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# A man-hour based order acceptance strategy for maximizing expected profit in EPC Projects

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Abstract: Accurate cost estimation is essential for any EPC contractor accepting profitable projects because the project price is determined prior to receiving the contract. Therefore the contractor needs to ensure man-hours (MH) in order to estimate project costs accurately as well as carry out the accepted orders. In this paper, we develop the MH based order acceptance strategies and investigate the effects of them on the total expected profit through a long-term operation in EPC projects under a competitive bidding situation. To this end we build a simulation model describing relations among the volume of MH for cost estimation, accepted orders, revenues, and profits in EPC projects. Using our model, we show that the strategy, which maintains the appropriate balance of MH for cost estimation and project execution under the variability of accepted orders with competitive bidding situations, improves the total expected profit in EPC projects.

# 1 Introduction

Although there are various types of project contracts, the importance of Engineering-Procurement-Construction (EPC) projects (Yeo and Ning, 2002; Towler and Sinnott, 2008; Ranjan, 2009) is widely recognized in the fields of construction, civil engineering, plant engineering, and so on, because of the increasing client requirements for reduced project cost and for a shorter schedule. In EPC projects, the contractor has the sole responsibility for project cost, quality, and schedule under a fixed-price, which is determined before the start of the project as a lump-sum contract. Thus a reduced project cost and shorter schedule are expected as Ranjan (2009), Lotfian et al. (2010), and Jinru (2011) stated.

In EPC projects, a contractor is usually selected by a client through a competitive bidding process (Ioannou and Leu, 1993; Rothkopf and Harstad, 1994; Helmus, 2008). Namely, the client prepares a Request For Proposal (RFP) for the order and invites several potential contractors to the bidding. The client evaluates contractors on the basis of the multi-attribute bid evaluation criteria, such as bidding price, past experience, past performance, company reputation, and the proposed method of delivery and technical solutions (Helmus, 2008; Kerzner, 2009; Watt et al., 2009). Then, the client basically selects the contractor who proposes the lowest price if there is not much difference in other criteria. The selected contractor undertakes a series of tasks including engineering, procurement, and constriction by directing and coordinating subcontractors within the limits of the predetermined budget and according to the predetermined schedule.

Since the contractor takes a significant risk with the project in the EPC contract, it is necessary for any contractor to determine the bidding price based on a precise estimation of its project cost by defining the project in as much detail as possible. If the contractor's bidding price is set higher than that of a competitor due to cost estimation error, the contractor could fail to receive the order. Conversely, if the cost estimation error results in an underestimation of the cost, the contractor would be granted the order; however, he would eventually suffer a deficit due to this order.

Cost estimation, however, is the highly intellectual task of predicting the costs of products or services to be provided in the future based on the analysis of the current client's requirements. Therefore, experienced and skilled human resources, i.e., MH (Man-Hour) of skilled engineers, are required for accurate cost estimation. Those resources, however, are limited in any company; furthermore, once the orders are successfully accepted, the corresponding projects will also need considerable MH to carry them out at the following periods. If the contractor accepts many orders at a particular period and thus cannot secure the sufficient volume of MH for estimating cost accurately, the profits at the following periods would decrease. This is because the probability of accepting loss-making orders increases as the cost estimation accuracy decreases in competitive bidding (Ishii and Muraki, 2011). As a result, the contractor suffers unstable and low profits at the following several periods.

For these reasons, to maximize the expected profit through a long-term operation in EPC projects, it is important for any contractor to accept orders with careful consideration of the appropriate MH balance of the cost estimation and project execution. However, the competitive bidding brings uncertainty about the volume of accepted orders, and hence, most contractors usually try to accept as many orders as possible so as to accomplish their original target for the volume of orders, especially when the uncertainty is large. As a result, they tend to accept an excessive volume of orders that reduces the MH for cost estimation at the following periods and diminishes the profit through a long-term operation.

In this paper, we develop the MH based order acceptance strategies and investigate the effects of them on the total expected profits through a long-term operation in EPC projects under a competitive bidding situation. We build a simulation model describing the relations among the volume of MH for cost estimation, accepted orders, revenues, and profits in EPC projects. Using our model, we evaluate the effectiveness of order acceptance strategies from the perspective of the total expected profit in EPC projects through a long-term operation. We then show that the total expected profit can be improved by the MH based order acceptance strategy which maintains the appropriate balance of MH for cost estimation and project execution through a long-term operation in EPC projects under the variability of accepted orders with competitive bidding situations.

## 2 Related Work

Related to the order acceptance strategy in EPC projects, many researchers have studied order acceptance and project selection in several ways over the last several decades.

Order acceptance is the problem of making the decision to accept each order or not, and its objective is to maximize profits with production capacity limitations. As shown by Herbots et al. (2007), Slotnick and Morton (2007), Rom and Slotnick (2009), and Wang et al. (2013), a variety of research topics exist. Project selection, on the other hand, is the problem of creating a mix of projects from candidate projects to help achieve an organization's goals within its resource constraints. Research and development (R&D), information technology, and capital budgeting are typical application fields of the project selection. Researchers have applied various kinds of methods to these problems (Dey, 2006; Medaglia et al., 2007; Wang et al., 2009).

It is noteworthy that most of the literature dealing with the above topics has assumed single tendering without competitive bidding, and has also assumed no limitation of the volume of MH for cost estimation. In EPC projects, however, the contractor decides a bidding price based on the project cost estimated by the limited MH, and the clients basically select a contractor from bidders through the competitive bidding process.

A variety of studies, such as bidding theory, bidding model and auction design, have been conducted on competitive bidding (Ballesteros-Pérez et al., 2012). In particular, a number of papers regarding the competitive bidding strategy date back to Friedman (1956), who presented a method to determine an optimal bidding price based on the distribution of the ratio of the bidding price to cost estimate. However, the constraint of the volume of MH for cost estimation has not been studied in previous research; nevertheless the volume of MH affects the cost estimation accuracy and the expected profits from the accepted orders in EPC projects.

Regarding cost estimation accuracy, various types of research have been performed. Oberlender and Trost (2001) studied determinants of cost estimation accuracy and developed a system for predicting the accuracy of the estimated cost. Bertisen and Davis (2008) analysed costs of 63 projects and evaluated the accuracy of estimated costs statistically. Brunoe and Nielsen (2012) applied a statistical method for cost estimation for quotation purpose in Engineer-To-Order environment where cost estimation is resource intensive. In addition, several cost estimation methods and their accuracy have been studied. For example, Page (1996), Humphreys (2004), and Towler and Sinnott (2008) studied relations among cost estimation methods, cost estimation data, and their accuracy in the field of plant engineering projects. More importantly, Gerrard (2000), and Towler and Sinnott (2008) suggested that the cost estimation accuracy is positively correlated with the volume of MH for cost estimation. Ishii et al. (2011) studied the effect of the cost estimation accuracy and the relevant MH on the expected profits in EPC projects under competitive bidding situations. In addition, Ishii and Muraki (2011) studied the effect of the volume of accepted orders at each period on the total expected profit through a long-term operation under the MH constraint for cost estimation. However, they did not study the order acceptance strategy to gain a high profit in consideration of the appropriate MH balance for cost estimation and project execution through a long-term operation.

In EPC projects, the bidding price must be determined before the start of the project; thus the volume of MH for project cost estimation is clearly one of the major factors for determining the profitability of EPC projects. Those MH, however, are limited in any contractor; furthermore, once the orders are accepted, the corresponding projects will also need considerable MH to carry them out. Thus it is important for any contractor in EPC projects to execute an appropriate MH based order acceptance strategy, which maintains the appropriate MH balance for cost estimation and project execution, in order to raise the expected profit though a long-term operation. Nevertheless, as stated in this section, few studies have ever attempted to study the MH based order acceptance strategy in consideration of the limitations of the MH for cost estimation and the project execution through a long-term operation in EPC projects under competitive bidding situations.

# 3 A Simulation Model of Order Acceptance and Profits in EPC Projects

## 3.1 An Overview of the Simulation Model

In this paper, we develop a simulation model to assess the effectiveness of the MH based order acceptance strategies for EPC projects under the competitive bidding situations through a long-term operation. Our simulation model, which is an extended model of the Multi-Period Order Acceptance (MPOA) and Profit model developed by Ishii and Muraki (2011), consists of the strategy module, the simulation module, and the simulation record module, as shown in Figure 1.

The strategy module determines the target volume of accepted orders at the *i*-th period ($TGV_i$) based on the simulation results to date, such as the volume of accepted orders at the previous period ($VAO_{i-1}$), the total MH for cost estimation at the present period ($TMH_i^{est}$), and so on. In this paper, we use the order acceptance strategies explained in Section 4 for the strategy module.

The simulation module simulates a competitive bidding situation, i.e., calculates $VAO_i$ from $TGV_i$ determined by the strategy volume and the conditions on variations of $VAO_i$. In our simulation model, the variations of $VAO_i$ are used to compare the effectiveness of the order acceptance strategies under the different variation conditions on $VAO_i$.

The simulation module also calculates the expected revenue ($ER_{i+1}$), the expected cost ($EC_{i+1}$), the expected profits ($EP_{i+1}$), and the volume of MH for cost estimation ($TMH_{i+1}^{est}$) at the $i$+1 period from the $VAO_i$, cost data, and the following model assumptions:

- There are three kinds of MH: regular engineers' MH, senior engineers' MH, and outsourcing MH.
- The senior engineers' MH must account for more than a certain percentage of MH for carrying out the projects.
- Only senior engineers can estimate a project cost.
- The expected cost ($EC_i$) consists of materials and labour cost, outsourcing MH cost, and fixed cost including in-house MH cost and overhead.
- The projects corresponding to the accepted orders at the *i*-th period are carried out from the next period.

In our simulation model, we assume that the target orders for bidding have the same project cost and competitive bidding conditions, which are determined from the average project cost and the competitive bidding conditions of one's own company. The project cost and the bidding conditions in each order are different in practice. However, in this paper, we use the simulation model to evaluate the effectiveness of the MH based order acceptance strategies in terms of the balance of the total MH for cost estimation and project execution through a long-term operation. Such MH balance depends not on each project cost, but on the total project cost at each period. Namely, the assumptions on the target orders for bidding are appropriate in our simulation.

The simulation record module stores the simulation results from the simulation module, such as *ER*, *EC*, *EP*, and *TMH* at each period, and provides those data to the strategy module. In addition, it provides the cost data, shown in Table 1 in section 5, and the competitive bidding conditions to the simulation module. The competitive bidding conditions are the number of competitors, the parameters for determining cost estimation accuracy and the average bidding price of one's own company, and the competitors' average and standard deviation of bidding price.

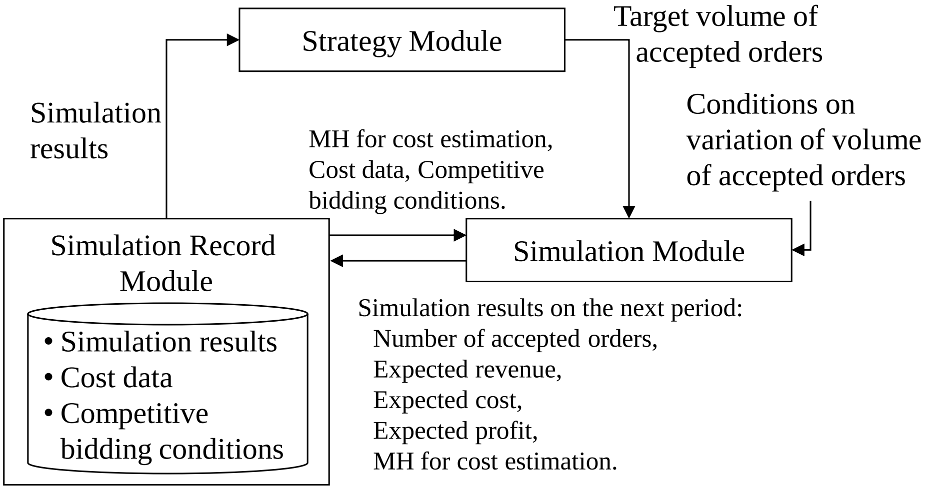

Figure 1: A framework of the simulation model.

## 3.2 Mechanism of the simulation module

The simulation module shown in Figure 2 determines the number of orders to bid at the *i*-th period ($NBD_i$). In this subsection, we formulate an optimization problem to calculate the minimum $NBD_i$ for accepting the target volume of orders at the *i*-th period ($TGV_i$) determined by the strategy module.

It is assumed in this paper that the total MH for cost estimation at the *i*-th period ($TMH_i^{est}$) is equally allocated to each order. Specifically, the volume of MH for cost estimation of each order at the *i*-th period ($PMH_i$) is determined as follows:

$$PMH_i = TMH_i^{est} / NBD_i \tag{1}$$

Towler and Sinnott (2008), Gerrard (2000) suggest that the cost estimation accuracy is positively correlated with the volume of MH for cost estimation. It is also clear that the marginal rate of cost estimation accuracy approaches zero as the volume of MH increases. From this, like Ishii and Muraki (2011), we define the cost estimation accuracy as the function of the $PMH_i$ based on the logistic curve:

$$\sigma_1^i = \sigma_{\max} \cdot \sigma_{\min} / (\sigma_{\max} - (\sigma_{\max} - \sigma_{\min}) \cdot e^{-C \cdot PMH_i}) \tag{2}$$

where $\sigma_1^i$ is the cost estimation accuracy of one's own company at the *i*-th period, $\sigma_{\min}$, $\sigma_{\max}$ are the minimum and the maximum value of the cost estimation accuracy, and $C$ is a parameter of the logistic curve. In cost engineering, cost estimation accuracy is usually defined as the percentage of the standard deviation to the actual cost (Towler and Sinnott, 2008; Kerzner, 2009). Namely, a lower deviation ( $\sigma$ ) means higher estimation accuracy.

The contractor can accept an order only when his bidding price is lower than that of competitors. Thus, the expected value of an order to bid at the *i*-th period ( $EPT_i^{est}$ ) is calculated as the average value of the bidding price of one's own company falling below those of all other competitors:

$$EPT_i^{est} = \int_0^{+\infty} x_1 \cdot p_1(x_1, \mu_1, \sigma_1^i) \cdot \prod_{k=2}^{n} \int_{x_1}^{+\infty} p_k(x_k, \mu_k, \sigma_k) dx_k \cdot dx_1 \qquad (3)$$

where *k* is the contractor (*k* =1: one's own company, *k* >=2: competitors), $p_k(x_k, \mu_k, \sigma_k)$ is the probability density of the bidding price ($x_k$ ) of the contractor (*k*), and its average value and standard deviation (i.e., cost estimation accuracy) are $\mu_k$ and $\sigma_k$, respectively. Note that the $EPT_i^{est}$ depends on the cost estimation accuracy ( $\sigma_1^i$ ).

Additionally, the number of orders to bid at the *i*-th period ($NBD_i$) must meet the following conditions for accepting the target volume of orders at the *i*-th period ($TGV_i$):

$$NBD_i \cdot EPT_i^{est} \geq TGV_i \qquad (4)$$

$$NBD_i \geq 1 \qquad (5)$$

Finally, the simulation module determines the minimum $NBD_i$ for accepting $TGV_i$ by solving the following optimization problem at each period:

**Minimize** $NBD_i$

**Subject to** Eqs. (1), (2), (3), (4), and (5)

with decision variables $NBD_i$, $PMH_i$, $\sigma_1^i$ , $EPT_i^{est}$ . This problem, however, is essentially an optimization of the single decision variable $NBD_i$ if other decision variables and the constraints (1), (2) and (3) are eliminated by substitution; therefore this optimization problem can be solved by using a line search method. One's own company then bids for the minimum $NBD_i$ orders in a competitive bidding at the *i*-th period.

In the simulation model, the volume of accepted orders at the *i*-th period ($VAO_i$) is determined as follows:

$$VAO_i = TGV_i + VAR_i \qquad (6)$$

where $VAR_i$ is a random variable representing the variability in $VAO_i$. In Eq. (6), $VAR_i$ is added to $TGV_i$ to study the effectiveness of the order acceptance strategies through a long-term operation against the variations of $VAO_i$ from the $TGV_i$.

In addition, the value of each order that has been accepted at the *i*-th period ($EPT_i^{awd}$) is calculated by dividing $EPT_i^{est}$ by the probability of winning:

$$EPT_i^{awd} = EPT_i^{est} / \int_0^{+\infty} p_1(x_1, \mu_1, \sigma_1^i) \prod_{k=2}^{n} \int_{x_1}^{+\infty} p_k(x_k, \mu_k, \sigma_k) dx_k \cdot dx_1 \tag{7}$$

and the number of accepted orders ($NAO_i$) is calculated as follows:

$$NAO_i = VAO_i / EPT_i^{awd} \tag{8}$$

The simulation module also calculates the expected total revenue ($ER_{i+1}$), the expected total cost ($EC_{i+1}$), the expected total profit ($EP_{i+1}$), and the total MH for cost estimation ($TMH_{i+1}^{est}$) based on $NAO_i$ until the *i*-th period and cost data. For the detailed calculation, see APPENDIX. However, it should be noticed that a large number of accepted orders require a lot of MH for project execution and therefore reduce the MH for cost estimation from the next period.

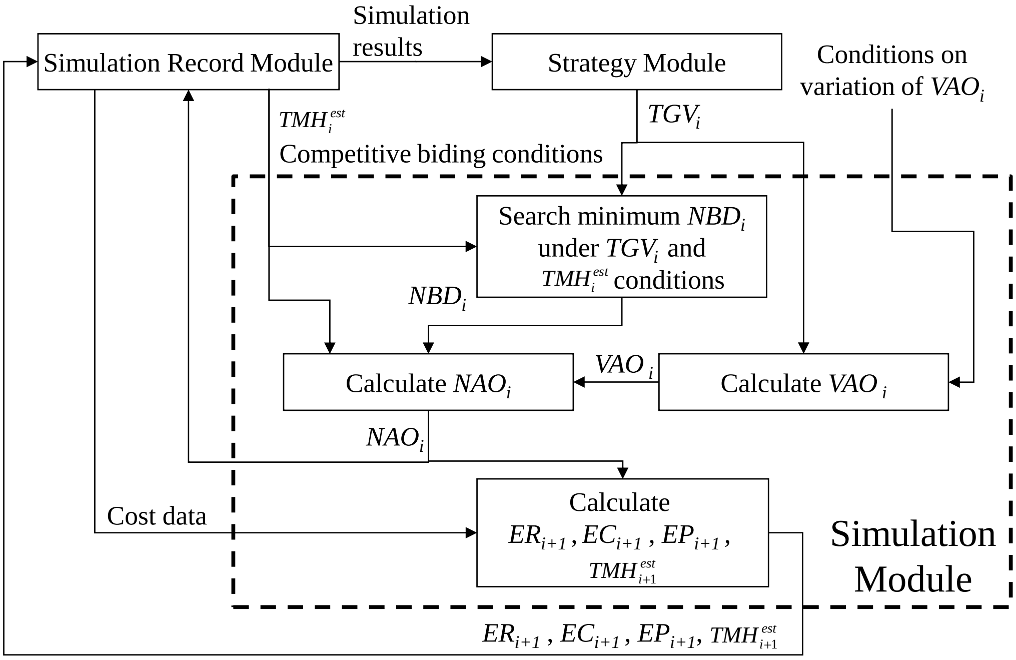

Figure 2: Mechanism of the simulation module.

# 4 Order Acceptance Strategies in EPC projects

As explained in Section 3, competitive bidding is simulated based on the target volume of orders (*TGV*) determined by the order acceptance strategy. Ishii and Muraki (2011) showed two findings on the order acceptance in EPC projects, i.e., (a) there is the optimal volume of orders for maximizing the total expected profit through a long-term operation depending on the competitive bidding situations, and (b) accepting excessive orders at one period results in the loss of expected profits at the following several periods. In this section, we develop three types of order acceptance strategies, SA, SB, and SC, based on the above findings and compare their effectiveness by simulation experiments in the next section.

Among the different strategies, the strategy SA is a simple one based on finding (a). Namely, it determines the *TGV* at each period, depending solely on the present competitive bidding situation. In contrast, the strategy SB and the strategy SC are based on findings (a) and (b). They control the *TGV* at each period in view of the volume of accepted orders (*VAO*), which is relevant to the volume of MH for carrying out projects, at the previous periods. Thus, among three strategies, the strategies SB and SC are recognized as the MH based order acceptance strategy.

We use the simulation model shown in section 3 to evaluate the effectiveness of these order acceptance strategies from the perspective of the total expected profit through a long-term operation in EPC projects.

(1) Strategy SA

In EPC projects, the accepted order brings in workloads to carry out the projects from the next period. For this reason, we suppose that the target expected revenue (*TER* = project costs + expected profits) is set up for each period, and the strategy SA sets the target volume of orders (*TGV*) by the *TER* at the next period:

$$TGV_i = TER_{i+1} \qquad (9)$$

*TER* is determined as sum of the project costs and the expected profits of accepted orders. Namely, the different *TER* can be set in Eq. (9) at each period depending on the competitive conditions. For instance, the higher *TER* is set when the higher profits are expected under the relaxed competitive conditions.

Since the strategy SA is based on finding (a) only, it determines the *TGV* without considering the volume of accepted orders (*VAO*) at the previous periods. Namely, the strategy SA has no mechanism for adjusting the volume of MH for cost estimation and project execution in response to the *VAO* at the previous periods. For instance, the strategy SA determines the *TGV* without considering that the MH for cost estimation has been decreased by the excessive *VAO* at the previous period. Since it is not beneficial to keep the target volume of orders in spite of the reduced MH for cost estimation, the strategy SA is probably effective only when the variation in the *VAO* is negligibly small.

(2) Strategy SB

The strategy SB is based on findings (a) and (b), and is recognized as an MH based order acceptance strategy. This strategy determines the target volume of orders (*TGV*) by considering the degree of attainment of the target expected revenue (*TER*) at the previous periods:

$$TGV_i = TER_{i+1} + \sum_{j=i-ncp+1}^{i} (TER_j - VAO_{j-1}) \tag{10}$$

where *ncp* is the number of periods required to complete the project of an accepted order.

The strategy SB aims to maintain stable project workloads through a long-term operation by changing the *TGV* depending on the difference between the past *TER* and the past volume of accepted orders (*VAO*). For instance, *TGV* is set low when many orders were accepted at previous periods. Conversely if *VAO* fell short of the target revenue at the previous periods, *TGV* is set high. The stable project workloads are essential to maintain the appropriate volume of MH for the cost estimation and project execution at each period. Accordingly, in a situation where there is great variability in the *VAO* among periods, the strategy SB is expected to improve the total expected profit compared to the strategy SA.

(3) Strategy SC

The strategy SC is also based on findings (a) and (b), and is recognized as an MH based order acceptance strategy. The strategy SC determines the target volume of orders (*TGV*) in the same way as the strategy SB (see Eq. (10)). In addition, this strategy can impose the upper limit on the volume of accepted orders (*VAO*), i.e., can adjust the $VAO_i$ as follows:

$$VAO_i = \min\{TGV_i + VAR_i, TGV_i \cdot (1 + upl)\} \tag{11}$$

instead of Eq. (6), where *upl* is the ratio of the upper limit. Namely, the strategy SC controls the *VAO* so that it will be less than or equal to $TGV_i \cdot (1+upl)$. The contractor can practically do this by increasing the bidding prices after learning that the probability of winning is higher than expected.

Accepting excessive orders at one period results in the loss of expected profits at the following several periods. The strategy SC is expected to be effective in improving the total expected profit when there is great variability in the *VAO* among periods or when the *TER* is much higher than the optimum.

# 5 Evaluation of Order Acceptance Strategy by simulation experiments

## 5.1 Cost and profit data

In the simulation experiments, we assume a midsize EPC contractor in the oil and gas plant engineering business whose annual sales are approximately one billion US dollars (1,000 [MM$]) and the project cost (*PEC*) of each accepted order is 100 [MM$/Order]. The cost and profit data are shown in Table 1.

Table 1: Cost and profit data.

| | |
|---|---|
| Rate of the *i*-th period revenue on the accepted orders at the *j*-th period ( $ROER_i^j$ ) | 0.333 |
| Periods to complete project of accepted order (*ncp*) | 3 periods |
| Evaluation periods | 15 periods |
| Rate of profit (*ROP*) | 10% |
| Rate of MH cost ($\alpha_1$) | 10% |
| Rate of materials & labour cost ($\alpha_3$) | 80% |
| Total in-house MH ($MH^T$) | 1,100 [M MH/period] |
| In-house senior engineer MH ($MH^S$) | 440 [M MH/period] |
| Rate of senior engineer MH to carry out orders ($\alpha_2$) | 30% |
| In-house and out sourcing MH rate ($\beta_1$, $\beta_2$) | 100 [$/MH] |
| Project cost (*PEC*) of each order | 100 [MM$/order] |
| Fixed cost (*FC*) | 220 [MM$] |

## 5.2 Cost estimation accuracy

We set the parameters for determining the cost estimation accuracy of one's own company ( $\sigma_1^i$ ) as follows (see also Eq. (2)); $\sigma_{\min}$ : 0.5% of the *PEC*; $\sigma_{\max}$ : 20% of the *PEC*; *C* : 0.25. In addition, we suppose that the competitors' cost estimation accuracy ( $\sigma_k$ （$k>=2$） ) is 5 [MM$ ], i.e., +/- 5% of the *PEC*. The accuracy of +/- 5% is considered the detailed estimate prepared from well-defined engineering data (Kerzner, 2009).

## 5.3 Probability density of the bidding price and competitive conditions

We suppose in Eqs. (3) and (7) that the bidding price ( $x_k$ ) follows lognormal distribution as in Bertisen and Davis (2008). In addition, we assume that the number of bidders (*n*) including one's own company is 3, and the competitors' average bidding price ( $\mu_k$ ) and one's own company' average bidding price （$\mu_1$） are 110[MM$ ] including profit.

## 5.4 Design of Experiments

(1) Variation of bid success probability

In the simulation experiments, we assume that $VAR_i$, shown in Eqs. (6) and (11) follows the normal distribution with zero mean and the standard deviation $TGV_i \cdot rv$, where *rv* is the ratio of deviation. In addition, we set the upper and the lower limits of the *TGV* as 1.2 times and 0.8 times of the *TER*, respectively, to avoid an extreme case in simulation experiments.

(2) Simulation scenarios

We consider 5 levels of the ratio of deviation (*rv* = 0.0, 0.05, 0.1, 0.15, and 0.2). In addition, we consider four levels of the ratio of the upper limit (*upl* = 0.1, 0.2, 0.3, and no upper limit) for the strategy SC. Note that the strategy SB is identical to the strategy SC in the case of no upper limit of *upl*. We set four levels of the *TER*, i.e.- 1,150, 1,200, 1,250, and 1,300 [MM$]. Therefore a total of 120 cases are evaluated by simulation experiments, i.e., 20 cases for the strategy SA, 20 cases for the strategy SB, and 80 cases for the strategy SC. In each case, 1000 samplings are conducted, and the average of the total expected profit among 15 periods is calculated.

In each simulation experiment, the volume of accepted orders (*VAO*) before the first period was set to the value of the *TER*, i.e.- 1,150, 1,200, 1,250, and 1,300 [MM$], as the initial condition.

## 5.5 Results of simulation experiments and discussion

### 5.5.1 Effectiveness of strategy SA

Table 2 summarises the average value of the total expected profits obtained by the strategy SA among 15 periods. It is found from Table 2 that the ratio of deviation from the *TGV* (*rv*) significantly affects the total expected profit in all cases of the *TER*. The total expected profit becomes monotonically smaller as *rv* increases except when the *TER* is 1,150. In the case that the *TER* is 1,150, the total expected profit is the largest at *rv*=0.05. In addition, the difference in the total expected profit between *rv*=0.0 and *rv*=0.20 becomes larger as the *TER* increases. For instance, the decrease in the total expected profit from *rv* =0.0 to *rv* =0.20 is 165.42 when the *TER* is 1,300. However, it is 34.06 when the *TER* is 1,150.

The *TER* generating the highest profitability differs depending on the *rv*. It is best to set the *TER* to 1,250 in the case that *rv*=0.00, 0.05, and 0.10; however, the best value of the *TER* is 1,200 at *rv*=0.15 and 0.20. The contractor tends to try to accept as many orders as possible so as to mitigate the risk of losing many orders when the variability in the *VAO* is large. However, the simulation results indicate that the contractor should reduce the number of orders to bid by setting the small *TER* when there is great variability in the *VAO*.

Table 2: Average value of the total expected profit obtained by the strategy SA.

| Ratio of deviation from *TGV* (*rv*) | Target expected revenue (*TER*) [MM$] | | | |
|---|---|---|---|---|
| | 1,150 | 1,200 | 1,250 | 1,300 |
| 0.00 | 562.54 | 615.38 | 621.70 | 591.91 |
| 0.05 | 565.03 | 607.24 | 617.08 | 576.94 |
| 0.10 | 560.56 | 599.42 | 599.90 | 538.40 |
| 0.15 | 549.53 | 580.61 | 557.48 | 466.06 |
| 0.20 | 528.48 | 547.31 | 515.73 | 426.49 |

### 5.5.2 Effectiveness of strategy SB

Table 3 summarizes the average value of the total expected profits obtained by the strategy SB among 15 periods. By comparing Table 2 with Table 3, it can be seen that the strategy SB performs better than the strategy SA on the total expected profit when *rv*>0.0. In addition, the effect of *rv* on the total expected profit in the strategy SB is smaller than that in the strategy SA. For instance, when the *TER* is 1,300, the decrease in the total expected profit from *rv* =0.0 to *rv* =0.20 is 68.80 in the strategy SB; however it is 165.42 in the strategy SA.

The *TER* generating the highest profitability differs depending on the *rv* in the strategy SB, similarly to the strategy SA. It is best to set the *TER* to 1,250 in the case that *rv*=0.00, 0.05, 0.10, and 0.15; however, the best value of the *TER* is 1,200 at *rv*=0.20.

Table 3: Average value of the total expected profit obtained by the strategy SB.

| Ratio of deviation from *TGV* (*rv*) | Target expected revenue (*TER*) [MM$] | | | |
|---|---|---|---|---|
| | 1,150 | 1,200 | 1,250 | 1,300 |
| 0.00 | 562.54 | 615.38 | 621.70 | 591.91 |
| 0.05 | 567.22 | 612.03 | 623.29 | 588.37 |
| 0.10 | 567.89 | 613.16 | 624.52 | 582.48 |
| 0.15 | 565.19 | 607.85 | 618.74 | 564.05 |
| 0.20 | 564.62 | 597.51 | 595.75 | 523.11 |

We calculate the average value of the standard deviation of MH for cost estimation as follows:

$$100 \times \sum_{s=1,\ldots,N} (STD\_MH_s / AVE\_MH_s) / N \qquad (12)$$

where $STD\_MH_s$ and $AVE\_MH_s$ are the standard deviation and the average of MH for cost estimation among 15 periods for the sampling *s* in a simulation experiment; *N* is the number of samplings. The standard deviation, which is expressed in percentage of the average of the standard deviation of MH for cost estimation as in Eq. (12), represents the degree of variability in the volume of MH for cost estimation among 15 periods.

Tables 4 and 5 show the value of the standard deviation of MH for cost estimation (see Eq. (12)) for the strategy SA and SB. As shown in Tables 4 and 5, the standard deviation of MH for cost estimation in the strategy SB is smaller than that in the strategy SA in all cases. These results indicate that the strategy SB can secure the stable volume of MH for cost estimation compared to the strategy SA. Since the strategy SB performs better than the Strategy SA on the total expected profit as stated above, we can say that the stable balance of the MH for cost estimation and project execution is effective in improving the total expected profit through a long-term operation in EPC projects.

Table 4: Average value of the standard deviation of MH for cost estimation in the strategy SA.

[%]

| Ratio of deviation from *TGV* (*rv*) | Target expected revenue (*TER*) [MM$] | | | |
|---|---|---|---|---|
| | 1,150 | 1,200 | 1,250 | 1,300 |
| 0.05 | 7.23 | 9.00 | 12.04 | 16.70 |
| 0.1 | 15.00 | 18.46 | 24.40 | 37.02 |
| 0.15 | 22.40 | 28.30 | 38.53 | 65.40 |
| 0.2 | 30.80 | 40.34 | 47.20 | 102.98 |

Table 5: Average value of the standard deviation of MH for cost estimation in the strategy SB.

[%]

| Ratio of deviation from *TGV* (*rv*) | Target expected revenue (*TER*) [MM$] | | | |
|---|---|---|---|---|
| | 1,150 | 1,200 | 1,250 | 1,300 |
| 0.05 | 4.96 | 6.03 | 7.70 | 10.64 |
| 0.1 | 10.52 | 13.17 | 16.68 | 22.95 |
| 0.15 | 16.72 | 20.54 | 26.52 | 37.66 |
| 0.2 | 23.22 | 28.99 | 38.11 | 55.73 |

### 5.5.3 Effectiveness of strategy SC

Table 6 summarises the average value of the total expected profits obtained by the strategy SC through 15 periods. As shown in Table 6, the upper limit (*upl*), where the maximum total expected profit is obtained, is different in each case. In the case that the *TER* is 1,150, the maximum total expected profit is obtained by relaxing the upper limit (*upl*) according to the increase of deviation from *TGV* (*rv*). For instance when *rv*=0.05, the maximum total expected profit is 567.79 at *upl*= 0.1 and that is 564.62 at the unlimited upper limit when *rv*=0.20. In contrast, in the case that the *TER* is 1,300, the maximum total expected profit is obtained by tightening the *upl* according to the increase of deviation from *TGV* (*rv*). For instance when *rv*=0.05, the maximum total expected profit is 590.73 at *upl*= 0.3 and that is 559.80 at *upl*=0.1 when *rv*=0.20.

As shown in Table 3, the optimal *TER* exists in between 1,150 and 1,300 when *rv* is less than or equal to 0.20. When the *TER* is low, the target volume of orders (*TGV*) is also small (see Eq. (10)). Accordingly, when the *TER* is 1,150, the low *upl* keeps the *VAO* away from the optimum and decreases the total expected profit. Moreover, the decrease in the total expected profit is large especially when *rv* is large. In contrast, when the *TER* is 1,300, the low *upl* improves the total expected profit by preventing the excessive *VAO.* In this case, the large *TER* leads to a lack of the MH for cost estimation, and the decreased cost estimation accuracy becomes the critical factor in decreasing the total expected profit. Namely, the tight upper limit on the volume of accepted orders (*VAO*) avoids the excessive volume of expected revenue (*ER*), secures the appropriate volume of MH for cost estimation, and improves the total expected profit.

Table 6: Average value of the total expected profit obtained by the strategy SC.

| Ratio of deviation from *TGV* (*rv*) | Ratio of upper limit (*upl*) | Target expected revenue (*TER*) [MM$] | | | |
|---|---|---|---|---|---|
| | | 1,150 | 1,200 | 1,250 | 1,300 |
| 0.00 | Unlimited, 0.3, 0.2, and 0.1 | 562.54 | 615.38 | 621.70 | 591.91 |
| 0.05 | Unlimited | 567.22 | 612.03 | 623.29 | 588.37 |
| | 0.3 | 566.48 | 611.88 | 623.13 | 590.73 |
| | 0.2 | 567.56 | 612.11 | 622.42 | 589.07 |
| | 0.1 | 567.79 | 611.65 | 625.51 | 588.11 |
| 0.10 | Unlimited | 567.89 | 613.16 | 624.52 | 582.48 |
| | 0.3 | 569.40 | 610.14 | 621.75 | 580.57 |
| | 0.2 | 568.27 | 612.50 | 622.78 | 586.27 |
| | 0.1 | 560.17 | 606.23 | 622.00 | 584.27 |
| 0.15 | Unlimited | 565.19 | 607.85 | 618.74 | 564.05 |
| | 0.3 | 569.45 | 606.99 | 617.32 | 559.48 |
| | 0.2 | 558.37 | 604.34 | 613.94 | 572.62 |
| | 0.1 | 546.95 | 587.66 | 604.97 | 579.18 |
| 0.20 | Unlimited | 564.62 | 597.51 | 595.75 | 523.11 |
| | 0.3 | 557.56 | 598.40 | 606.75 | 540.43 |
| | 0.2 | 546.38 | 591.79 | 600.68 | 550.21 |
| | 0.1 | 525.61 | 574.74 | 587.89 | 559.80 |

### 5.5.4 Comparison of the order acceptance strategies

As shown above, the strategy SA performs worst on the total expected profit among the three strategies. For instance, as shown in Figure 3, when the *TER* is 1250 and *rv*=0.2, the difference in the total expected profit between the strategy SA and SC is 91.02 [MM$]. In addition, as shown in Figure 4, it is 133.31 [MM$] when the *TER* is 1300 and *rv*=0.2. **(**In Figures 3 and 4, the highest total expected profit among *upl* conditions at each *rv* is shown for the strategy SC.) Moreover, by properly adjusting the upper limit (*upl*), the strategy SC can achieve better total expected profit than the strategy SB especially when the *TER* is higher than the optimum. For instance, the strategy SC improves the total expected profit of 11.0 [MM$] compared to the strategy SB when the *TER* is 1250 and *rv*=0.2. However, the strategy SC improves the total expected profit of 36.69 [MM$] compared to the strategy SB when the *TER* is 1300 and *rv*=0.2.

In EPC projects, the contractor usually tries to accept as many orders as possible so as to mitigate the risk of losing many orders under competitive bidding situations. Thus, he tends to accept excessive volume of orders especially when the number of accepted orders has large variability. Since the contractor needs more MH for carrying out the projects of the excessive orders, he loses the balance of available MH for cost estimation and project execution at the following several periods. The reduced MH for cost estimation makes the cost estimation accuracy worse, and decreases the total expected profit.

We conclude that the contractor in EPC projects must control the *VAO* to improve the expected profit through a long-term operation. The MH based order acceptance strategy, which controls the *VAO* based on the *TER* and also the upper limit of the *VAO* in the case of strategy SC, is effective in achieving the appropriate balance of MH for cost estimation and project execution, and thus it improves the total expected profit in the EPC projects.

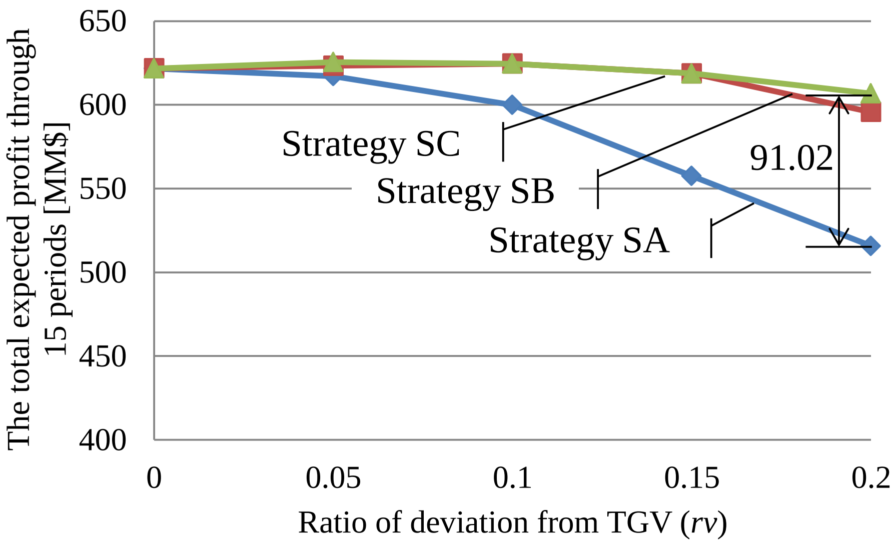

Figure 3: Performance of order acceptance strategies (*TER* : 1,250 [MM$])

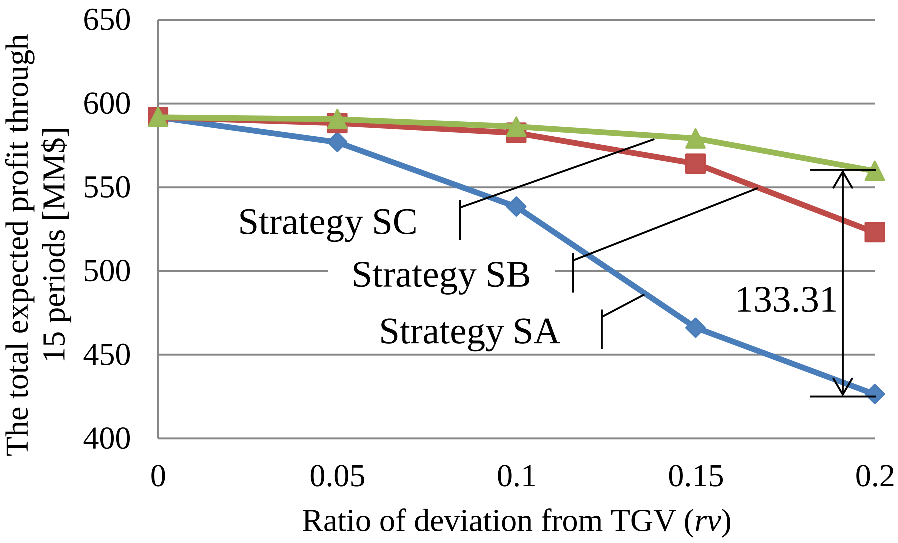

Figure 4: Performance of order acceptance strategies (*TER* : 1,300 [MM$])

# 6 Conclusions

In this paper, we investigate the effects of the order acceptance strategy on the total expected profit through a long-term operation in EPC projects under a competitive bidding situation. For this purpose, we develop three order acceptance strategies, which affect the balance of available MH for cost estimation and project execution in EPC projects. We evaluate the effectiveness of the strategies from the perspective of the total expected profit in EPC projects through a long-term operation by using a simulation model describing the relations among the volume of MH for cost estimation, the accepted orders, revenues, and the profits in EPC projects with competitive bidding.

Based on the simulation experiments, we reveal that the contractor must avoid bidding and accepting excessive orders to improve the expected profit through a long-term operation in EPC projects. Although the contractor usually tries, in practice, to accept as many orders as possible to mitigate the risk of losing many orders in competitive bidding, it is important to maintain the appropriate balance of available MH for cost estimation and project execution for improving the expected profit. Furthermore, we show that the MH based order acceptance strategies, which control the volume of accepted orders (*VAO*) based on the target revenue at each period with the upper limit constraint on the accepted orders, are effective in achieving the appropriate balance of MH under the variability of accepted orders, and thus they improve the expected profit from EPC projects with the competitive bidding.

Managing the balance of MH for cost estimation and projects execution under the variability of accepted orders is critical for the EPC contractor to make a stable profit from accepted projects. Namely, an MH based management framework consisting of the MH based order acceptance strategy, MH monitoring, and MH based scheduling under the constraint of the total volume of MH is worth studying in the future. The MH based scheduling regarding cost estimation and projects execution under the dynamic order arrivals is an especially important issue.

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# APPENDIX

In the simulation module shown in Figure 2, *EP*, *ER*, *EC*, and $TMH^{est}$ at the $i+1$ th period are determined as follows:

$$EP_{i+1} = ER_{i+1} - EC_{i+1} \tag{A1}$$

$$ER_{i+1} = \sum_{j=i-ncp+1}^{i} TGV_j \cdot ROER_j^{i+1} \tag{A2}$$

$$EC_{i+1} = \alpha_3 \cdot PEC \cdot \sum_{j=i-ncp+1}^{i} NAO_j \cdot ROER_j^{i+1} + \beta_2 \cdot OS_{i+1} + FC \tag{A3}$$

where *ncp* is the number of periods to complete the project of the accepted order; $ROER_j^{i+1}$ is the rate of revenues at the $i+1$ th period on the accepted orders at the *j*-th period determined as $ROER_j^{i+1} = 1/ncp$; $\alpha_3$ is the rate of materials & labour cost; *PEC* is the project cost determined by Eq. (A4); $NAO_j$ is the positive real value, meaning the number of accepted orders at the *j*-th period; $\beta_2$ is the out sourcing MH rate; $OS_{i+1}$ is the out sourcing MH determined by Eq. (A5); and *FC* is the fixed cost.

$$PEC = \mu_1 /(1+ROP) \tag{A4}$$

$$OS_{i+1} = TMH_{i+1}^{exe} + TMH_{i+1}^{est} - MH_{i+1}^{T} \tag{A5}$$

s.t.

$OS_{i+1} = 0$ in case of $TMH_{i+1}^{exe} + TMH_{i+1}^{est} \le MH_{i+1}^{T}$

where $\mu_1$ is the bidding price without cost estimation error; *ROP* is the rate of profit; $TMH_{i+1}^{exe}$ is total MH for carrying out all the projects at the $i+1$ th period as determined by Eq. (A6); $TMH_{i+1}^{est}$ is the total MH for cost estimation at the $i+1$ th period as determined by Eq. (A7); and $MH_{i+1}^{T}$ is the total in-house MH at the $i+1$ th period.

$$TMH_{i+1}^{exe} = \alpha_1 / \beta_1 \cdot PEC \cdot \sum_{j=i-ncp+1}^{i} NAO_j \cdot ROER_j^{i+1} \tag{A6}$$

$$TMH_{i+1}^{est} = MH_{i+1}^{S} - \alpha_2 \cdot TMH_{i+1}^{exe} \tag{A7}$$

s.t.

$TMH_{i+1}^{est} = 0$ in case of $MH_{i+1}^{S} \le \alpha_2 \cdot TMH_{i+1}^{exe}$

where $\alpha_1$ is the rate of MH cost, $\beta_1$ is the in-house MH rate; $\alpha_2$ is the rate of senior engineer MH to carry out projects; and $MH_{i+1}^{S}$ is the in-house senior engineer MH at the $i+1$ th period.