A FMEA-aided Project Bidding Decision System

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Abstract: This paper studies risk elimination of risk in the current bid evaluation process, addressing the problem of frequent accidents and disadvantages of the popular "lowest-price" bid policy. Failure mode and effect analysis (FMEA), a systematic analysis technique successfully applied in electronic industries, is introduced. A FMEA-aided model for project bidding evaluation is developed through analyzing and applying FMEA factors and methods to project bidding. An actual case is used to prove the applicability and suitability of the proposed approach. The FMEA-aided model was applied to effectively support the lowest-expected-cost (LEC) bidding decision method beneficial for meeting project goals to reduce the risk of decision making.

Keywords: FMEA, Project bidding evaluation, Risk management, lowest expected cost

1 INTRODUCTION

The lowest bid policy awards contracts for engineering, facility and/or a construction projects to the bidder who submits the lowest bid price. One major shortcoming of this policy is that unreasonably low bid proposals are often submitted. Awarding contracts to unreasonably low bidders frequently causes delays and results in poor quality engineering, facility and/or construction projects. Most such cases end up with contractual disputes or litigation. Statistical data tells us that projects awarded with the lowest bids are more likely to experience excessive cost growth than projects awarded with more reasonable bids. Although project administrators have the authority to reject the lowest bid if the bid price is considered unreasonable, in reality, very few bids are rejected. Without an objective process described in the bidding documents to support their bid evaluations, a rejected bidder may challenge such a practice by appealing to a court that may yield lengthy court procedures and delay the procurement process, particularly in public construction projects. Up to around 99% of public construction projects in Taiwan adopted the lowest bid tendering method in the past five years. However, less than 1% of these lowest-bid projects executed a process for evaluating the lowest bid, despite many owners complaining that their lowest bids were suspiciously low. However, an unrealistically low bid implies that the winner may cut corners during construction to maintain profits. The bid winner may execute the project in bad faith using substituted equipment or materials with inferior quality, constructing poor quality work, or allocating insufficient numbers of engineers and laborers to save costs. (As a result, the management quality is impacted.) Ensuring that the lowest bid price is reasonable is critical given the work to be performed is essential to successful project procurement. The past approaches showed that assessing bids based on other policies, for example, total-bid-price level, cannot adequately defend against the internal and external organization bid-rejection argument. Consequently, executives of organizations or administrators of public construction projects in Taiwan remain very reluctant to challenge the lowest bid because of the lack of a quantitative model to objectively review the lowest bid and justify bid rejection decisions [14].

Risk and uncertainty always exist in a project and often cause scheduling delays or cost overrun. Identifying the possible sources of risks and uncertainties is an essential area in the risk management process because it allows project

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parties to recognize the existence of risk and uncertainty in the project and hence, analyze the potential impact and consider an appropriate strategy to mitigate the risk effect on a project[15]. Failure Mode and Effect Analysis (FMEA) is known as a systematic procedure analyzing a system to identify potential failure modes, their causes and effects on system performance. The analysis is successfully performed preferably early in the development cycle so that failure mode removal or mitigation is most cost effective[2]. Some recent FMEA researches are applied in this study, identifying and prioritizing the process part of potential problems/risk that have a financial impact on an operation or project. The probability for a certain failure/risk and the probability that this failure/risk will not be detected to obtain the expected failure/risk cost, proposing A FMEA-facilitated model that examines the best bid based on effective estimation of the lowest expected cost of each bidding proposal from various bidders. The development of FMEA-aided bidding selection and its operating system described in this article is based on our work with a building project developer, Y Company in Taipei. In addition to describing the system, the process used to develop such an approach is reviewed and application conclusions are drawn.

2 LITERATURE REVIEW

The literature on FMEA, risk and uncertainty management is varied. In this section reviews literature that closely relates to the topic of interest, leading to the development of our research focus.

2.1 Failure Mode and Effect Analysis (FMEA)

Failure modes and effects analysis (FMEA), which originated in1950, is a form of reliability analysis technology for the prevention of accidents. It was first used at Grumman Aircraft Corporation to analyze relevant processes, detect potential failure modes and effects, take corrective action to eliminate potential failures and bring about continuous improvement[6]. As a risk management method, FMEA has been frequently used in various industries to prevent mistakes, including electronic, aeronautical, automotive, military and other industries requiring strict standards and sophisticated technologies. FMEA is an inductive technique that works from the bottom up – assuming a component failure has occurred and then assesses the effects of that initial event on the rest of the system. The end result is a table of failures and their effects on the system, which provide the analyst with an overview of the possible faults. Usually, these effects are evaluated according to a number of criteria, such as Severity (S), Occurrence (O) and Detection (D), and often these criteria are then combined into an overall estimate of risk [10].

Severity(S)

Effect of the potential failure mode (if it occurs) to the subsystem, system, customer or next component. Severity is estimated based on a 1 to 10 scale from “None” to “Hazardous without warning”. The more severe the consequence, the higher the severity value assigned to the effect.

Occurrence (O)

It is the likelihood that a specific cause or failure mechanism will occur and it emphasizes the frequency level rather than specific values. Occurrence is assessed on a scale of 1 to 10 in increasing order of occurrence ranging from “Remote” to “Very high”.

Detection (D)

It is an assessment of the ability of the current actions to detect a potential cause or failure mode. Detection is also estimated based on a 1 to 10 scale from “Controls certain to detect” to “Absolute certainty of non-detection”.

Risk Priority Number (RPN)

It is calculated by multiplying by the Severity (O), the Occurrence (O) and the Detection (D) of the failure, which is mathematically represented as follows:

$$\text{Risk priority number (RPN)} = (S) \times (O) \times (D) \quad (1)$$

Ranking scales of (S), (O) and (D) are all defined from 1 to 10, so the RPN ranges from 1 to 100. As the risk increases, the ranking values rise and actions will be taken with priority given to the failure that accorded the highest RPN. All of these data are then presented in the form of a table which allows the analyst to quickly see what the effects of each failure mode are. FMEA is a useful method that we can use to identify potential faults in a system, so that we can then use that information to correct or prevent those faults.

2.2 Project Risk Management

In times of increasing global competition, the success of projects becomes more decisive to an organization’s business performance. However, many projects still present delays, changes in their scope, failures and some might be cancelled. As a general rule those problems may occur due to inefficient management of project risk. Managing risk has become fundamental to successful project management[1], however, techniques and tools for risk management that have been developed and used to increase the chances of project success are not yet widespread or generally applied [8]. Project management considers risk management as one of the key knowledge areas for managers (Wang and [13].

Project risk is defined by PMBOK (Project Management Body of Knowledge) Guide as: an uncertain event or condition that, if it occurs, has a positive or a negative effect on at least one project objective, such as time, cost, span, or quality, which implies an uncertainty about identified events and conditions[3]. This definition of risk and uncertainty is the considered definition through the entire paper. A risk may have more than one cause, and if so, it may have an impact on more than one dimension of a project. Dias and Ioannou [4] emphasized that project financing requires identification and analysis of sources/areas of risk and uncertainty during different phases of the project. Several authors have proposed classification and definition of risk in project financing concluding that the allocation of risks is a key ingredient for successful project financing undertaking. There are 10 categories of classified risk sources: country (political and regulatory), force majeure, physical, financial, revenue, promoting, procurement, developmental, construction and operating risks [15]. Risks were also identified and grouped into categories by Hillson [5], which reflect common sources of risk to the project, such as the following: technical risks, project management risks, organizational risks, and external risks. Technical risks include those that originate in the use of unproven or complex technology or that unrealistic development goals will not be reached. The management risk category includes risks derived from inappropriate allocation of resources and unrealistic estimates due to poor project plan quality. Organizational risks include poor project objectives (with regard to cost, scope, etc.), a lack of prioritization, or interrupted or misallocated financial resources. Finally, external risks are those which occur due to changes to the legislation, changes in market trends, working troubles and alterations in the priorities of project sponsors [11].

Shenhar added that project management and risk management methodologies cannot be standardized for all kinds of projects, but must be adapted to the nature of the goals and uncertainties of each project [12]. Some studies suggest models/frameworks relating to managing risks in information technology projects[8], in the distribution of electric energy, and in identifying technical risks in the development of new products [7]. These are generally based on qualitative risks analysis concepts generated by FMEA.

3 METHOD

The popular three-step risk and uncertainty management approach used and worked with the building project developer to develop the FMEA-facilitated bidding decision system and its operation are discussed in this paper. A case study is then given to verify the application feasibility.

The structured project bidding FMEA (BFMEA, a revised FMEA table) mechanism with four tables, as showed below, Table 1, BFMEA table, Table 2, Severity levels: severity should be estimated on a “1” to “10” scale, Table 3, Occurrence levels: occurrence should be estimated on a “1” to “10” scale, and Table IV, Risk priority number (RPN) versus Risk index (R), is developed for going through the discussing a three-step approach as follows,

Table 1. BFMEA Table

Project bidding: { 1 } FMEA number.: { 2 }

Subproject: { 3 } FMEA date/Rev.: { 4 }

Company name/ Prepared by: { 5 } Page of { 6 }

Executed Projects in the Past Five Years								Action Results			
Project / Period	**Failure mode**	**Effect(s) of failures**	**Occurring date/period**	**Cause(s) of failures**	**Severity (S)**	**Class**	**Corrective actions/by/ date**	**Results of actions**	**Occurrence (O)**	**Risk priority number (RPN)**	**Risk index (R)**
{ 7 }	{ 8 }	{ 9 }	{ 10 }	{ 11 }	{ 12 }	{ 13 }	{ 14 }	{ 15 }	{ 16 }	{ 17 }	{18 }

TABLE 2. SEVETITY LEVELS: SEVERITY SHOULD BE ESTIMATED ON A "1" TO"10" SCALE

Effect	Criteria: Severity of Effect	Ranking(S)
Hazardous without warning	Affect safety of personnel and/or non-compliance with government regulations,without warning	10
Hazardous with warning	Affects safety of personnel and/or non-compliance with government regulations,with warning	9
Very high	Very severely schedule delay and increased cost,higher than 100%	8
High	Construction defects rate,schedule delay or increased cost higher than 61–99%	7
Moderate	Construction defects rate,schedule delay or increased cost higher than 41–60%	6
Low	Constrution defects rate,schedule delay or increased cost higher than 31–40%	5
Very low	Construction defects rate,schedule delay or increased cost higher than 21–30%	4
Minor	Constrution defects rate,schedule delay or increased cost higher than 11–20%	3
Very minor	Constrution defects rate,schedule delay or increased cost higher than 1–10%	2
None	Construction defects rate,schedule delay or increased cost within contract limit	1

TABLE 3. OCCURRENCE LEVELS:OCCURRENCE SHOULD BE ESTIMATED ON A "1" TO "10" SCALE

Probability of Failure	Possible Failure Rate	Ranking(O)
Very high[a]	Higher than 1 in 2	10
Very high	1 in 3	9
High[b]	1 in 8	8
High	1 in 20	7
Moderate[c]	1 in 50	6
Moderate	1 in 80	5
Moderate	1 in 100	4
Low[d]	1 in 200	3
Low	1 in 500	2
Remote[e]	1 in 1000	1

a. Failure is almost inevitable, b. Repeated failure, c. Occasional,

d. Relatively few failure, e. Failure unlikely

Step 1: Risk identification: The first step in the risk management process is risk identification. It includes the recognition of potential event conditions/sources and their risk and uncertainty effect on the project and clarification of risk and uncertainty responsibilities. It is accomplished using a structured surveillance of every prequalified bidder's executed projects in the past five years using the BFMEA table (Table I) – what events may possibly occur that will impede and impact the achievement of meeting specifications of project. The items{1}−{18}of BFMEA should be entered completely and honestly by bidder who will be liable, particularly, for the descriptions of failure mode{8}and their effect{9}, occurring date/period{10} and severity ranking{12}. A bidder project facilitating team well trained in BFMBA methodology can greatly reduce the review time requirements and ensure that all items can be entered with the same evaluation criteria as specified in Tables II and III without inconsistency.

Step 2: Risk assessment: Risk assessment identifies the importance and impact of risk/failure to the project goals. It comes as a response from the surveillance – what is the probability (O) of this risk/failure? And what is the severity (S) of the impact on the project if a risk/failure takes place? A traditional FMEA uses risk priority number (PRN) to assess risk in three categories: Severity (S), Occurrence (O) and Detection (D). To ignore the Detection (D) category in project bidding evaluation is suggested. Trying to measure how easy it is to detect where a failure has occurred or when it has occurred will confuse the bidding FMEA users. Instead, trying to measure how easy or difficult it is to prevent failure through assessing the effectiveness of corrective actions{14}is emphasized critically. The risk index (R){18}is accomplished by a project tendering committee after reviewing items{1}–{17}of BFMEA table, to multiply the probability of occurrence (O) and severity of risk/failure impact (S) equals to RPN {17}and to obtain (R) through transforming RPN, as showed in Table 4.

TABLE 4. RPN VERSUS RISK INDEX (R)

RPN	Risk Index(R)
91≤RPN≤100	10
81≤RPN≤90	9
71≤RPN≤80	7
61≤RPN≤70	5
51≤RPN≤60	3
41≤RPN≤50	2
31≤RPN≤40	1.5
21≤RPN≤30	1.2
11≤RPN≤20	1.05
1≤RPN≤10	1

The highest RPN is used to measure risk index if more than one failure or cause occurs during a project. Cost is a universal language that can be easily understood or compared in terms of the impact among bidders. The risk index (R) is used to estimate the expected cost that is the multiplied product of the original bid price (P) submitted by the bidder and risk index (R), respectively. The expected cost (EC) is accumulated if a project is formed by several sub-projects. The formula is as below,

$$\text{Expected cost (EC)} = \sum PiRi,\ 1\leq i \leq n \qquad (2)$$

The lowest-expected-cost (LEC) method can be adopted to award a construction project contract to the bidder who submits the bidding proposal with the lowest expected cost examined and finalized by the tendering committee. The bid with the lowest severity (S) ranking number will be awarded if the EC of two or more than two bidders' are comparable.

Step 3: Risk mitigation: Mitigation establishes a plan that reduces or eliminates risk sources and failure impact to the project's deployment. The plan includes professional and careful review of events/failures listed in the BFMEA table and corrective actions{14}and evidence meeting the requirements for systematic solutions. An audit and monitoring program is enacted during project execution to ensure that effective corrective and preventive actions can be considered. An actual cost (risk) less than the lowest-expected-cost bid can be achieved through solid plan implementation.

4 CASE STUDY

4.1 Background

An architectural project provided by Y Company is presented to demonstrate how the proposed LEC model, Equation (3) could be applied in project bidding. The developer plans to construct a residential district that covers an area of five thousand square meters. The structure is six stories with a reinforced concrete frame structure. The total project budget is approximate 75 million RMB. The architectural project attracted six bidders. Two of them were disqualified during the prequalification process, including bidder A, B, C and D. The original bid prices and the entire failure investigation are presented as follows:

- Bidder A: The original bid price is 74 million RMB. The company has a good reputation with no failures in the past five years.

- Bidder B: The original bid price is 70 million RMB. In the last five years a schedule delayed for two months which exceeded the construction contract by 23%. The company treated it in a timely manner and strengthened prevention measures. Only one small incident occurred, delaying the schedule for several days.

- Bidder C: The original bid price is 68 million RMB. In the last five years construction cost exceeded the contract by 15%. The construction quality did not meet the standard and the final settlement of accounts exceeded 40%. No specific measures were taken to prevent this situation and similar accidents occurred in another project in the same year.

- Bidder D: The original bid price is 73.5 million RMB. Serious casualty accidents happened in the last five years. A constructor was killed by a high altitude fall. After that, leaders took notice and intervened personally in the issue, such as holding an introspection conference, retraining the managers and staffs, etc. All of these measures received good results and no accidents occurred in the following two years.

4.2 Operation of BFMEA

The bid evaluation committee evaluated the bid using BFMEA. We took Bidder B as an example to build a BFMEA table and the contents are shown in Table 5. As mentioned above, the specific standards can be discussed and decided by the bid evaluation committee according to the specific project.

TABLE 5 BFMEA TABLE OF BIDDER B

Project bidding: A residential district architectural project FMEA number.: 1100001-B

Subproject: B Construction Co., LTD FMEA date/Rev.: 2011-10-01

Company name/ Prepared by: { 5 } Page of { 6 }

Projects Executed in the Past Five Years								Action Results			
Project / Period	*Failure modes*	*Effect(s) of failures*	*Date/period*	*Cause(s) of failures*	*Sev. (S)*	*Class*	*Corrective actions/by/date*	*Results of actions*	*Occ. (O)*	*Risk priority number (RPN)*	*Risk index (R)*
An architectural project of a residential district.	Schedual delayed in the construction of Z project.	Schedule delayed for two months and exceeded the construction contract for 23%.	2010-09-09	No reasonable measures for time control.	4	Moderate	The company timely took control measures,strengthened prevention measures and compensate the developer.	A small incident happened. Schedule delayed for several days	3	12	1.05

The EC comparison results are shown in Table 6. The original bid price (P) of bidder C is the lowest. Bidder C should be the winner of the project if the selection principle was based on the lowest bid method. The result is very different from applying the proposed LEC model that bidder B is awarded this project (The bid of bidder B has lower severity ranking number than bidder D's.). Significant effective project bidding decision was obtained applying the proposed LEC model.

5 CONCLUSION

FMEA is a charting technique for risk assessment design and is used in automotive and mechanical engineering. There has been limited application of this technique within the construction industry. It is considered an appropriate tool for this study in that it allows for subjective assessment of case study material, producing empirical values for statistical analysis[9]. This research is relevant to both researchers and practitioners. It provides practitioners with a model to evaluate and prioritize projects based on risk management, a quantitative model to objectively quantifying the qualitative effect of subjective events or sources. The entire modeling process can be viewed as a FMEA-aided evaluation and estimation approach to the expected cost of a bid with certain probability of risk and failure. Although the proposed lowest-expected-cost (LEC) model may not be developed using complex

mathematical theories, its' practical implications can contribute to several industrial practitioners or public procurement practices.

FMEA is a new tool for project bidding that when adequately performed can reduce the risk for developers. The lowest-expect-cost policy will be more accurate using FMEA and it will reflect the real price of bid enterprises more accurately to reduce the risk of decision making. There is no doubt that the FMEA-facilitated model is the best method for owners to ensure project quality with the least cost.

TABLE 6. EXPECTED COST COMPARISON (MILLION US$)

Bidder	P	(S)	(O)	RPN	R	EC
A	74.0	5	1	5	1	74.0
B	70.0	6	2	12	1.05	73.5
C	68.0	6	8	48	2	136.0

D	73.5	9	1	9	1	73.5

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