Probability of Failure in Infrastructure Project Unbalanced Bidding

Yuhan Jiang, MS, Yong Bai, Ph.D., PE and Sisi Han, MS
Marquette University
Milwaukee, Wisconsin

Ting Lin, Ph.D.
Texas Tech University
Lubbock, Texas

Design-Bid-Build infrastructure projects with Unit-Price Contracts have a high risk of quantity and price deviations. Those deviations might be the result of contractors' unbalanced bidding. At the same time, contractors' performance was unknown under unbalanced bidding situations. The researchers utilized the First Order Reliability Method and Statistical Analysis to evaluate contractors' bidding performances and engineers' estimating performances with bidding and settlement data of 163 NDDOT projects. Results showed that contractors adopted unbalanced bidding strategies as follows: if quantities were overestimated, then they underrated unit price; if quantities were underestimated, then they overrated unit price to maintain projects' Bid Total Amount slightly less than Estimated Total Cost. Contractors had a 49% probability of failure in unbalanced bidding. Engineers had an 83% probability of failure in quantities overestimated and 15% in quantities underestimated. Among the estimating uncertainties, Design Errors or Changes were the main reasons of engineers' overestimating failure. The researchers recommend the use of cooperating project delivery methods such as design-build to protect owners' interests in infrastructure projects. In addition, engineers should improve their estimating accuracy by reducing design errors or changes. These research findings will help to reduce unbalanced bidding practice in public funded infrastructure projects.

Key words: Bidding; Contract; Infrastructure; Probability; NDDOT

Introduction

Public funded infrastructure projects require the Unit-Price Contracts (UPC), which are awarded to the lowest reasonable price bidders (Salem Hiyassat, 2001; Hyari, Shatarat & Khalafallah, 2017). However, a "hazard" to both owners and contractors of UPC would be the deviations of items' Actual Quantities (AQ) from the Estimated Quantities (EQ) that directly impact contractors' profit and owners' cost (Hyari et al., 2017). Those deviations cause the hazard of unbalanced bidding from contractors to recover their profit (Ewerhart & Fieseler, 2003; Gransberg & Riemer, 2009; Hyari, Tarawneh, & Katkhuda, 2016). This unbalanced bidding is named as "Quantity Error Exploitation" or "Individual Rate Loading" (Cattell, Bowen & Kaka, 2007). It means that contractors bid a higher unit price on items whose final quantities are expected to exceed the initially proposed quantities in the bid document (Cattell et al., 2007) or whose quantities were underrated by the projects' owner agency engineers (Arditi & Chotibhongs, 2009). Under those conditions, contractors still have enough chances to win projects with the lowest bidding amount, as the overall bidding amount is maintained by dropping down other items' unit price rate (Stark, 1974). Once the projects' contracts are performed, owners end up paying more money than the proposed amount (Arditi & Chotibhongs, 2009). Another type of unbalanced bidding is considering the cash flow and money time value, as "Front-end Loading", which increases unit costs for early performed items and decreases unit price for later scheduled tasks, and vice versa for "Back-end Loading" (Cattell et al., 2007; Arditi & Chotibhongs, 2009).

Avoiding unbalanced biddings in public funded infrastructure projects is important to save tax payers' money. With the trillion dollars needed to re-build U.S. national infrastructure, it is urgent and important to evaluate contractors' bidding behaviors and strategies, evaluate engineers' estimate behaviors and skills, and investigate the reasons behind their behaviors as well. Figuring out the probability of failure in engineers' estimations will help engineers to take actions to avoid them; knowing the probability of failure in unbalanced bidding strategies will help contractors to decide whether to accept this risk or not (Cattell et al., 2007). Knowing that might help to reduce the risk of the unbalanced bidding in infrastructure projects and protect the projects' partners. Due to data limitation, it is hard to know projects' detailed schedules, and the "Front-end Loading" unbalanced bidding is less harmful than "Individual Rate Loading," which only tries to get money back early to finance later jobs (Cattell et al., 2007; Arditi & Chotibhongs, 2009). Therefore, in this paper, unbalanced bidding is specific to "Quantity Error Exploitation" only. The Engineering Reliability Method is introduced and utilized to compute the "probability of failure" in quantities takeoff by engineers and the probability of failure in contractors' bidding among 163 North Dakota State Department of Transportation (NDDOT) projects. This paper focus on revealing adverse effects of contractors' unbalanced bidding, beyond making profits in a single project. Based on the results and discussions, suggestions are provided to reduce some unbalanced bidding issues.

Background

Bidding Procedures and Data

Design-Bid-Build (DBB) is the major project delivery method for public funded infrastructure projects in the U.S. (Pietroforte & Miller, 2002). For UPC, DBB starts with owners providing bid documents, including Drawings, Specifications, and Bill of Quantities (BoQ) to potential contractors. Then, contractors propose the cost for each item, and combine them to make bidding decisions.

- During the bidding stage, owner engineers breakdown projects into various work items, list items' Estimated Quantity (EQ) in the BoQ, propose items' Estimated Unit Price (EP) and projects' Estimated Total Cost (ETC) as bidding evaluation references; contractors prepare biddings, propose Bid Unit Price (BP) for all items in BoQ and sum up Bid Total Amount (BTA) for projects; then the owners open submitted bids in the specific date and award projects to the lowest bidders.
- During the building stage, when items are performed, items' Actual Quantity (AQ) will be used to calculate the payments, then they are summed up to be projects' settlement, as Actual Total Amount (ATA) (Konchar & Sanvido, 1998; Pietroforte & Miller, 2002; Hyari et al., 2017).

Estimating and Bidding Uncertainties

Typically, engineers' takeoff quantities based on drawings and specifications could obtain the correct EQ; but for infrastructure projects, engineers' prediction of the accuracy AQ based on the information at the design stage has a high uncertainty. Standard Specifications of NDDOT (NDDOT, 2014) and several other states clearly state that EQ provided in the BoQ are solely for comparison purposes to evaluate submitted bids (Hyari et al., 2017). The uncertainties of estimating at the bidding stage include:

- Estimation Errors. Including, Writing Error, engineers put the wrong number, wrong unit, wrong decimal point etc. in the BoQ; Calculation Error, engineers measured the wrong size on the drawing, and calculate quantity with the wrong number; and even Missing Error, engineers miss counting an entire item, or parts of an item. Those common errors could be eliminated by carefully reviewing the estimation.
- Design Errors or Design Changes. UPC is usually adopted for complex projects or projects with higher uncertainty in the plan, whose design might be changed during projects' progressing (Love, Edwards & Irani, 2012). Even though engineers could perform accurate quantities takeoff based on the drawings, design changes are unable to be predicated in advance.

Well-trained contractors could find out Estimation Errors based on bid documents and site visits. In addition, some experienced contractors could forecast items' quantities changes by finding out Design Errors and forecasting Design Changes at the bidding stage and perform the "Individual Rate Loading" unbalanced bidding strategy to earn more profit (Ewerhart & Fieseler, 2003; Gransberg & Riemer, 2009; Hyari et al., 2016). However, contractors have the risk of failure to forecast quantities changes and result in the failure of their biddings. What is more, unbalanced biddings have higher risk to be rejected by owners on the basis of unresponsiveness to bidding rules (Hyari, 2015).

Unbalanced Bidding Model

Tong & Lu (1992) set up an unbalanced bidding model (see equation 1), without considering cash flow and time value of money. To satisfy the condition $q^T p = q^T y$, same as BTA equals to ETC, contractors would adjust each y_i (to be more expensive than p_i or cheaper than p_i) as they think the i^{th} item's AQ is overrun or underrun than the EQ listed in BoQ (Tong & Lu, 1992; Hyari et al., 2017). That is the ideal unbalanced bidding, but in practice, contractors' BTA is less than engineers' ETC (Gransberg & Riemer, 2009). The benefit of unbalanced bidding for contractors is the difference of $a^T y$ and $q^T p$, which is shown as $Max\emptyset(y)$ in equation 1, a positive deviation means contractors earn more profit and owners pay more money (Tong & Lu, 1992).

$$Max\emptyset(y) = a^T y - q^T p$$
$$s.t. q^T p = q^T y \qquad (1)$$

Where, $q = (q_1, \ldots, q_i, \ldots, q_n)$, Engineers' Estimated Quantity (EQ) uses for bidding and signing contracts;
$a = (a_1, \ldots, a_i, \ldots, a_n)$, Contractors' Anticipated Quantity can be considered as Actual Quantity (AQ)*;
$p = (p_1, \ldots, p_i, \ldots, p_n)$, Engineers' Estimated Unit Price (EP) uses for bids evaluating;
$y = (y_1, \ldots, y_i, \ldots, y_n)$, Contractors' Bid Unit Price (BP) uses for bidding and issuing payment;
*note: if the contractor has good estimation skills.

Methodologies

Research Assumptions

Assumptions 1 to 4 are used for setting up "limit state functions" for calculating the probability of failure and Assumptions 5 and 6 are used to evaluate the nature of the collected data.

- Assumption 1: the $a = (a_1, a_1, \ldots, a_n)$ in equation 1 is equal to AQ. As the data collected from 163 North Dakota State Department of Transportation Projects only contains winners' bidding and settlement information, this paper assumes all contractors are equipped with good estimating and forecasting skills.
- Assumption 2: if a_i (in equation 1, same to q_i, y_i, p_i) exceeds 10% of its associated q_i means engineers underestimate ($a_i/q_i \geq 1.1$), while if a_i is less than 90% of its associated q_i means engineers overestimate ($a_i/q_i \leq 0.9$). As the NDDOT adopts the criteria for renegotiating unit price when AQ exceeds 25% of EQ for major cost items (NDDOT, 2014; Hyari et al., 2017), this paper uses 10% for every single item without distinguishing the major and minor items.
- Assumption 3: if y_i exceeds 10% of its associated p_i means contractors overbid ($y_i/p_i \geq 1.1$), while if y_i is less than 90% of its associated p_i means contractors underbid ($y_i/p_i \leq 0.9$). As the BP should have a range constraint ($L_i < y_i < U_i$) for each $item_i$ to be considered as reasonable price (Tong & Lu, 1992; Cattell, Bowen & Kaka, 2008), this paper sets lower bound $L_i = 0.9p_i$ and upper bound $U_i = 1.1p_i$.
- Assumption 4: if $a^T y$ is less than 95% of its associated $q^T p$ then contractors are losing money in projects ($a^T y / q^T p \leq 0.95$). As the New York University Stern Database (Damodaran, 2018) shows that on Jan.5, 2018 the U.S. Construction Industry had a 11.15% gross margin and a 1.99% net margin, this paper assumes a 5% margin for infrastructure projects.
- Assumption 5: the 163 winning bidders applied the "Quantity Error Exploitation" unbalanced bidding strategies as follows: if engineers overestimate then contractors underbid; if engineers underestimate then contractors overbid (Ewerhart & Fieseler, 2003; Hyari et al., 2016).
- Assumption 6: the 163 winning bidders awarded the project with the lowest price, and BTA did not exceed a certain percentage of ETC (Gransberg & Riemer, 2009).

Random Variables and Data Descriptive Statistics

Seven properties of the 163 NDDOT projects are selected and listed in table 1 and summarized in table 2 based on the research assumptions and unbalanced bidding model (equation 1). Those projects were open-bid in 2007, and 46 North Dakota and Minnesota contractors were awarded those 163 projects. The three project level properties, BTA, ATA and ETC have the same unit (million dollars), and can be used as random variables for setting up limit state function. While the four item level properties, EQ, EP, BP, and AQ have different units, are unable to be used as random variables for analyzing, until unit differences are eliminated. Therefore, random variables X_1 and X_2 are created (see table 3). AQ/EQ is a unitless random variable with the range $[0, +\infty)$, similar, (EQ×BP) / (EQ ×EP) or

BP/EP is a unitless random variable with the range (0, +∞). Tables 3 and 4 show the random variables' information, including descriptive statistics, distributions and correlations after outliers have been removed. The removed outliers are three extreme large numbers in X_3 and their corresponding X_4; similarly, the biggest five data are deleted from X_1 and X_2; those outliers will not affect the data distribution fitting.

Table 1. Variables of the Collected Data

Properties	Description	No. of Sample	Note
EQ	Estimated Quantity	3247	Item level
EP	Estimated Unit Price	3247	Item level
BP	Bid Unit Price	3247	Item level
AQ	Actual Quantity	3247	Item level
BTA	Bid Total Amount	163	Project level, $\text{BTA} = \sum EQ \times BP$
ATA	Actual Total Amount	163	Project level, $\text{ATA} = \sum AQ \times BP$
ETC	Estimated Total Cost	163	Project level, $\text{ETC} = \sum EQ \times EP$

Table 2. Project Data Descriptive Statistics

Property	No.	**MIN** (million $)	**MAX** (million $)	Mean	StDev
BTA	163	0.009	10.416	0.815	1.209
ATA	163	0.009	10.794	0.773	1.200
ETC	163	0.007	10.977	0.878	1.388

Table 3. Random Variables Descriptive Statistics and Distributions (w/o outliers)

Var.	Des.	No.	MIN	MAX	Mean	StDev	Distribution	Distribution Parameter
X_1	AQ / EQ	3242	0.00	7.5767	0.9779	0.5633	Gamma	GAMMA (0.0586, 16.7)
X_2	BP / EP	3242	0.00	9.9167	1.0517	0.7948	Gamma	GAMMA (0.459, 2.29)
X_3	BTA	160	0.0092	3.1653	0.6834	0.6630	Lognormal	LOGN (0.739, 1.02)
X_4	ATA	160	0.0092	3.0921	0.6442	0.6342	Lognormal	LOGN (0.693, 0.946)

Table 4. Random Variables Correlations (w/o outliers)

Var.	X1	X2	X3	X4
X1	1	0.955	-	-
X2	0.955	1	-	-
X3	-	-	1	0.985
X4	-	-	0.985	1

Limit State Functions and Reliability Index Method

Equation 2 is the basic reliability problem, the failure occurs when R is less than the L (Melchers,1999). Similarly, this paper created several reasonable limit state functions (LSF) (see table 5) to calculate the probability of failure in quantities takeoff by engineers and the probability of failure in contractors' unbalanced bidding strategies.

$$\text{pf} = \text{P}(\text{R} \leq \text{L}) = \text{P}(\text{R} - \text{L} \leq 0) = \text{P}(\text{R/L} \leq 1) \Leftrightarrow \text{pf} = \text{P}[g(\text{R}, \text{L}) \leq 0] \quad (2)$$

Where, g is the "limit state function", pf is the failure probability, R is structural strength, L is the load effect

Table 5. Limit State Functions

Probability of Failure (***Limit State Functions***)	Note
$\text{P}_{f1} = P(G_1(X_3, X_4) \leq 0) = P(X_4 - 0.95X_3 \leq 0)$	Contractors' unbalanced bidding failure
$\text{P}_{f2} = P(G_2(X_1, X_2) \leq 0) = P(X_1 \times X_2 - 0.81 \leq 0)$	Engineers' overestimate failure
$\text{P}_{f3} = P(G_3(X_1, X_2) \leq 0) = P(1.21 - X_1 \times X_2 \leq 0)$	Engineers' underestimate failure
$\text{P}_{f4} = \text{P}_{f2} + \text{P}_{f3}$	Engineers' estimate failure (Combination)
$\text{P}'_{f4} = P(X_1 \leq 0.9 \; and \; X_1 \geq 1.1) = P(X_1 \leq 0.9) + 1 - P(X_1 \leq 1.1)$	Engineers' estimate failure

- P_{f1} , Contractors' unbalanced bidding strategies failure. According to assumptions 1,4 and 5, if ATA ≤ 95%

BTA then the contractors are losing money, so the LSF is $G_1(X_3, X_4) = X_4 - 0.95X_3 \leq 0$ in terms of the random variable.

- P_{f2} , Engineers' overestimate failure. According to assumptions 1,2,3 and 5, if $X_1 \leq 0.9$, the engineers overestimate the quantities (EQ>AQ), at this time, the contractor will underbid (BP<EP) that item $X_2 \leq 0.9$, then $X_1 \times X_2 \leq 0.81$, and the LSF is $G_2(X_1, X_2) = X_1 \times X_2 - 0.81$ in terms of the random variable.
- P_{f3} , Engineers' underestimate failure. According to assumptions 1,2,3 and 5, $X_1 \geq 1.1$, the engineers underestimate the quantities (EQ<AQ), at this time, the contractor will overbid (BP>EP) that item $X_2 \geq 1.1$, then $X_1 \times X_2 \geq 1.21$, and the LSF is $G_3(X_1, X_2) = 1.21 - X_1 \times X_2$ in terms of the random variable.
- P_{f4} , Engineers' estimate failure (Combination). Engineers' estimate failures including overestimation and underestimation failures, adding up $P_{f2}$and P_{f3} to get the engineers' estimate failure P_{f4}.
- P'_{f4}, Engineers' estimate failure, only considering X_1.

Considering the distributions (table 3) and correlations (table 4) of X_i, the First Order Reliability Method (FORM) (Liu & Der Kiureghian, 1986) is adopted to evaluate the reliability index β_i for LSF $G_1(X_3, X_4)$, $G_2(X_1, X_2)$, and $G_3(X_1, X_2)$, then get the probability of failure $P_{fi} = \Phi(-\beta_i)$. The FORM procedures including:

- In LSF $G_1(X_3, X_4)$, X_3 and X_4 are Correlated Non-Normal variables, using Nataf Distribution to transform Lognormal variables X into Correlated Normal $Z \sim N(0,1)$, then transform Z to Uncorrelated Normal variable U.
- In LSF $G_2(X_1, X_2)$ and $G_3(X_1, X_2)$, X_1 and X_2 are Correlated Non-Normal variables, using Nataf Distribution to transform them from Correlated Gamma variables X into Correlated Normal $Z \sim N(0,1)$, then transform Z to Uncorrelated Normal variable U.
- Then, use the Hasofer-Lind Rackwitz-Feissler Algorithm to find the design point u^* by MATLAB codes, the final estimate of β is the First Order Reliability Method Index β_{FORM}.

Hypothesis Test and Regression Analysis Methods

This paper conducts Regression Analysis and Paired Sample T-test to verify assumptions 5 and 6:

- Assumption 5 assumed all winners applied the "Quantity Error Exploitation" unbalanced bidding strategy. To verify whether it is true or not for the collected data, Regression Analysis (see equation 3) is used to inspect the relationship between X_2 and X_1. If this assumption is true, then $b > 0$, for which the increasing of X_1 leads to the increasing of X_2.
- Assumption 6 assumed all winners are the lowest price bidders, and the BTA does not exceed a percentage of ETC. To test whether it is true or not for the collected data, Paired Sample T-test is used to test the Null Hypothesis H_0: $\mu_{BTA-ETC} = 0$. If H_0 is true, then in project level, BTA does not have a significant difference to ETC. Furthermore, the confidence interval (*CI*) could be used to explain the relationship between BTA and ETC.

$$X_2 = a + bX_1 \tag{3}$$

$$H_0: \mu_{BTA-ETC} = 0 \qquad H_1: \mu_{BTA-ETC} \neq 0 \tag{4}$$

Results and Discussions

Statistic-Testing Results and Discussions

Scatterplot (see figure 1) shows a positive relationship between $X_1$and X_2, and Regression Analysis has factor $b = 1.34708 > 0$. Those results confirmed that assumption 5 is true, the "Quantity Error Exploitation" unbalanced bidding strategies was applied to the collected data. Paired Sample T-test with an alpha level of 0.10 ($\alpha = 0.10$) has result *T-value* = - 3.11 and *P-value* = 0.002, which means with a 90% level of confidence to reject the Null Hypothesis H_0: $\mu_{BTA-ETC} = 0$. So, the mean of BTA is significantly different from the mean of ETC in the collected data, the ideal unbalanced bidding in equation 1 does not exist. Furthermore, the 90% *CI* (-0.0974, -0.0297) of

$\mu_{BTA-ETC}$ confirmed that contractors decreased BTA to win projects (Gransberg & Riemer, 2009). These above statistic-testing results confirmed "Quantity Error Exploitation" unbalanced bidding existed in the 163 NDDOT projects. The next step is to evaluate unbalanced bidding's performances and inspect the performances' reasons.

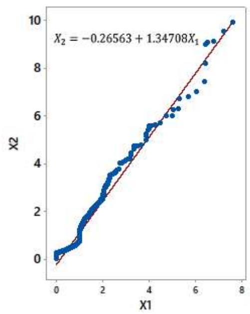


Figure 1. Scatterplot of X1 and X2

Unbalanced Bidding Failures and Discussions

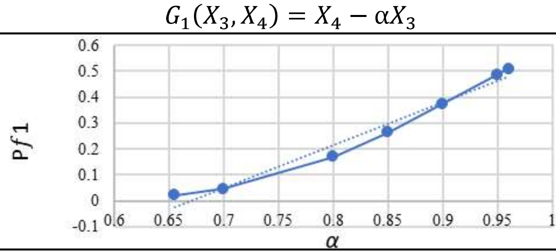
From the LSF $G_1(X_3, X_4)$ get Reliability Index $\beta_1 = 0.02853$ and $P_{f1} = \Phi(-\beta_1) = 0.4886$, which means that the probability of failure of contractors' unbalanced bidding strategies is 0.4886. Additionally, table 6 shows the results of different P_{f1} with different limit state functions $G_1(X_3, X_4) = X_4 - \alpha X_3$.

- The dotted line indicates the P_{f1} is closing to zero when *factor* α is closing to 0.65. Describing this number in project bidding, if contractors accept only earning 65% of BTA and they still can balance projects' income and cost, then the probability of failure of unbalanced bidding is nearly zero. That is only an ideal case; no contractor can make 35% profit in the construction industry.
- Damodaran (2018) shows the construction industry has 11.15% gross margin, converting this number to *factor* $\alpha = 0.8885$, and get $P_{f1}{}' = 0.3485$. Describing this number in project bidding, the probability of failure of contractors' unbalanced bidding strategies is 35% for the U.S. construction industry.
- Furthermore, calculating the γ value for LSF $G_1(X_3, X_4)$, get $\gamma_{X_3} = 0.7332, \gamma_{X_4} = -0.68$. The large $|\gamma|$ value shows that X_3 (BTA) is the main variable result in contractors' bidding failure, and BTA has a positive relationship with bidding failure; ATA has a negative relationship with bidding failure.

The reliability analysis results indicate a large failure probability in contractors' unbalanced bidding, then the reasons of ATA less than BTA must be inspected. Based on equations ATA $= \sum AQ \times BP$ and BTA $= \sum EQ \times BP$, if most AQ < EQ in item level, then ATA < BTA in project level. Referring to the uncertainties stated before, the Missing Error could be eliminated, as the missing items could have a reasonable price makeup after negotiating with owners. However, it is hard to say whether Calculating/ Writing Error or Design Error/ Changes caused the higher risk of failure on unbalanced bidding. The next step is to evaluate engineers' estimation and identify the main reason for failure.

Table 6. Sensitive Analysis

$G_1(X_3, X_4) = X_4 - \alpha X_3$



α	β_1	$P_{f1} = \Phi(-\beta_1)$
0.960	-0.02791	0.5111
0.950	0.02853	0.4886
0.900	0.3199	0.3745
0.850	0.628	0.2650
0.800	0.9548	0.1698
0.700	1.674	0.04702
0.655	2.033	0.02105

Engineer Estimate Failures and Discussions

From the LSF $G_2(X_1, X_2)$ get Reliability Index $\beta_2 = -0.9574$ and $P_{f2} = \Phi(-\beta_2) = 0.8308$, which means the probability of engineers' overestimate failure is 0.8308; again, from the LSF $G_3(X_1, X_2)$ get Reliability Index $\beta_3 = 1.021$ and $P_{f3} = \Phi(-\beta_3) = 0.1536$, which means the probability of engineers' underestimate failure is 0.1536. then, the engineers' estimate failure (Combination) $P_{f4} = P_{f2} + P_{f3} = 0.9844$, which is close to $P'_{f4} = 0.9903$ $(P(X_1 \leq 0.9) + 1 - P(X_1 \leq 1.1) = 0.8667 + 1 - 0.8764 = 0.9903)$ that only considering X_1. Furthermore, calculating the γ value, $\gamma_{X_1} = -0.9901, \gamma_{X_2} = -0.1403$ for $G_2(X_1, X_2)$, and $\gamma_{X_1} = 0.99, \gamma_{X_2} = 0.1414$ for $G_3(X_1, X_2)$. The large $|\gamma|$ value confirmed X_1 is the main variable that leads to engineers' estimate failure. Describing in engineers' estimations, AQ/EQ and BP/EP have negative relationships with engineers' overestimate failure, while they have positive relationships with engineers' underestimate failure.

Those results confirmed that engineers have a low accuracy rate of quantities takeoff at the design and bid stage. The main error of engineers' quantities takeoff is quantity overestimation. Quantity reducing exposes contractors to a high risk of not recovering indirect costs allocated to items. That is the motive for contractors to submit unbalanced bids. If the Estimation Errors could be eliminated after carefully reviewing the estimation, then the infrastructure projects overestimate failure is driven from the Design Errors or Design Changes.

Conclusion

This paper conducted statistical analysis and reliability analysis method with 163 infrastructure projects' bidding and settlement data. The project level variables like contractors' Bid Total Amount and projects' Actual Total Amount fit the Lognormal Distribution, while the item level variables Actual Quantity/Estimated Quantity and Bid Price/Estimated Price fit the Gamma Distribution. The Paired Sample T-Test and Regression Analysis confirmed that assumptions made in this paper are true; the "Quantity Error Exploitation" unbalanced bidding strategies were applied to the collected projects and keep a low bidding price to win projects. To inspect the reasons behind those phenomena, several limit state functions were created to calculate the probability of failure of engineers' estimating and contractors' bidding. The results showed:

- Engineers have a 98.44% failure of estimation, and the main failure is Quantity Overestimated (83.08%). The expected quantities overrating is the major reason for contractors' unbalanced bidding actions to recover their cost.
- Contractors have a 48.86% failure of unbalanced bidding when using a 5% margin. To eliminate this failure, the construction industry should have a 35% margin. But it is imposable for contractors to significantly increase their bidding price to reach this higher margin, as those abnormal bids will lead to a higher risk of rejection by the owners.
- Design Errors or Design Changes might be identified as the reason of engineers' overestimation. To avoid this failure, the Design-Build delivery method is better than DBB (Konchar & Sanvido, 1998). Otherwise, engineers should make their design and estimated quantities as close to the actual project as possible, and owners should build a cooperating relationship with the contractors to avoid the unbalanced bidding.

Applying the First Order Reliability Method needs the distribution of each variable, in this paper, the variables' distributions were fitted from 163 NODOT projects from 2007, and the contractors were from North Dakota and Minnesota States; the results may not update to represent the national wide contractors' bidding behaviors and engineers' estimating skills. Further study could be conducted by categorizing items into different types and inspecting the engineers' estimate behaviors among different item categories. Additionally, other quantity variables like project size, item bid amount (BP×EQ), item estimate amount (EP×EQ), percentage of item amount of total project amount (BP×EQ/BTA, EP×EQ/ETC, or BP×AQ/ATA), and quality variables like major item, minor item (discussed in assumption 2), could be used to set up limit state functions.

Acknowledgements

The researches wish to thank Dr. Joseph Szmerekovsky in North Dakota State University, Fargo, who provided the 163 NDDOT project winning bidder dataset for analyzing.

References

Arditi, D., & Chotibhongs, R. (2009). Detection and prevention of unbalanced bids. *Construction Management and Economics*, *27*(8), 721-732.

Cattell, D. W., Bowen, P. A., & Kaka, A. P. (2007). Review of unbalanced bidding models in construction. *Journal of construction engineering and management*, *133*(8), 562-573.

Cattell, D. W., Bowen, P. A., & Kaka, A. P. (2008). A simplified unbalanced bidding model. *Construction management and economics*, *26*(12), 1283-1290.

Damodaran, A. (2018, Jan 05). *Margins by sector (US). NYU*. URL http://pages. stern. nyu. edu/~ adamodar/New_Home_Page/datafile/margin. html.

Ewerhart, C., & Fieseler, K. (2003). Procurement auctions and unit-price contracts. *RAND Journal of Economics*, 569-581.

Gransberg, D. D., & Riemer, C. (2009). Impact of inaccurate engineer's estimated quantities on unit price contracts. *Journal of Construction Engineering and Management*, *135*(11), 1138-1145.

Hyari, K. H. (2015). Handling unbalanced bidding in construction projects: Prevention rather than detection. *Journal of Construction Engineering and Management*, *142*(2), 04015060.

Hyari, K. H., Shatarat, N., & Khalafallah, A. (2017). Handling Risks of Quantity Variations in Unit-Price Contracts. *Journal of Construction Engineering and Management*, *143*(10), 04017079.

Hyari, K. H., Tarawneh, Z. S., & Katkhuda, H. N. (2016). Detection model for unbalanced pricing in construction projects: A risk-based approach. *Journal of Construction Engineering and Management*, *142*(12), 04016078.

Konchar, M., & Sanvido, V. (1998). Comparison of US project delivery systems. *Journal of construction engineering and management*, *124*(6), 435-444.

Liu, P. L., & Der Kiureghian, A. (1986). Multivariate distribution models with prescribed marginals and covariances. *Probabilistic Engineering Mechanics*, *1*(2), 105-112.

Love, P. E., Edwards, D. J., & Irani, Z. (2012). Moving beyond optimism bias and strategic misrepresentation: An explanation for social infrastructure project cost overruns. *IEEE Transactions on Engineering Management*, *59*(4), 560-571.

NDDOT (North Dakota Department of Transportation). (2014). *Standard specifications for road and bridge construction*, Bismarck, ND

Pietroforte, R., & Miller, J. B. (2002). Procurement methods for US infrastructure: historical perspectives and recent trends. *Building Research & Information*, *30*(6), 425-434.

Melchers, R. E. (1999). Structural reliability analysis and prediction. *West Sussex, England: Wiley.*

Salem Hiyassat, M. A. (2001). Construction bid price evaluation. *Canadian Journal of Civil Engineering*, *28*(2), 264-270.

Stark, R. M. (1974). Unbalanced highway contract tendering. *Journal of the Operational Research Society*, *25*(3), 373-388.

Tong, Y. and Lu, Y. (1992). Unbalanced bidding on contracts with variation trends in client-provided quantities. *Construction Management and Economics*, *10*(1), 69-80.