A STRATEGY FOR ACCEPTING ORDERS IN ETO MANUFACTURING WITH COMPETITIVE BIDDING

Analysis of Bidding Strategy and Expected Profits via Multi-Period Operations

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Abstract: In Engineer-To-Order manufacturing with competitive bidding, improving cost estimation accuracy is necessary for the contractor to gain highly expected profits from accepted orders. Thus, it is critical to maintain the number of human resources required for cost estimation. However, the human resources are also required for execution of the accepted orders. Namely, in the Engineer-To-Order manufacturing, a balance of common resources for cost estimation in yielding the future profits and for execution of the accepted orders is essential for making a stable profit. In this paper, we build a mathematical model describing relations among cost estimation accuracy, order acceptance, sales, and profits through multi-period operations in consideration of characteristics of competitive bidding. Using our model, we analyse the relations between the volume of human resources allocated for the cost estimation and the expected profits from the accepted orders as well as the effect of a strategy for accepting orders on the expected profits through multi-period operations.

1 INTRODUCTION

Nowadays, the importance of Engineer-To-Order (ETO) manufacturing (Kolisch, 2001) or project-based manufacturing (Project Management Institute, 2008), where a selected contractor designs and builds unique products or services based on the client requirements, such as construction, civil engineering, plant engineering, industrial machinery, is widely recognized in practice.

In ETO manufacturing, a contractor is usually selected by a client through a competitive bidding process (Friedman, 1956; Ioannou and Leu, 1993; Rothkopf and Harstad, 1994). Namely, the client prepares a Request For Proposal (RFP) for the order and invites several potential contractors to the bidding. The client usually 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. Then, the client basically selects the contractor who proposes the lowest price if there is not much difference in other criteria.

In ETO manufacturing, accordingly, it is necessary for any contractor to decide the bidding price based on accurate cost estimation. 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 loss on this order.

Cost estimation, however, is a highly intellectual task of predicting the costs of products or services to be provided in the future based on the analysis of the client's requirements and their tacit knowledge. So, 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 orders will also need considerable MH to carry them out successfully.

If the contractor eventually accepts too many

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orders during a particular period and cannot maintain the sufficient MH for estimating cost accurately at the following periods to carry out the accepted orders, the profits of orders to be accepted at the following periods would decrease because the probability of accepting lower profit orders increases according to the decrease of cost estimation accuracy in competitive bidding. Thus, the contractor suffers unstable and low profits during several periods.

For these reasons, it is important to realize the appropriate balance of available MH for the cost estimation and execution of accepted orders to result in a stable profit through successive multi-period operations. However, most of the literature dealing with ETO manufacturing has assumed that the contractor can select orders according to his criteria by the contractor's initiative without competitive bidding. In practice, however, the contractor basically offers a bidding price in competitive bidding and then receives the order by the client's decision. In addition, most literature on the competitive bidding does not consider the relations between the cost estimation accuracy associated with the cost estimation MH and the expected profits from the accepted orders.

In this paper, we analyse the relations among cost estimation MH, order acceptance, and expected profits through successive multi-period operations in competitive bidding by using the Multi-Period Order Acceptance (MPOA) and Profit model. In addition, we discuss tools and techniques required to make a stable profit and assure sustainability in ETO manufacturing.

2 A MODEL OF COMPETITIVE BIDDING PROCESS

There are several ways to select a contractor in competitive bidding (Elfving et al., 2005; Helmus, 2008; Wang et al., 2009). In a generic competitive bidding process, shown in Figure 1, the client prepares RFP, and invites several potential contractors to the bidding. The contractor first carries out the preliminary analysis followed by the bid or no-bid decision. In the preliminary analysis, the contractor evaluates the RFP and estimates the preliminary cost based on limited information such as the order information included in the RFP and the past project data of the contractor. In the bid or no-bid decision, the contractor evaluates the order from the viewpoints of profitability, technical feasibility and so on, and makes a decision whether to bid or not. If the contractor decides to place the bid, then he starts the bidding price decision process, that is, he estimates the cost more accurately and determines the bidding price. At the end of the competitive bidding, the client assesses the proposals offered by contractors and selects a contractor as the successful bidder. The selected contractor carries out the accepted order using his resources.

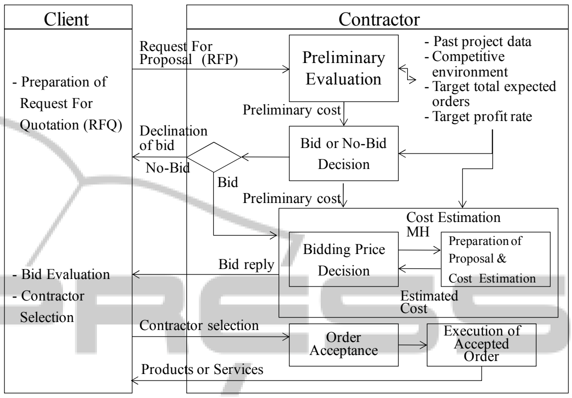

Figure 1: An overview of competitive bidding and execution of accepted orders.

3 MODELS OF ORDER ACCEPTANCE AND PROFITS IN ETO MANUFACTURING

3.1 A Cost Estimation Accuracy Model

Since the cost estimation requires a detailed analysis conducted by experienced engineers, it can be seen that the volume of MH for cost estimation affects the cost estimation accuracy significantly. In fact, Towler and Sinnott (2008), Gerrard (2000) suggest that the cost estimation accuracy is positively correlated with the volume of cost estimation MH. It is also clear that the marginal rate of cost estimation accuracy approaches zero according to the increase of the volume of MH. Thus, in this paper, we define the cost estimation accuracy (σ) as the function of the cost estimation MH per order (*PMH*) based on the logistic curve as follows:

$$\sigma(PMH) = \frac{\sigma_{\min} \cdot \sigma_{\max}}{\sigma_{\max} + (\sigma_{\min} - \sigma_{\max}) \cdot e^{-C \cdot PMH}} \quad (PMH > 0.0) \tag{1}$$

where σ_{min}, σ_{max}, and C are the minimum and the maximum value of the standard deviation of the bidding price or the order execution cost (*OEC*), and a parameter of the logistic curve. These parameters could be determined from the past records.

3.2 A Multi-Period Order Acceptance and Profit Model

In this paper, as shown in Figure 2, we set the target volume of orders (TCT_i), and calculate the expected total revenue (ER_i), the expected total cost (EC_i), the expected total profits (EP_i) of each i-th period using the MPOA and Profit model based on the following assumptions. EC_i consists of materials and labour cost, outsourcing MH cost, and fixed cost consisting of in-house MH cost and overhead cost.

Model Assumptions:

- MH can be divided into regular engineers' MH and senior engineers' MH,
- MH of a certain percentage or more must be senior engineers' MH for executing the accepted orders,
- Only senior engineers can estimate cost, and no outsourcing MH is available for the cost estimation.

Namely, we calculate ER_i, EC_i, and EP_i, repeatedly from the 1st to fp (>1) periods, based on the accepted order data until the i-th period, such as the number of orders satisfying TCT_i and the cost estimation accuracy at the i-th period. In addition, we evaluate the cost estimation accuracy based on the number of orders and the total cost estimation MH (TMH_i^{est}) obtained by subtracting total order execution MH (TMH_i^{exe}) from the total MH available at the i-th period. We present the detailed explanation of the model in APPENDIX.

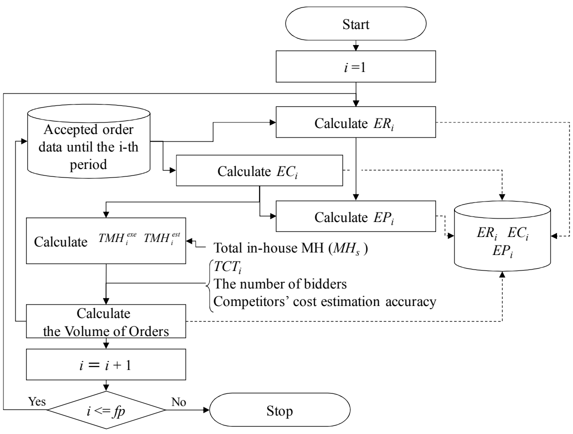

Figure 2: An overview of Multi-Period Order Acceptance (MPOA) and Profit model.

4 MODELS OF ORDER ACCEPTANCE AND PROFITS IN ETO MANUFACTURING

4.1 Cost Estimation Accuracy and Expected Profit

We analyse the relations among cost estimation MH, cost estimation accuracy, and expected profit based on the case data shown in Table 1. Namely, we calculate the cost estimation accuracy by Eq. (1), the expected value of accepted order by Eq. (2), and the expected profit by subtracting the OEC from the expected order.

$$EPT^{awd} = \frac{\int_0^{+\infty} x_1 \cdot p_1(x_1,\mu_1,\sigma_1)\cdot \prod_{k=2}^{n}\int_{x_1}^{+\infty} p_k(x_k,\mu_k,\sigma_k)dx_k \cdot dx_1}{\int_0^{+\infty} \prod_{k=2}^{n}\int_{x_1}^{+\infty} p_k(x_k,\mu_k,\sigma_k)dx_k \cdot dx_1} \quad (2)$$

where k is the contractor (k =1: his own company, k >=2: competitors), p_k (x_k, μ_k, σ_k) is the probability density of the bidding price (x_k) of the contractor (k), and its average value and standard deviation are μ_k and σ_k (cost estimation accuracy), respectively. As shown in Eq. (2), the expected value of the accepted order is the average value of one's own company's bidding price falling below those of all other competitors (k>=2).

Figure 3 shows the results of the calculations. We can see that the higher accuracy of cost estimation, i.e., lower deviation, increases the expected profits. The expected profits decrease according to the increase of the number of competitors. Namely, we can conclude that the probability of accepting lower profit order increases according to the decreasing cost estimation MH and cost estimation accuracy. On the other hand, the contractor can expect improved profit by investing MH for the cost estimation under the severe competitive environment with many competitors.

Table 1: Case data for evaluation of cost estimation accuracy and expected profit.

The number of bidders (n)	2 or 3 bidders including one's own company
Probability density of the bidding price	Normal distribution
Order execution cost (OEC)	100 [MM$/Order]
Parameters of Eq. (1)	σ_{min} : 0.5% of OEC, σ_{max} : 20% of OEC, C : 0.25
Parameters of Eq. (2)	μ_k (including profit) : 110, σ_k (k>=2) : 5 [MM$]

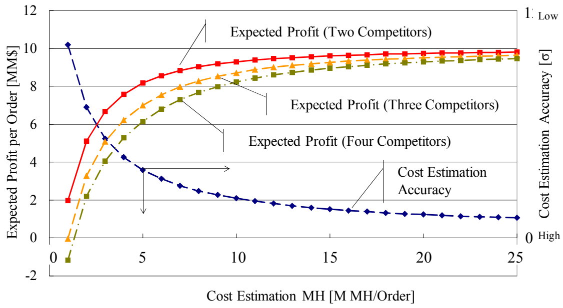

Figure 3: Relations among cost estimation MH, cost estimation accuracy, and expected profits.

4.2 Multi-Period Evaluation on Order Acceptance and Expected Profits

We analyse the relations between the order acceptance and the expected profits through successive multi-period operations using the MPOA and Profit model, shown in Figure 2 and APPENDIX. Table 2 shows the conditions of a model company for this analysis.

We use two scenarios to compare profits based on two different strategies for accepting orders, i.e., the high-order strategy (Case A), and the stable-order strategy (Case B). The contractor tries to get orders as many orders as possible at every period under the high-order strategy. In contrast, the contractor controls the volume of accepted orders at a certain level via a multi-period basis in the case of stable-order strategy. Namely, in Case A, the volume of the order acceptance is set to 1,800 [MM$] at the 3rd period and to 1,200 [MM$] at other periods. In Case B, the volume of the order acceptance is set to 1,800 [MM$] at the 3rd period, to 600 [MM$] at the 4th period, and to 1,200 [MM$] at other periods, to control the accepted orders through entire periods as the 1,200 [MM$/Period] level.

Figures 4 and 5 show the orders, revenues, and total costs over the periods, respectively, in Cases A and B. In addition, Figure 6 shows a comparison of profits in Case A and Case B over the periods.

As shown in Figures 4 and 6, in Case A, the increased accepted orders at the 3rd period improves revenues of the following three periods. Profits also increase at the 4th period. However, profits start decreasing from the 5th period, and it takes seven periods to recover the profits at the 3rd period level. If the same profit levels are maintained at the same level of those of the 3rd period for 12 periods, the total profits are 335 [MM$]. However, the increased accepted orders at the 3rd period reduce profits during the 6th to the 12th periods, and the total profits for 12 periods are 190 [MM$] in Case A. In contrast, as shown in Figures 5 and 6, the total profits for 12 periods are 318 [MM$] in Case B. The decline in profits after the 4th period in Case A occurred because of the reduced cost estimation MH by the increased MH requirements for executing the orders accepted at the 3rd period. Namely, the reduced cost estimation MH decreases the cost estimation accuracy, and thus the profits are reduced as presented in the previous section. In Case B, since the order acceptance at the 4th period is controlled, and cost estimation MH is sufficiently maintained to estimate cost accurately, the loss of profits is reduced in comparison to that of Case A.

We can conclude based on these observations that the strategy for accepting an adequate volume of orders via multi-period operations is effective to avoid decreasing cost estimation MH and cost estimation accuracy, and thus a stable profit is the end result.

Most contractors, in practice, tend to take a high-order strategy. However, this strategy could reduce cost estimation accuracy and reduce profits as presented in this section. Namely, contractors in ETO manufacturing should establish a strategy for accepting orders in consideration of the balance of MH for the cost estimation and execution of the accepted orders via multi-period operations.

Table 2: Conditions of model company.

Rate of the i-th period revenue on the accepted orders at the j-th period ($ROER_i^j$)	0.333
The number of bidders (*n*) including one's own company	3 bidders
Periods for sales of accepted order (*NST*)	3 Successive periods
Evaluation period	-2 (*1-NST*) to 12
Probability density of the bidding price	Normal distribution
Order execution cost (*OEC*)	100 [MM$ /order]
Rate of profit (*ROP*)	10%
Rate of MH cost (α_1)	10%
Rate of materials & labour cost (α_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 for carry out orders (α_2)	30%
In-house and out sourcing MH rate (β_1, β_2)	100 [$/MH]
Parameters of Eq. (1) and Eq. (2) are shown in Table 1.	

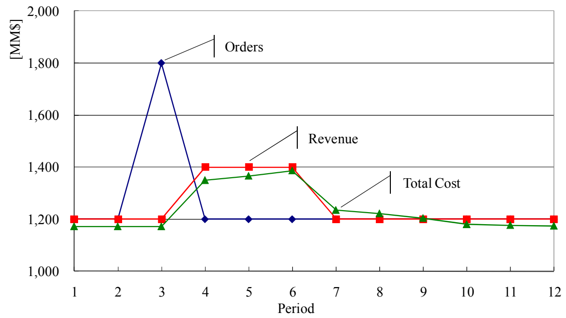

Figure 4: Orders, revenues, and costs over the periods (Case A).

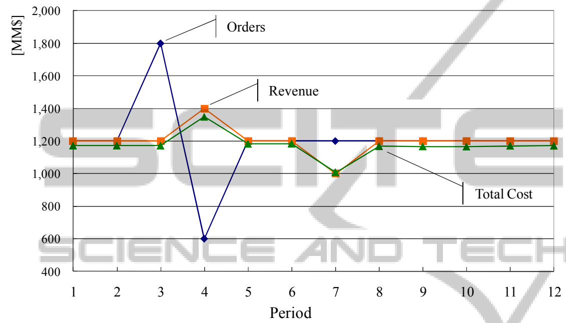

Figure 5: Orders, revenues, and costs over the periods (Case B).

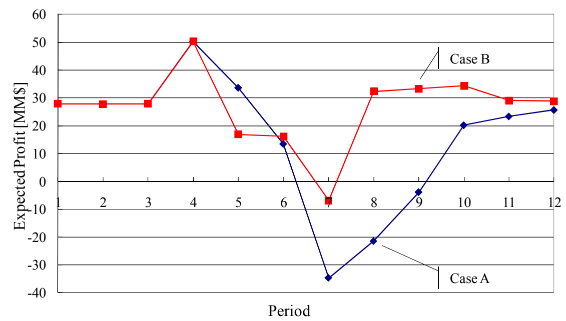

Figure 6: Comparison of profits (revenue-total cost of each period) in Case A and Case B over the periods.

5 CONCLUSIONS

In this paper, we analyse the relations among cost estimation MH, order acceptance, and expected profits through successive multi-period operations in ETO manufacturing with competitive bidding by using the Multi-Period Order Acceptance (MPOA) and Profit model.

Namely, we reveal that the cost estimation accuracy affects the expected profits from the accepted orders, and the contractor needs to maintain MH for cost estimation to make a stable profit through successive multi-period operations in ETO manufacturing. Furthermore, we show that accepting too many orders by the high-order strategy decreases the expected profits at the following periods. This is because the contractor needs more MH to carry out the accepted orders, and thus the MH for cost estimation at the period is reduced, and then the low cost estimation accuracy results in the low expected profits from the accepted orders based on the estimation in competitive bidding.

For these reasons, we conclude that the contractor should manage the volume of accepting orders in consideration of the MH allocation for the cost estimation and the execution of accepted orders through successive multi-period operations, such as the stable-order strategy to make a stable profit.

There are several issues which require further research. For example, the strategy for accepting orders effectively to maximize expected profits through successive multi-period operations in ETO manufacturing with competitive bidding should be examined in detail. The bidding price decision process to maximize the expected profits with MH constraint should also be established. In addition, tools and techniques to support the strategy and the bidding process should be studied and implemented in practice.

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APPENDIX

EP_i, ER_i, and, EC_i at the i-th period are determined as follows:

$$EP_i = ER_i - EC_i \quad \text{(A1)}$$

$$ER_i = \sum_{j=i-NST}^{i-1} TCT_j \cdot ROER_j^i \quad \text{(A2)}$$

$$EC_i = \alpha_3 \cdot OEC \cdot \sum_{j=i-NST}^{i-1} NAP_j \cdot ROER_j^i + \beta_2 \cdot OS_i + FC \quad \text{(A3)}$$

where NST is the periods for sales of the accepted order; $ROER_j^i$ is the rate of the i-th period revenues on the accepted orders at the j-th period; α_3 is the rate of materials & labour cost; OEC is the order execution cost determined by Eq. (A4); NAP_j is the positive real value meaning the number of orders satisfying TCT_j at the j-th period; β_2 is the out sourcing MH rate; OS_i is the out sourcing MH determined by Eq. (A5); and FC is the fixed cost. Since NST is the same positive integer for all orders in this model, $ROER_j^i$ is determined as $ROER_j^i = 1/NST$.

$$OEC = \mu_1 / (1 + ROP) \quad \text{(A4)}$$

$$OS_i = TMH_i^{exe} + TMH_i^{est} - MH_T \quad \text{(A5)}$$

s.t. $OS_i = 0$ in case of $TMH_i^{exe} + TMH_i^{est} \le MH_T$

where μ_1 is the bidding price without cost estimation error; ROP is the rate of profit; TMH_i^{exe} is total order execution MH at the i-th period as determined by Eq. (A6); TMH_i^{est} is the total cost estimation MH at the i-th period as determined by Eq. (A7); and MH_T is the total in-house MH at the i-th period.

$$TMH_i^{exe} = \alpha_1 / \beta_1 \cdot OEC \cdot \sum_{j=i-NST}^{i-1} NAP_j \cdot ROER_j^i \quad \text{(A6)}$$

$$TMH_i^{est} = MH_S - \alpha_2 \cdot TMH_i^{exe} \quad \text{(A7)}$$

s.t. $TMH_i^{est} = 0$ in case of $MH_S \le \alpha_2 \cdot TMH_i^{exe}$

where α_1 is the rate of MH cost, β_1 is the in-house MH rate; α_2 is the rate of senior engineer MH to carry out orders.
NAP_j is determined by the Eq. (A8):

$$NAP_j = TCT_j / EPT_j^{awd} \quad \text{(A8)}$$

where EPT_j^{awd} is the expected value of accepted order determined by Eq. (2).
In the Eq. (2), σ_1 is determined by Eq. (1) as the cost estimation accuracy at PMH_j determined by Eq. (A9).

$$PMH_j = TMH_j^{est} / NP_j \quad \text{(A9)}$$

where NP_j is the positive integer showing the number of bidding orders which maximizes the expected profit at TCT_j condition.