty or guarantee provisions based on the identified key clauses and the forecasted project cash flow. This part has been well studied in previous literature, as summarized in the literature review section. In previous studies, the guarantee and warranty provisions are usually regarded as some managerial flexibilities added to the contract and evaluated through the real-option method. In line with these studies, a binomial lattice real-option model is used in the current work. With the use of this model, the value of the warranty or guarantee liability can be described with a path in a binomial tree, which starts at a parent node and ends at several child nodes from left to right. The warranty or guarantee liability can be calculated by using a backward algorithm, which was also used in the study of Cui et al. (2008).

The fourth step of the procedure is to calculate the reliability of the contract. A contract reliability index was constructed in this part and is expressed in Eq. (1).

$$\beta = \frac{E(\text{Benefit}) - E(\text{Cost})}{\sigma_{B-C}}, \tag{1}$$

where β represents the contract reliability index, $E(\text{Benefit})$ and $E(\text{Cost})$ represent the expected benefits and costs of the guarantee or warranty, respectively, and σ_{B-C} reflects the volatility of the project cash flow. This index indicates the confidence level at which the benefits of the guarantee or warrantee can exceed its costs. Moreover, this index can illustrate the contract viability against risks and the effectiveness of the contract arrangement (incremental analysis). If the contract reliability index of a guarantee or warrantee is positive ($\beta > 0$), then this finding shows that adding this guarantee or warrantee in the contract can reinforce the contract viability against risks and the effectiveness of the contract arrangement. Otherwise (if $\beta < 0$), adding this guarantee or warrantee in the contract will weaken the contract viability against risks and the effectiveness of the contract arrangement.

The fifth step of the procedure is to set the reliability objective. Given that the cash flow of the infrastructure project is deemed highly volatile, predicting the cash flow precisely is difficult. The Wiener process was extensively used in previous studies (Cui et al., 2008; Brandão et al., 2012; Hawas and Cifuentes, 2017; Fai et al., 2017) to describe the cash flow of the infrastructure project. Under this assumption, the contract reliability index is determined to follow a standard normal distribution. Thus, the success probability of reaching a proposed contract reliability index value can be calculated. Suppose the proposed reliability index value is β_0, the success probability can be derived by calculating $1 - N(\beta_0)$, where the function $N(\cdot)$ means the normal probability distribution function. Given that $N(\cdot)$ is a monotonically increasing function, the success probability is small when the reliability index value is large. The random characteristic of the contract reliability index reflects the following two aspects: (a) designing a contract that can cope with all the uncertainties in the project, which is in line with incomplete contract theory (Hart and Moore, 2004; Hart, 2003); (b) changing the guarantee or warranty clause may address the opposition from the private sector, which increases the failure probability of the contract. Therefore, when the government sets the target of the contract reliability, the reliability index value and the success probability must be traded off.

The final step of the procedure is to verify whether the reliability of the contract can be further improved. In this part, the scenario analysis is conducted by changing the guarantee or warranty clause and calculating their contract reliability index values. If the reliability index value of the contract can meet the predetermined target value, then changing the guarantee or warranty clause is no longer necessary. Otherwise, the value at risk (VaR) profile (as shown in the following case study) of the guarantee or warranty must be established to examine how these clauses affect the contract. Then, reaching the objective reliability value by changing the guarantee or warranty clause or adding other contract provisions is verified.

A summary regarding the contract reliability evaluation procedure is displayed in Fig. 1.

4 Case analysis

In this section, the New Mexico Highway 44 (NM 44) project is used to illustrate the analysis process summarized in Fig. 1. This particular case is selected due to the availability of project data and the existence of a ceiling clause in the warranty provision of the project that is

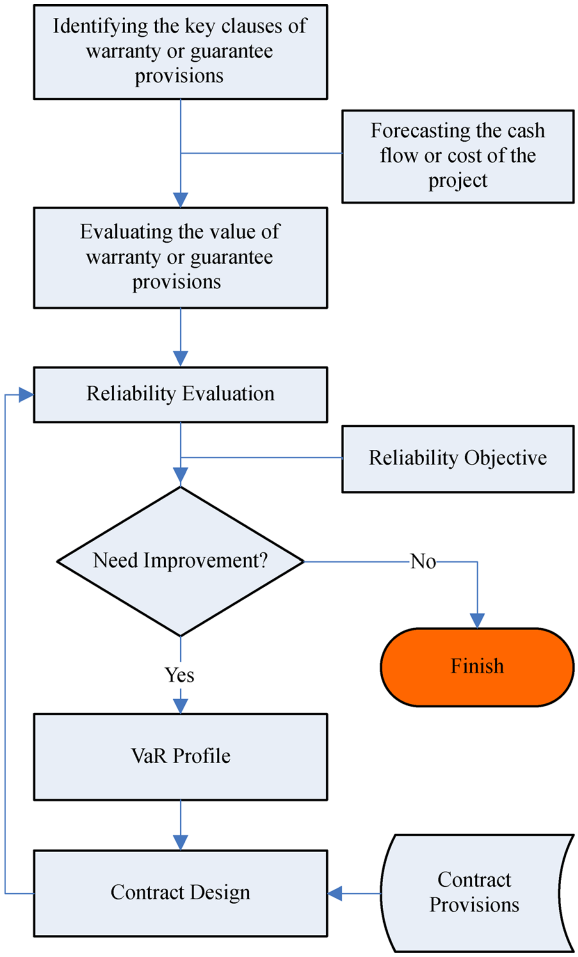

Fig. 1 Evaluation framework of the contract reliability index

deemed as an inappropriate clause (Cui et al., 2008). By using this case to illustrate the analysis process, the appropriateness of an additional ceiling clause to the warranty provision and the further improvement of the warranty provision are determined.

In 1998, the New Mexico State Highway and Transportation Department (NMSHTD) signed a long-term warranty agreement with a private sector, Mesa Project Development Contractor (PDC). According to the agreement, the NMSHTD will pay \$60 million for a 20-year pavement warranty on the New Mexico Highway 44 (NM 44) project. In return, the Mesa PDC will be responsible for the project maintenance based on the design criteria and performance requirements of the NMSHTD. Two ceiling clauses are included in the agreement: 4 million equivalent single-axle loads (ESALs) and 110 million in total pavement maintenance expenditures. Therefore, the Mesa PDC must provide up to \$110 million in maintenance over a period of 20 years or 4 million ESALs. For simplicity, the total warranty payments to the Mesa PDC can be lumped into two installments, namely, \$5 million in 2000 and \$55 million in 2001 (Cui et al., 2008). In 2004, an interim audit report of the NM 44 project was disclosed (Abbey, 2004). In this report, three estimated maintenance expenditure scenarios in 2021 are presented: the best-, the moderate-, and the worst-case scenarios, and their cumulative expenditure values of \$73, \$110, and \$146, respectively.

4.1 Evaluating the contract reliability of the naked warranty provision

The naked warranty provision means that the NMSHTD pays the Mesa PDC \$60 million in return for maintaining the NM 44 project without considering the ceiling clause. The VaR profile of the naked warranty provision is presented in Fig. 2, in which graph "a" shows the payoff required from the NMSHTD to maintain the NM 44 project without the warranty, graph "b" represents the payoff of buying a warranty, and adding the two graphs can derive the payoff of the NMSHTD with the warranty (graph "c"). By discounting the warranty payments back to 1998, the value of warranty cost is determined to be \$52.5 million. The discounting rate is 4.7%, which is the same as the grant anticipation revenue vehicle bond rate at that time. Similarly, according to a discounting of the estimated maintenance expenditure in 2021 back to 1998, the value is \$53.6 million under the moderate scenario. Therefore, the naked warranty provision can help the NMSHTD totally save \$1.1 (53.6 – 52.5) million discounted back to 1998, which shows that the naked warranty provision is beneficial to the NMSHTD. Furthermore, according to the interim audit report of the NM 44 project, the standard deviation of the project's maintenance cost is 5.97. Thus, the contract reliability index value of the naked warranty provision (denoted as β_0) can be calculated by the Eq. (1), $\beta_0 = 0.18$ (1.1/5.97). Although the naked warranty provision is beneficial to the NMSHTD, it may be detrimental to the private sector. The addition of the naked warranty provision in the contract depends on the negotiation between the government (NMSHTD) and the private sector (Mesa PDC). The probability (denoted as P_0) that the government and the private sector agree on adding the naked provision in the contract can be calculated by $1-N(\beta_0)$, where $N(\beta_0)$ means that the probability of a standardized and normally distributed random variable is less than or equal to β_0; therefore, $P_0 = 0.4286$ can be derived.

According to a calculation of the contract reliability index value of the naked warranty provision and evaluating the success probability of the additional naked warranty provision in the contract, results show that although the naked warranty provision is beneficial to the government, the success probability of the additional warranty provision in the contract is low (less than 50%). The underlying reason for the low success probability is that the naked warranty provision is averse to the private sector because the price of the naked warranty provision is low for the private sector, which may cause their objection. Moreover, the contract reliability index value and the success probability are elastic to the warranty payment schedule.

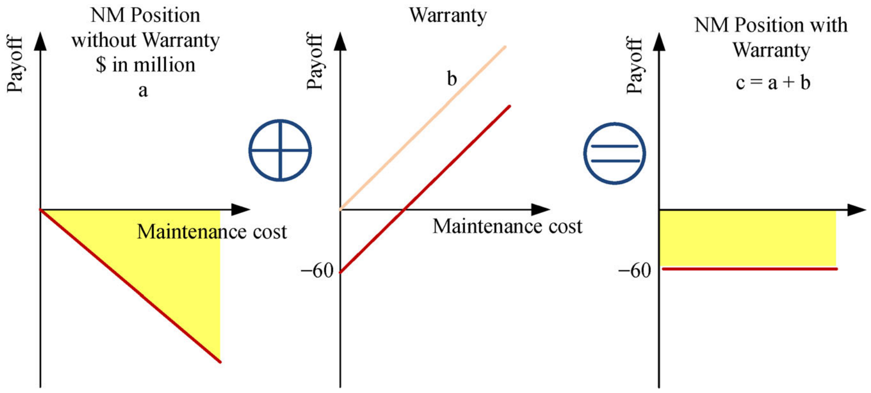

Fig. 2 VaR profile under the naked warranty provision

If the total warranty payments are scheduled as \$55 million in 2000 and \$5 million in 2001, then the warranty cost discounted back to 1998 is determined to be \$54.5 million. Therefore, the expected net present worth of the warranty provision for the NMSHTD is \$ – 0.9 (53.6 – 54.5) million. Following the same calculation procedure as above, the contract reliability index value and the success probability under the new warranty payment schedule are –0.15 and 0.5596, respectively. Although the total warranty payments are unchanged (\$60 million), different payment schedules will lead to significantly different contract reliability. Therefore, when determining the payment schedule of the warranty, the government should focus on the influence of the payment schedule on contract reliability.

4.2 Evaluating the contract reliability of the warranty provision in combination with the ceiling clause

The warranty agreement contains an expenditure ceiling clause that constrains the cost of the Mesa PDC to \$110 million. According to the ceiling clause, any actual accumulated maintenance cost of the NM 44 project exceeding \$110 million will be the responsibility of the NMSHTD. Apparently, the addition of the ceiling clause increases the liability of the NMSHTD relative to that under the naked warranty provision. The VaR profile under the warranty provision in combination with the ceiling clause is presented in Fig. 3.

As suggested in Cui et al. (2008), the value of the ceiling clause in 1998 is \$4.8 million for the NMSHTD. Therefore, the contract reliability index value of the warranty provision in combination with the ceiling clause is $\beta_1 = -0.62$ ((1.1–4.8)/5.97), and the success probability is $P_1 = 0.7324$. These results show that the ceiling clause in the warranty provision heavily deteriorates the benefits of the NMSHTD and increases those of the Mesa PDC, which results in the strong willingness of the Mesa PDC to accept the warranty provision (high success probability). Thus, the ceiling clause value is modified to prevent the Mesa PDC from making extra profits at the cost of the NMSHTD. A sensitivity analysis is conducted to examine the changes of contract reliability index value with the expenditure ceiling value, and the results are shown in Fig. 4.

Figure 4 shows that the contract reliability index value is large when the expenditure ceiling value large. However, a large expenditure ceiling value also leads to a decreased contract success probability, given that increasing the expenditure ceiling value will reduce the benefits of the Mesa PDC, thereby potentially causing the resistance of the private sector. Therefore, when designing the ceiling clause, the government must balance the value of the

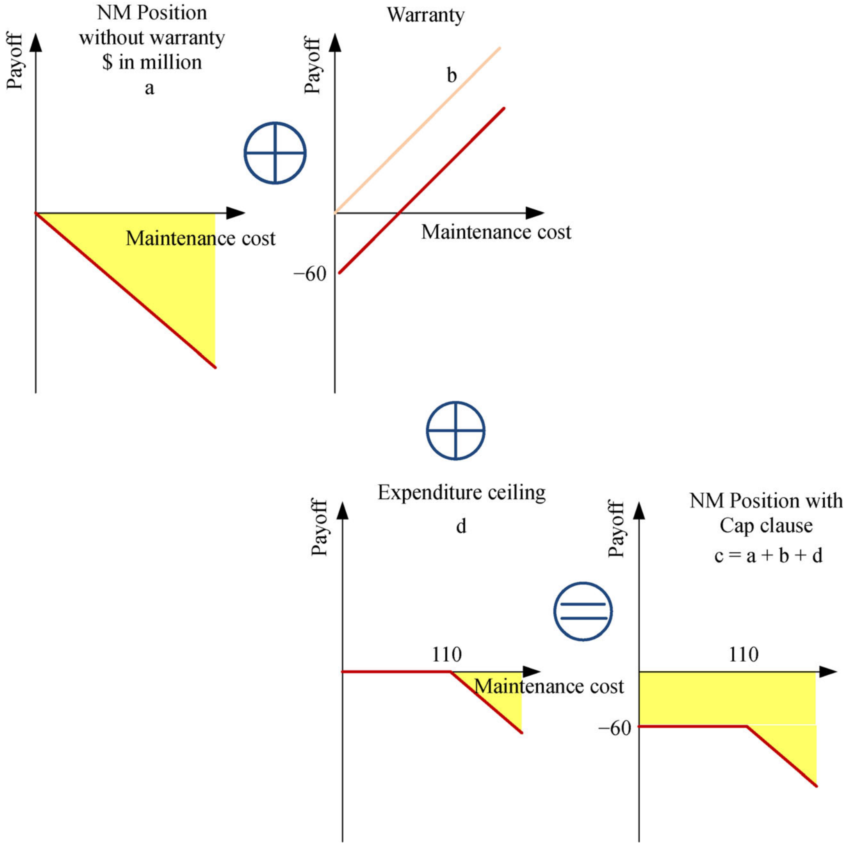

Fig. 3 VaR profile under the warranty provision with the expenditure ceiling

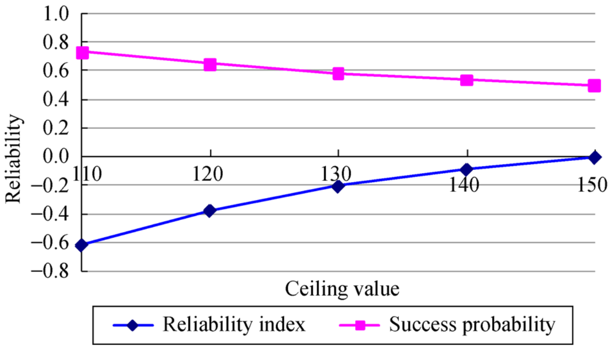

Fig. 4 Relationship between the contract reliability index and the expenditure ceiling

contract reliability and contract success probability. Furthermore, the marginal increment of the contract reliability index value decreases with the expenditure ceiling value. This result reflects that the effectiveness of increasing the expenditure ceiling value to improve contract reliability is decreasing. Therefore, when the expenditure ceiling value is sufficiently large, the government should find other approaches, such as combining with the warranty option, to enhance the contract reliability.

4.3 Evaluating the contract reliability of the warranty provision in combination with the warranty option

Cui et al. (2004) proposed the concept of the warranty option in their study. According to their definition, "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 (Cui et al., 2004)." Once a warranty option is included in the warranty agreement, the government can make the warranty payment decision according to the actual maintenance cost of the project. If the maintenance cost of the project is low, then the government can disregard the warranty option and pay the private sector the maintenance cost. Otherwise, if the maintenance cost of the project is high, then the government can execute the warranty option and only pay the warranty payments. The VaR profile under the warranty provision combined with the warranty option is presented in Fig. 5.

In the case, a warranty option was added in the warranty agreement between the NMSHTD and the Mesa PDC. The warranty option would then allow the NMSHTD to make the warranty payment decision until 2004. If the actual accumulated maintenance cost in 2004 is larger than $60 million, then the NMSHTD will execute the option and pay the warranty payments of $60 million, which is the same as that of the naked warranty scenario (the upper part of Fig. 5, "a + b"). If the actual accumulated maintenance cost in 2004 is less than $60 million, then the NMSHTD will not execute the option and pay the Mesa PDC the maintenance cost (the lower part of Fig. 5, "a + b + d"). Following the work of Cui et al. (2008), a two-period binomial model is set up to value the uncertainty and flexibility due to the warranty option (see Fig. 6).

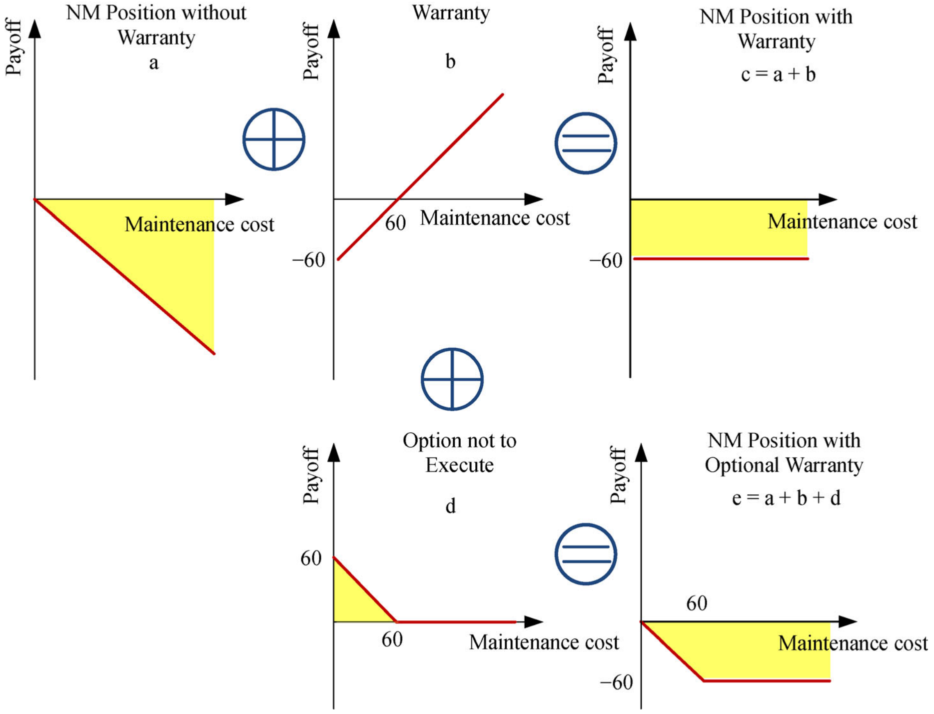

Fig. 5 VaR profile under the warranty provision with the warranty option

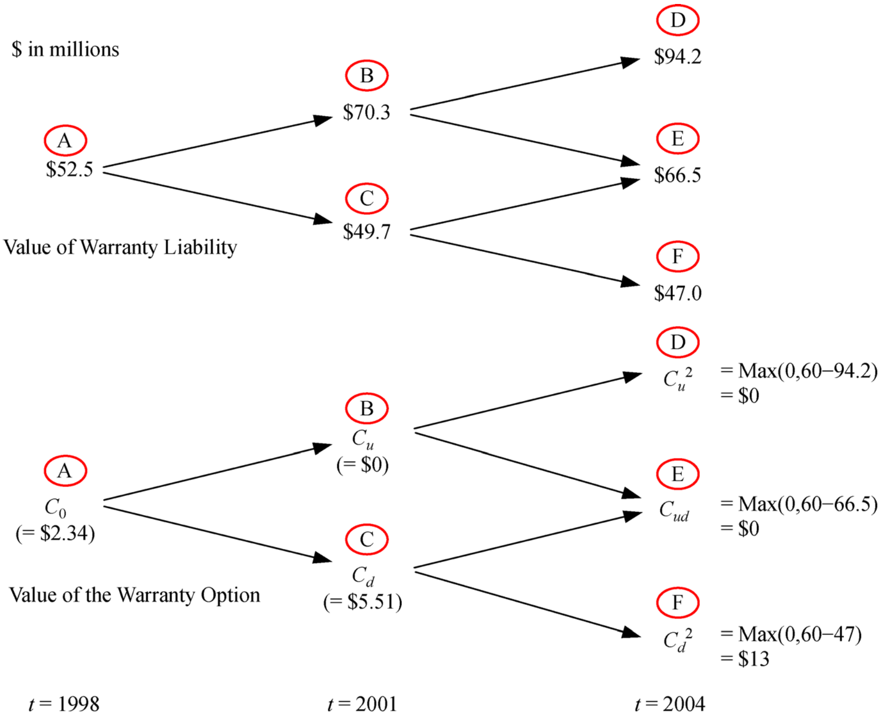

Fig. 6 Binomial tree for valuing the warranty option

Cui et al. (2008) estimated the value of the ceiling clause in the NM 44 project and derived the binomial tree of the warranty liability. Based on their study, this paper further investigates the value of the warranty option and the contract reliability of the warranty provision combined with the warranty option. The rise and fall rate of the binomial tree are $u = 1.339$ (70.3/52.5) and $d = 0.947$ (49.7/52.5), respectively. Given that the annual risk-free interest rate is 4.7%, the interest rate over a three-year period is 14.8%. Denoting the risk-neutral probability of rise (fall) is $p\,(1-p)$, then the following equation is satisfied:

$$14.8\% = p\cdot(u-1) + (1-p)\cdot(d-1). \tag{2}$$

Solving the equation, the risk-neutral probability of rise is approximately 51.3%, and the probability of a fall is 48.7%. Three scenarios were found in 2004. Under the worst scenario, the warranty liability rises to $94.2 million; therefore, the NMSHTD will execute the option. The value of the warranty option is equal to the following:

$$\begin{aligned} C_u^2 &= \mathrm{Max}(0,60-94.2) \\ &= \$0. \end{aligned} \tag{3}$$

Under the moderate scenario, the warranty liability rises to $66.5 million, and the NMSHTD will also execute the option. The value of the warranty option is then equal to:

$$\begin{aligned} C_{ud} &= \mathrm{Max}(0,60-66.5) \\ &= \$0. \end{aligned} \tag{4}$$

Under the best scenario, the warranty liability decreases to $47 million, and the NMSHTD will not execute the option. The value of the warranty option is equal to:

$$\begin{aligned} C_d^2 &= \mathrm{Max}(0,60-47) \\ &= \$13 \ \text{million}. \end{aligned} \tag{5}$$

Two scenarios were found back in 2001. Given that the value of the warranty option is equal to $0 under the worst and the moderate scenarios in 2004, $C_u = 0$ is satisfied. The value of the warranty option in 2001 is equal to:

$$\begin{aligned} C_d &= (0.487 \times 13 + 0.513 \times 0)/(1 + 14.8\%) \\ &= \$5.51 \quad \text{million}. \end{aligned} \tag{6}$$

Similarly, the value of the warranty option in 1998 can be calculated:

$$\begin{aligned} C_0 &= (0.487 \times 5.51 + 0.513 \times 0)/(1 + 14.8\%) \\ &= \$2.34 \quad \text{million}. \end{aligned} \tag{7}$$

Therefore, the value of the warranty option that allows the NMSHTD to make the warranty payment decision until 2004 is $2.34 million. Furthermore, the contract reliability index value of the warranty provision combined with the warranty option can be calculated as follows: $\beta_2 = 0.58\times((1.1 + 2.34)/5.97)$, and the success probability is $P_2 = 0.281$.

The aforementioned result indicates that adding the warranty option in the warranty agreement is beneficial to the NMSHTD. However, the private sector is smart; they will deny project participation if the contract clause is unfavorable to them. This condition contributes to the low success probability of adding the warranty option in the warranty agreement.

4.4 Enhanced warranty provision

From the preceding analyses, although the ceiling clause can effectively motivate the private sector to participate in the project, it sacrifices numerous public benefits. Meanwhile, although the warranty option can effectively protect public benefits, it cannot incentivize the private sector to participate in the contract. Combining the ceiling clause and the warranty option in the warranty agreement will actually be better. In this way, the contract reliability index value of the warranty provision is $\beta_3 = -0.28\times((1.1 + 2.34 - 4.8) / 5.97)$, and the success probability is $P_3 = 0.6103$. Therefore, combining the ceiling clause and the warranty option can effectively incentivize the private sector and prevent them from making a considerable amount of extra benefits. Furthermore, adding a warranty option in the agreement can help the government acquire additional information regarding the maintenance cost of the project before making warranty payments, which can reduce the opportunistic behavior of the private sector.

The evaluation result of four warranty provision arrangements is summarized in Table 1 as follows.

Table 1 Evaluation result of four warranty provision arrangements

	Contract reliability index value	Success probability value
Naked warranty provision	0.18	0.4286
Warranty provision combined with the ceiling clause	− 0.62	0.7324
Warranty provision combined with the warranty option	0.58	0.2810
Warranty provision combined with the ceiling clause and the warranty option	− 0.28	0.6103

5 Conclusions

This study constructed a contract reliability index and proposed an evaluation process for the reliability of the contract. The NM 44 project was used as a case study to illustrate the analysis process, in which three warranty provision arrangements were investigated: the naked warranty provision, the warranty provision combined with the ceiling clause, and the warranty provision combined with the warranty option. These results reveal that although the ceiling clause can effectively motivate the private sector to participate in the project, it sacrifices numerous public benefits. While the warranty option can protect the public benefits, it cannot effectively incentivize the private sector. Hence, a combination of the ceiling clause and the warranty option will result in better warranty provision. Furthermore, the scenario analysis shows that the contract reliability index is elastic to the warranty clause and the warranty payment schedule, which means that this index can effectively and sensitively reflect whether the warranty provision is designed properly for the contract engineer. Although only the warranty provision is analyzed in the case study, other flexible provisions, such as the governmental guarantee, cost fluctuation clause, and optional pavement warranty, can also be explored in this way. The methodology proposed in this study is especially useful for the government to properly determine contract clauses in infrastructure development.

Two main limitations exist for the method proposed in this study. First, the contract reliability index proposed in this study is a general formulation. The project characteristic should be further considered in future studies to precisely evaluate the appropriateness of the contract. Second, the contract reliability evaluation method proposed in this study did not consider some influence factors, such as the degree of loss aversion and the bargaining power of different participants. Future study can further explore the proper inclusion of these factors into the current model to obtain an instructive and meaningful contract reliability index.

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