Contractor Performance Evaluation for the Best Value of Superpave Projects

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Abstract: The best-value (BV) procurement process uses other key factors as well as bid price in the evaluation and selection of the best-performing contractor for the job. Contract time, lane rental, warranty, and quality of delivered product are examples of the key factors that indicate the contractor-expected performance. Literature on best value shows a need for analyzing the past performance of the contractor in similar jobs as an indicator of his/her qualification trend. This paper addresses this issue and proposes a methodology to incorporate quality of delivered product in the BV procurement system of asphalt construction. The paper uses past quality control (QC) testing results and utilizes Monte Carlo simulation to estimate the probability that the contractor gets full payment as an indication of qualification trend. The QC data were obtained from the Nebraska Department of Roads for a number of Superpave pavement projects. The results show the possibility of assigning a quality score for the contractor based on the past performance. This paper contributes to the current practice of best value with a new approach of employing QC as part of the selection process.

DOI: 10.1061/(ASCE)CO.1943-7862.0000158

CE Database subject headings: Procurement; Quality control; Pavements; Contractors; Simulation; Highways and roads; Payment.

Author keywords: Best value; Procurement; Quality control; Pavement; Contractors; Simulation; Highway construction; Payment.

Introduction

The best value (BV) is becoming a well-known procurement practice in many states in the country. BV is defined as "a procurement process where price and other key factors are considered in the evaluation and selection process to enhance the long-term performance and value of construction" (Scott et al. 2006). The need to employ the BV arises as construction projects suffer cost and time overruns as well as poor quality and workmanship. These problems are always associated with the low-bid system, which encourages contractors to implement cost-cutting measures instead of quality-enhancing measures. Therefore, it is less likely that the contracts will be awarded to the best-performing contractors who will deliver the highest quality projects [Naval Facilities Engineering Command (NAVFAC) 1996]. State and federal sectors have moved aggressively toward the use of BV procurement, have attempted to measure its relative success, and are convinced that it achieves better results than the low-bid method. At the federal level, the U.S. Postal Service, the Army, the Navy, the Department of Veterans Affairs, and the Federal Bureau of Prisons have developed procedures and guidelines for source selection contracting applicable to their construction programs [U.S. Postal Service 2005; U.S. Army Contracting Agency 2007]. Various states and local agencies have adopted legislation, in some cases based on the model code, allowing BV concepts to be considered in the selection decision. The American Bar Association's model procurement code provides for BV concepts to be incorporated into the procurement process. The "competitive sealed bidding" process described in Sec. 3-202 of the model code would allow "objectively measurable" criteria to be taken into account in the selection decision (Scott et al. 2006).

A key concept in BV procurements is the focus on selecting the contractor with the offer that is most advantageous to the agency where price and other factors are considered. The factors other than price can vary, but they typically include technical and managerial merits, financial health, and past performance (Gransberg and Ellicott 1997; Gransberg and Senadheera 1999; Gransberg et al. 2006). Construction quality is a key factor in the BV procurement process. Most BV models include an evaluation process that is conducted based on subjective criteria. The agency decision makers are used to prioritize the contractor-expected performance based on experience and subjective judgment. It is necessary for an agency implementing the BV to adopt a rational ranking system for contractor qualifications that is based on the agency's expected level of performance (Abdelrahman et al. 2008b). The level of quality expected by the owner can be estimated based on actual records. Many agencies already have significant amounts of quality control (QC) and/or acceptance testing results for the past few years (Burati et al. 2003). No previous research has used the available records to develop a quantitative measure of the contractor performance. Developing a performance measure for quality would potentially help in assigning a score for quality in the BV procurement process. The significance of this objective measure is to minimize the subjectivity inherent in the process, which is the major cause of the legislative issues related to the contractor selection process.

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Note. This manuscript was submitted on March 3, 2009; approved on September 29, 2009; published online on April 15, 2010. Discussion period open until October 1, 2010; separate discussions must be submitted for individual papers. This paper is part of the ***Journal of Construction Engineering and Management***, Vol. 136, No. 5, May 1, 2010. ©ASCE, ISSN 0733-9364/2010/5-606–614/$25.00.

Table 1. Parameters Raw Value and BV Scores

Parameter	Units	CON-A	CON-B	CON-C	CON-D	CON-E	CON-F
		Parameter raw value					
Bid price	\$M	10.67	9.93	11.1	10.92	10.54	10.12
Quality	%	79.2	66.2	90.8	65.0	55.6	83.1
Parameter	Weight	BV score					
Bid price (PS_B)	0.70	93.06	100	89.46	90.93	94.21	98.12
Quality (PS_Q)	0.30	70.20	83.99	61.23	85.54	100.00	66.91
BV		86.20	95.20	80.99	89.31	95.95	88.76

Study Objectives

This study aims to develop a rational score for the contractor quality that is based on the past performance. This quality score (QS) will be the quantitative measure used by the BV model to support the decision of selecting the performing contractor. The BV model employed in the study was previously developed by the authors with a broad spectrum of parameters (Abdelrahman et al. 2008a). The major improvements added to this model are focusing on the quality parameter and how its score is derived. The methodology presented in this paper focuses on the development of a QS for projects following the Superpave specifications.

BV Procurement

The development of BV procurement concepts in the public sector has borrowed ideas and approaches used to procure products and services from the private sector. Private sector construction owners have long sought to get the best value for dollars expended. BV procurement practices are increasingly being transferred to the public sector where permitted by legislation or when determined to be in the best interests of the agency under both traditional and alternative contracts. Based on the definition mentioned earlier, the general equation for the BV is shown in Eq. (1)

$$\mathrm{BV}_j = \sum_{i=1}^{n} \mathrm{PS}_i \times W_i \tag{1}$$

where BV_j=best value for contractor j; n=number of parameters; W_i=parameter i weight; and PS_i=parameter i score.

Parameters Score (PS_i)

The parameters of each project are identified and their scores are calculated and normalized on a scale of 0–100 depending on which parameters are most important for the new project. Contractor selection is typically based on multiple factors that include cost, schedule, quality management, safety, and technical ability, which are considered as the model parameters (Dorsey 1995). Eq. (2) is used to normalize each parameter value to fall between 1 and 100. The parameter score (PS_i) depends on the parameter values of the other contractors

$$\mathrm{PS}_i = (\text{best parameter value}/\text{contractor parameter value}) \times 100 \tag{2}$$

The contractor that has the best parameter value will get PS_i =100. The contractor with the worst parameter value has PS_i=1. The value of one (small number) is elected to avoid any mathematical flaw in the score implementation.

Parameters Weight (W_i)

The next step is to obtain the relative weight (W_i) of the parameters included in the BV model. The total summation of parameters' weights should add up to 1. These weights are determined based on the opinions of DOT experts using a questionnaire. A previous study recommended the assignment of a higher weight to the bid price to maintain the clarity of the selection and to match the preferences of most owners (Scott et al. 2006). Table 1 shows a BV system that has only two parameters, the bid price and the quality. The same BV concept could be expanded to a larger scale with more parameters as needed. The best contractor in Table 1 is not the lowest bidder but the one with the highest performance. The interested readers may refer to Abdelrahman et al. 2008b for more details on the parameter's score and weight. The focus of this study is to develop a methodology to obtain a rational score for quality using the quality testing records of Superpave projects.

Superpave QC

The superior performing asphalt pavement (Superpave) technology was developed as an effort to create performance-based tests and specifications for asphalt binders and hot mix asphalt mixes (Roberts et al. 1996). The National Cooperative Highway Research Program sponsored a project to develop a generic QC methodology for pavements constructed with Superpave mixes (Cominsky et al. 1998). The QC process requires that the constructor collects samples of the asphalt concrete. A random sampling process is used to ensure that the material is representative of the total amount of material placed during the project (Zaniewski and Adams 2005).

Payment Factor

Assigning a score for the contractor based on the quality of the pavement material is equivalent to adjusting the payment with what is known as the payment factor (PF). The PF can be defined as a multiplication factor that is often expressed as a percentage and is used to determine a contractor's payment for a unit of work. After the project or a project stage is completed, the owner/agency evaluates the product, and based on this evaluation the contractor gets paid. The contractor could be paid in full, penalized, or rewarded depending on the performance and the quality of the final product [Transportation Research Board (TRB) 2005].

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Table 2. Quality Characteristics Considered by State DOTs for PF

Quality characteristic	Consideration (%)
DEN	77.3
AC	77.3
GR	72.7
AVs	27.3
VMA	22.7
Smoothness	18.2
Thickness	9.1

The majority of highway agencies have their own specifications for QC and acceptance plans. Table 2 shows the quality characteristics considered by a sample of 22 state highway agencies in the PF calculations. The popularity of PF grows with the recognition that the construction quality cannot adequately be described by a single point value but is better characterized as a statistical distribution, which allows considerable product variability. It is found that, in many cases, the distributions are sufficiently normal. The normal curve theory could be used both to describe the quality level desired and to assess the quality level actually achieved. This characteristic has led many agencies to define the specification limits in terms of percent within limits (PWL) (Burati et al. 2003).

PWL

PWL is defined as the percentage of the lot falling above the lower specification limit (LSL), beneath the upper specification limit (USL), or between the LSL and the USL [Transportation Research Board (TRB) 2005]. This quality measure uses the sample mean and the sample standard deviation to estimate the percentage of the population (lot) that is within the specification limits. In theory, the use of the PWL method assumes that the population being sampled is normally distributed. In practice, it has been found that statistical estimates of quality are reasonably accurate, provided the sampled population is at least approximately normal, i.e., reasonably bell shaped and not bimodal or highly skewed. The PWL is the recommended statistical measure for material and construction quality in many applications with a quality level of approximately 90% being considered acceptably, which means 10% is defective or of lesser quality (Burati et al. 2003).

Study Methodology

At the beginning, there was a debate on which measure to use in evaluating the contractor performance: PF or PWL. Considering that PF can be estimated from PWL data, the proposed methodology uses the PF for two other reasons. The first is the popularity of PF; Nearly all agencies use the payment-adjustment approach for most construction practices. Not all state agencies depend on PWL in their construction specifications. The second reason for selecting the PF is the availability of data. Documented PF data and models are more available than detailed acceptance testing records necessary for calculating the PWL. The methodology defines the expected quality performance as the probability of receiving less than 100% PF (100PF) for each selected quality characteristic. The probability is obtained by simulating the past contractor performance in the PF equation. The relation between the expected performance and the probability of 100PF is a reverse relation; The lower the probability of 100PF is, the higher the expected performance and vice versa. Fig. 1 summarizes the methodology employed to obtain the total QS (QS_T) of the contractor past performance in the following nine steps.

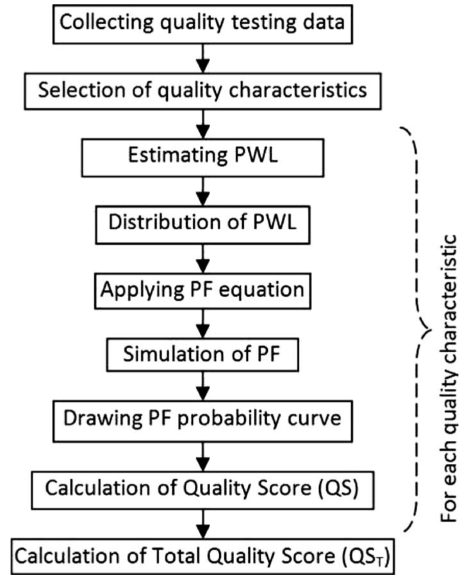

Fig. 1. Flow chart of developing total QS

Step 1: Collecting Quality Testing Data

The QC data used in the analysis were obtained from the records of the Nebraska Department of Roads (NDOR) of some 500 projects that used seven Superpave mix types and completed between 1999 and 2005. Table 3 shows typical traffic ranges for each mix with higher traffic corresponds to higher-level mixes [Nebraska Department of Roads (NDOR) 2005; Schram and Abdelrahman 2008].

Step 2: Selection of Quality Characteristics

The quality of Superpave mixes is dependent on several materials and construction factors. The specifications of a sample of 22 states are analyzed in order to select the most important and applicable quality characteristics. According to the data shown in Table 2, the top 5 quality characteristics are field density (DEN), asphalt content (AC), gradation (GR), air voids (AVs), and void mineral aggregate (VMA). Due to the availability of data, only DEN, AC, AV, and GR are used in the model developed in this study.

Step 3: Estimating PWL

Conceptually, the PWL procedure is based on the normal distribution. The area under the normal curve can be calculated to

Table 3. Mix Type by Traffic

Average daily truck traffic	Mix type
<160	SPS, SP1, SP2
161–500	SP3, SP4
>500	SP5, SP6

Note: SP stands for Superpave.

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Table 4. Quality Index Values for Estimating PWL

PWL	$n=10$	$n=12-14$	$n=15-18$	$n=19-25$	$n=26-37$
100	2.65	2.83	3.03	3.2	3.38
99	2.04	2.09	2.14	2.18	2.22
98	1.86	1.91	1.93	1.96	1.99
97	1.74	1.77	1.79	1.81	1.83
96	1.65	1.67	1.68	1.7	1.71
95	1.56	1.58	1.59	1.61	1.62
94	1.49	1.5	1.51	1.52	1.53
93	1.43	1.44	1.44	1.45	1.46
92	1.37	1.37	1.38	1.39	1.39
91	1.31	1.32	1.32	1.33	1.33
90	1.26	1.26	1.27	1.27	1.27

determine the percentage of the population that is within certain limits. Similarly, the percentage of the lot that is within the specification limits can be estimated. Instead of using the Z value and the standard normal curve, a similar statistic, the quality index (Q), is used to estimate PWL. As shown in Table 4, the Q value is used with a sample size (n) to determine the estimated PWL for the lot (Burati et al. 2003). To understand the parameters of the PWL and the calculation procedures, the following are used (Breakah et al. 2007; Burati et al. 2003; Anderson and Russell 2001):

1. The approved target value and the upper and lower tolerances should be known.
2. Calculate the LSL and the USL using the following equations:

$$\mathrm{LSL} = \text{target value} - \text{lower tolerance} \tag{3}$$

$$\mathrm{USL} = \text{target value} + \text{upper tolerance} \tag{4}$$

3. The lower and upper quality indices Q_L and Q_U are calculated using the following equations:

$$Q_L = (\bar{x} - \mathrm{LSL})/s \tag{5}$$

$$Q_U = (\mathrm{USL} - \bar{x})/s \tag{6}$$

where Q_L=lower quality index; Q_U=upper quality index; $\bar{x}$=lot average; and s=lot standard deviation.

4. The lower PWL ($\mathrm{PWL_L}$) and the upper PWL ($\mathrm{PWL_U}$) are then determined from PWL table using Q_L for $\mathrm{PWL_L}$ and Q_U for $\mathrm{PWL_U}$ together with the n value.
5. For each quality characteristic, the total PWL ($\mathrm{PWL_T}$) is calculated using Eq. (7)

$$\mathrm{PWL_T} = (\mathrm{PWL_L} + \mathrm{PWL_U}) - 100 \tag{7}$$

A sample of the calculation of PWL for field density test results is shown in Table 5.

Step 4: Distribution of PWL

The calculated PWL values are analyzed in order to identify the distribution necessary for running the simulation. The distribution of the contractor's PWL values is reasonably assumed to follow a normal distribution (Schram and Abdelrahman 2008). The normal curve theory could be used both to describe the quality level desired and to assess the quality level actually achieved (Burati et al. 2003). The normal distribution of the quality characteristic has μ and σ equal to the mean and standard deviation of the PWL values for the quality characteristic calculated in Step 3, respectively. PWL values were categorized either by the contractor with subcategory as the mix type or by the mix type for all contractors combined. Values of μ, σ and number of projects (N) for PWL data are shown in Tables 6 and 7.

Step 5: Apply PF Equation

Two PF equations are considered to transform PWL values into a PF, the linear and the nonlinear equations. Eq. (8) is a linear equation that is widely recognized by the highway agencies (Burati et al. 2003)

$$\mathrm{PF} = 55 + 0.5 \times \mathrm{PWL} \tag{8}$$

This equation assumes that the maximum and the minimum PFs are 105 and 55 at 100PWL and 0PWL, respectively. Many practitioners and researchers suggest the accepted quality limit to be satisfied at 90PWL with a PF equal to 100. They also suggested the rejected quality limit to be satisfied at 50PWL with a PF equal to 80 (Burati et al. 2003). Another equation studied is a nonlinear PF equation proposed by another agency (Burati et al. 2003). Eq. (9) assumes that the minimum and the maximum PFs are 0 and 105 at 15.6PWL and 100PWL, respectively. Here

$$\mathrm{PF} = (0.024 \times \mathrm{PWL} - 0.0001 \times \mathrm{PWL}^2 - 0.35) \times 100 \tag{9}$$

Since the minimum PF of 0 is not logical, this equation should have a minimum PWL between 40 and 50 to keep the minimum

Table 5. Sample PWL Values for Field Density

Project	$\bar{x}$	s	n	LSL	Q_L	$\mathrm{PWL_L}$	USL	Q_U	$\mathrm{PWL_U}$	$\mathrm{PWL_T}$
1	93.6	0.7	18	90	4.7	100	95	1.8	97.07	97.07
2	92.8	1.3	10	90	2.1	99.1	95	1.5	94.14	93.24
3	93.4	0.9	28	90	3.7	100	95	1.6	93.7	93.7
4	92.7	0.5	12	90	4.8	100	95	3.9	100	100

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Table 6. PWL_T of the Quality Characteristics for Contractors[a]

		CON-A	CON-B	CON-C	CON-D	CON-E	CON-F
AC	μ	72.93	78.29	75.29	76.26	92.37	78.84
	σ	30.84	22.18	33.39	30.90	6.93	29.87
	N	93	40	29	32	15	17
GR	μ	75.51	87.16	80.36	81.96	92.49	84.73
	σ	17.05	15.14	16.04	17.02	12.32	15.93
	N	182	108	75	58	21	79
DEN	μ	90.74		78.87			77.01
	σ	22.35		18.87			22.87
	N	12		9			10
AV	μ	71.38	65.70	46.22	66.93	69.04	52.28
	σ	23.84	26.40	34.18	21.93	26.86	37.11
	N	140	104	62	55	21	73

[a]Blank fields are related to missing data.

PF between 45 and 60. The nonlinear PF equation has a steeper slope so it behaves more aggressively with the quality cuts in the field performance. The behavior of both equations is represented graphically in Fig. 2.

Step 6: Simulation of PF

The simulation is used here to develop the probability curves of receiving certain PF. The Monte Carlo simulation technique is used here to simulate the contractor long-term performance and estimate the probability of achieving less than the expected and/or the accepted PF. Generally, Monte Carlo method is a computational algorithm that relies on repeated random sampling to compute the result. Monte Carlo methods tend to be used when it is unfeasible or impossible to compute the exact result with a deterministic algorithm (Hubbard 2007). The output of a Monte Carlo simulation is a probability distribution describing the probability associated with each possible outcome (Zaniewski and Adams 2005).

Simulation Methodology

As mentioned earlier, there is an agreement that 90PWL is an accepted quality level. PWL distribution is used as the input of the simulation in the PF equation while the output is the PF. The Monte Carlo simulation is used to simulate the contractor PWL for 10,000 times and calculate the corresponding PF achieved assuming that the distribution of the PWL values for all quality characteristics follows a normal distribution. The simulation process is represented graphically in Fig. 3. Crystal Ball software (Oracle 2008) was useful in running the simulation and drawing the probability curves for each mix type. The probability curves are developed using both PF equations [Eqs. (8) and (9)].

Step 7: Drawing PF Probability Curve

Fig. 4 shows the graphs developed for the quality characteristics of different Superpave mixes using the simulation. Each graph represents a relation between the PF and the probability of receiving <PF. If the contractor achieved the desired level of quality all the time, the probability curve will be very steep and probability of receiving <100PF will approach zero. Practically, the desired level of quality could be achieved most of the time rather than all the time, which means the probability of achieving PF lower than 100 ranges between 0 and 1.

The simulation is applied to both PF equations to compare the differences between them on the long term. Table 8 shows that the probability obtained by both PF equations is relatively equal. The paired two samples t-Test are used to test whether the mean of the probability obtained from both equations is equal or not. The p value of the t-Test for AC, GR, DEN, and AV are 0.21, 0.02, 0.66, and 0.25, respectively. These values show that the mean probabilities obtained from both equations are equal at $\alpha = 0.01$. Based on this analysis, we should provide the same conclusion if used in

Table 7. PWL_T of the Quality Characteristics for Mix Types[a]

		SP1	SP2	SP3	SP4	SP5	SP6	SPS
AC	μ	19.7	95.9	85.4	79.5	75.1		80.4
	σ	28.9	5.72	18.9	22.6	27.3		24.6
	N	26	11	4	147	31		73
GR	μ	86.3	84.3	86.2	75.1	77	77.4	91.1
	σ	14.5	15.2	13.4	15.9	15.2	10.9	13.3
	N	20	63	19	305	71	3	222
DEN	μ				89.2			58.7
	σ				12			32.4
	N				26			12
AV	μ	33	60.5	69.5	74.7	69.9	66.4	37.3
	σ	35.6	29	15.1	17.9	28	1.7	28.7
	N	67	62	19	283	69	3	119

[a]Blank fields are related to missing data.

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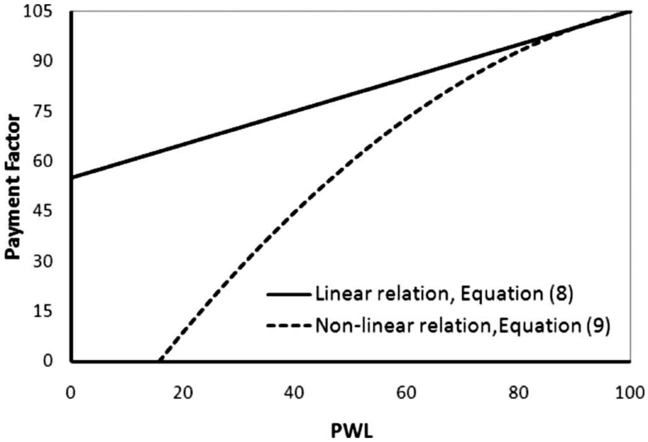

Fig. 2. Graphical representations of PF equations

the simulation. However, the decision is to use the linear PF equation in the model for its simplicity and its familiarity to the pavement community.

Step 8: Calculation of QS

The concept of assigning a score for the past contractor performance in the BV model is crucial to correctly give the most experienced contractor, with the best produced quality, the advantage over others with less experience. This situation could support the decision of selecting a higher-priced bid, as the higher price would mean a higher quality and lower life cycle cost for the constructed facility. The agency might want to assign the contractor a specific score relative to an expected performance, say 100PF. The score of the quality characteristic is linked to the probability of receiving <PF. The probability of receiving <PF is obtained from Fig. 4 for the desired mix type and then transformed to the QS using Eq. (10). Here

$$QS_i = \text{probability of receiving} < PF \times 100 \qquad (10)$$

The QS indicates the capability of the contractor to achieve the expected quality level. The lower the probability of receiving <PF is, the higher the expected contractor performance. When contractors are good performers, the standard deviations of their historical records are very low which make the probability curves of their long-term performance very steep. On the other hand, the probability curves of the poor performing contractors with high standard deviations have mild slop. Based on the previous discussion, low QS values are desired and will be normalized to a higher PS_i within the BV model.

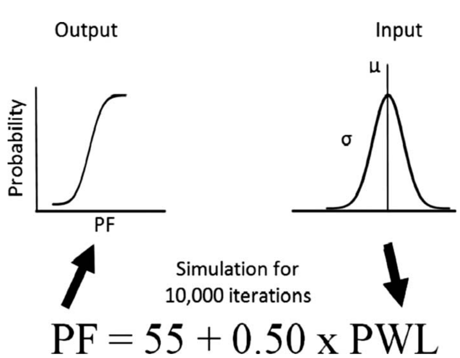

Fig. 3. Graphical representation of simulation process

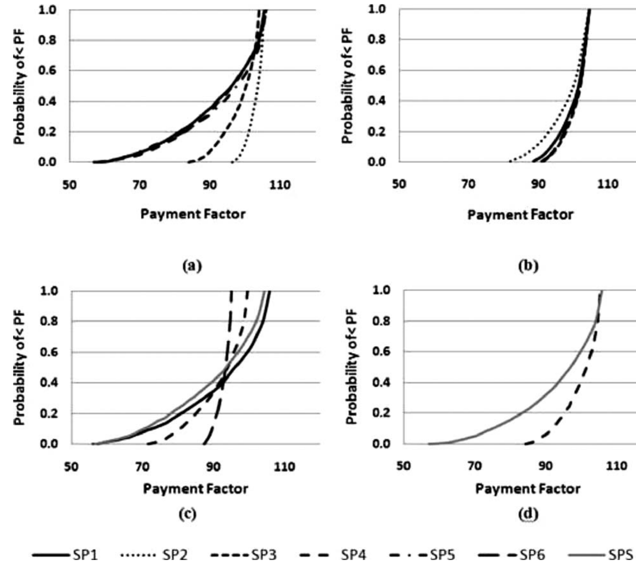

Fig. 4. Probability curves of mixes for (a) AC, (b) GR, (c) AV, and (d) DEN

Step 9: Calculation of Total QS

For each contractor, there will be multiple QSs relevant to the selected quality characteristics. The methodology suggests two alternatives to obtain the total QS (QS_T) that combines the individual QSs of the each contractor. The first method is the average method (AM) in which all the quality characteristic scores are averaged to obtain the QS_T as stated in Eq. (11)

$$QS_T = 0.25 \times QS_{AV} + 0.25 \times QS_{AC} + 0.25 \times QS_{DEN} + 0.25 \times QS_{GR} \qquad (11)$$

This method assumes that all quality characteristics have the same importance in measuring contractor performance, which is not quite precise. Some quality characteristics are more important than others and tell more about the contractor performance. Therefore, the other method to obtain the QS_T is the weighted AM (WAM). Weighting the QS in the QS_T equation has the same purpose as combing multiple PFs into a combined PF. Several agencies have chosen to weight the PFs with the concept that some quality characteristics are more important than others (Burati et al. 2003). For example, when mixture properties and field compaction are used as quality characteristics, the in-place AVs are often weighted more heavily than the mixture properties. Examples of the weighting systems used by some agencies are shown in Eqs. (12) and (13) (Burati et al. 2003)

$$PF = 0.20 \times AV + 0.10 \times VMA + 0.10 \times AC + 0.60 \times DEN \qquad (12)$$

$$PF = 0.35 \times AV + 0.10 \times VMA + 0.20 \times AC + 0.35 \times DEN \qquad (13)$$

The QS_T equation suggested by the WAM is shown in Eq. (14)

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Table 8. Probability of Receiving <100PF Using Two PF Equations[a]

	Mix type						
	SP1	SP2	SP3	SP4	SP5	SP6	SPS
				PF using Eq. (8)			
AC	0.64	0.15	0.52	0.66	0.6		0.6
GR	0.4	0.51	0.31	0.51	0.51	0.34	0.51
DEN				0.41			0.62
AV	0.61			1		1	0.61
				PF using Eq. (9)			
AC	0.6	0.15	0.51	0.49	0.62		0.56
GR	0.39	0.6	0.34	0.6	0.6	0.35	0.6
DEN				0.42			0.58
AV	0.63			1		1	0.67

[a]Blank fields are related to missing data.

$$QS_T = 0.30 \times QS_{AV} + 0.15 \times QS_{AC} + 0.45 \times QS_{DEN} + 0.10 \times QS_{GR} \tag{14}$$

Eq. (14) considers the intermediate values of the weights in Eqs. (12) and (13) as the weight of the QS in Eq. (14) for AV, AC, and DEN. The weights in Eqs. (12) and (13) for AV range from 0.20 to 0.35, AC from 0.10 to 0.20, and DEN from 0.35 to 0.60. The selected weights of the QS become 0.30, 0.15, and 0.45 for AV, AC, and DEN. Since Table 2 indicates that GR is more important than VMA from the PF point of view, GR in Eq. (14) replaced VMA in Eqs. (12) and (13) with the same weight of 0.1.

Fig. 5 shows a comparison between the results of two methods of calculating the QS_T using the case study data that will be discussed later in the paper.

QS for Contractors with Unknown History

Generally, the procedure adopted to develop the probability curves for Superpave mixes or contractors is the same. The main difference is that the past records of all the contractors for each mix will be combined together and the developed curves will represent the average contractor performance for this type of projects. The probability curves developed for the mixes are very useful particularly when the contractor does not have a solid history with the owner agency. In this case, the average performance is assigned to the contractor to minimize the risk of awarding the project to a poor performing contractor. However, the proposed procedure could be biased if the new contractors, or those with unknown history, are better than the old ones. The new contractors may use new technology to complete the work, which may enable them to drive a higher quality with fewer costs and make them one of the BV candidates. This bias could be eliminated by adding another parameter in the BV model to represent the advantage offered by the new contractor. The BV model is assumed to be a multiparameter system that could be tailored to fit specific project needs. For example, if the agency considers the time as a critical factor in the project, then a time parameter, such as project duration, might be added separately to the BV model. The agency could reflect the importance of this new parameter with its relative weight. Adding new parameters to the BV model will give the performing contractors the advantage over nonperforming ones in this specific part of the model and create a fair competition among them. Another way to deal with contractors with unknown history is to depend on the contractor prequalification as the basis of assigning the contractor the average performance. Prequalification can ensure that the contractors with unknown history in the BV system are getting a fair score equal to the average of all contractors using the mix curves.

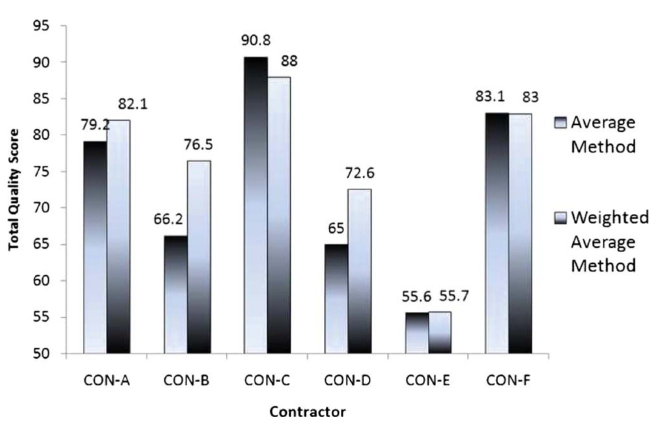

Fig. 5. Contractors QS_T using two combining methods

Case Study

The approach of developing the QS_T using the historical data applies for data classified either by the mix or the contractor. Developing the probability curve for each mix is useful when the agency likes to assign scores for the contractors based on the same reference curve. It is also possible that the mix curve is used if the contractor does not have a previous record. The agency may assign him/her a specific score, say relative to 100PF. The probability curves developed with the data categorized by the contractor represent the actual contactor performance. Contractors' curves are more accurate than mixes' curves when the goal is to predict the future performance of the contractor.

The case study uses the probability curves for contractors when the data are available and those for mixes when it is missing. The data obtained from NDOR are used in the case study to develop the QS_T for a group of six contractors. The procedure discussed in Fig. 1 is followed to obtain the QS_T.

1. Collecting quality testing data from NDOR for about 500 asphalt pavement projects.
2. Selection of the quality characteristics required to evaluate

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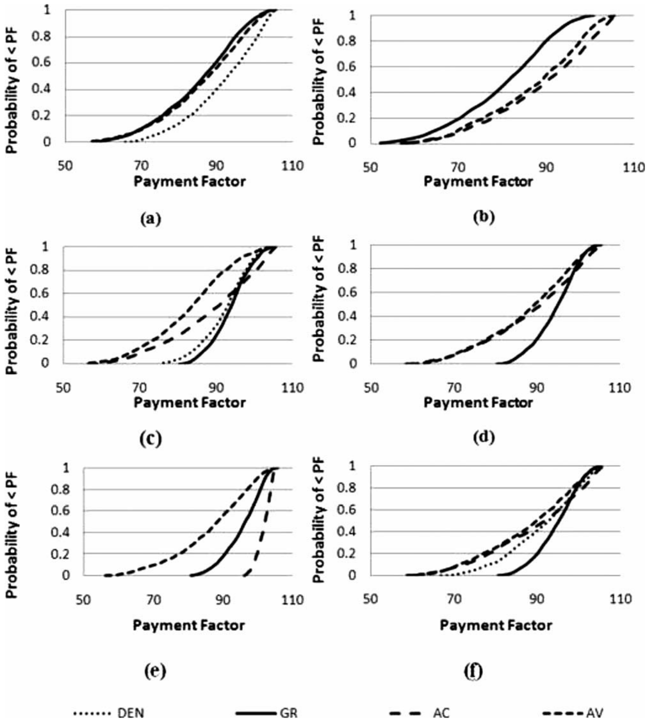

Fig. 6. Probability curves for contractors (a) CON-A; (b) CON-B; (c) CON-C; (d) CON-D; (e) CON-E; and (f) CON-F

the contractor past quality performance. In the case study, there are four quality characteristics: DEN, AC, AV, and GR.

3. Estimating PWL values for the selected quality characteristics using the collected data.
4. Determination of μ and σ of the calculated PWL values for each contractor. PWL is assumed to have a normal distribution with μ and σ in the PF equation shown in Eq. (8).
5. PF equation is simulated 10,000 times to reflect the contractor long-term performance.
6. PF probability curves are drawn for the six contractors as shown in Fig. 6.
7. The probability of receiving <100PF is obtained from contractor curves developed in Fig. 6. The probability of receiving <100PF, for the missing quality characteristic, is obtained from mix curves developed in Fig. 4.
8. Eq. (10) is used to calculate the QS.
9. Eqs. (11) and (14) are used to obtain the QS_T.

With QS_T calculated for each contractor, it would be easy to recognize the individual differences in performance among the contractors. Table 9 shows the QS of the quality characteristics and Fig. 5 shows the QS_T for the six contractors. The QS_T values obtained from both methods were tested for equal means using the paired two sample t-Test. The *p* value of the t-Test is 0.203, which interpreted as the mean QS_T calculated using both methods is equal at $\alpha=0.05$. However, if both methods return different contractor rankings, it will be the owner agency decision to consider one of the two methods. The owner agency may consider all the quality characteristics to have the same importance and use the AM. Otherwise the WAM may be more appropriate to consider if the agency think of relative importance between the quality characteristics. As mentioned earlier, lower QS_T relates to higher performance and indicates a better contractor. In Fig. 5, CON-E appears to have the lowest QS_T using both combining methods.

Calculating the Best Value

The case study shows how the proposed methodology is used to obtain the QS_T. To understand how the QS_T will fit in the BV model, assume the following situation. The NDOR contract office has a new Superpave project with mix type of SP4 and they decided to use the BV model to procure this project. They have received six offers from contractors who have previously worked with the NDOR. They wish to use the QS_T developed in the case study to decide which contractor's offer is the best. The BV model is implemented as follows:

1. The decision maker has to decide what parameters to include in the selection process. In the current situation there are only two parameters, bid price and quality.
2. The bid price score (PS_B) is obtained using the offered bid prices and normalized using Eq. (2).
3. The QS (PS_Q) is obtained using the QS_T and normalized using Eq. (2).
4. The relative weights of bid price and quality are assumed to be 70 and 30%, respectively (Scott et al. 2006).
5. The weighted PSs are combined together as the total BV score. The contractor with the highest total BV score is considered to have the best offer.

Table 1 shows the parameter raw values, scores, and the final BV for the six contractors. CON-E got the highest score in quality but is not the lowest bidder. CON-B offers the lowest price but ranked third for the QS. However, CON-E obtains the highest overall BV score, with 0.75 point over CON-B, and is considered the winning contractor. The results show clearly that the BV model succeeded in selecting the best-performing contractor in an objective way. Indeed, there is a 6% increase in the bid price as the cost of this expected quality. However, it is expected that the overall saving during the life of the project could be more than 6%.

Summary and Conclusions

The BV model has two main components, the parameter score and the parameter weight. The parameter score is obtained from

Table 9. QS for Contractors

QS	Contractor code					
	CON-A	CON-B	CON-C	CON-D	CON-E	CON-F
QS_{AC}	76.7	78.8	76.8	80.8	22.2	77.4
QS_{GR}	93.1	99.6	85.9	80.8	70.3	87.8
QS_{DEN}	72.1	41.0	93.2	41.0	41.0	84.7
QS_{AV}	86.3	86.5	95.9	87.9	89.3	82.1

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historical data analysis or simply by comparing the contractor offer to the other offers. The weight of a particular parameter is assigned according to the relative importance of that parameter as compared to others. One of the challenges facing the implementation of BV on a wider scale is the subjectivity of some key parameters of the project. This paper introduces an approach to derive a score for the quality parameter using the results of Superpave quality testing as a common practice in the construction industry. Many agencies have used the PWL to adjust the payment using a PF equation or a payment schedule. The same concept is used here to calculate the PF for the past performance. The simulation technique provided the model with the probability of receiving <PF. The probability is not meaningful by itself except when comparing multiple contactors at the same time. The proposed approach suggested an equation to combine the multiple QSs into one QS_T. However, other methods may be applicable in some other cases. The case study shows the applicability of this approach by using the test results for real contractors. The results show that CON-E achieves the best quality in past projects and has the highest probability to achieve the best quality in future projects. The findings of this study fill the gap of assigning a quantitative QS for Superpave projects. Also, the findings could justify the decision of selecting a higher-priced offer from the performing contractor. The rationale of paying more money when it is possible to pay less is the expected savings during the project life cycle.

Acknowledgments

The writers would like to recognize the NDOR for the provided data and also the contribution of Dr. Scott Schram for helping with the data collection.

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