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A TWO-STEP BIDDING PRICE DECISION ALGORITHM UNDER LIMITED MAN-HOURS IN EPC PROJECTS

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Overview of the Presentation

① Background & Objectives
② Related work
③ Bidding price decision problem in EPC project
④ A two-step bidding price decision algorithm
⑤ Numerical examples
⑥ Summary & Conclusions

Background

EPC（Engineering-Procurement-Construction） Project from contactor’s standpoint

- Contractors design and build unique products based on the client requirements
- Contractor has a solo responsibility for QCD under a fixed-price before the start of the project as a lump-sum contract
- Contractor is selected by client through competitive bidding

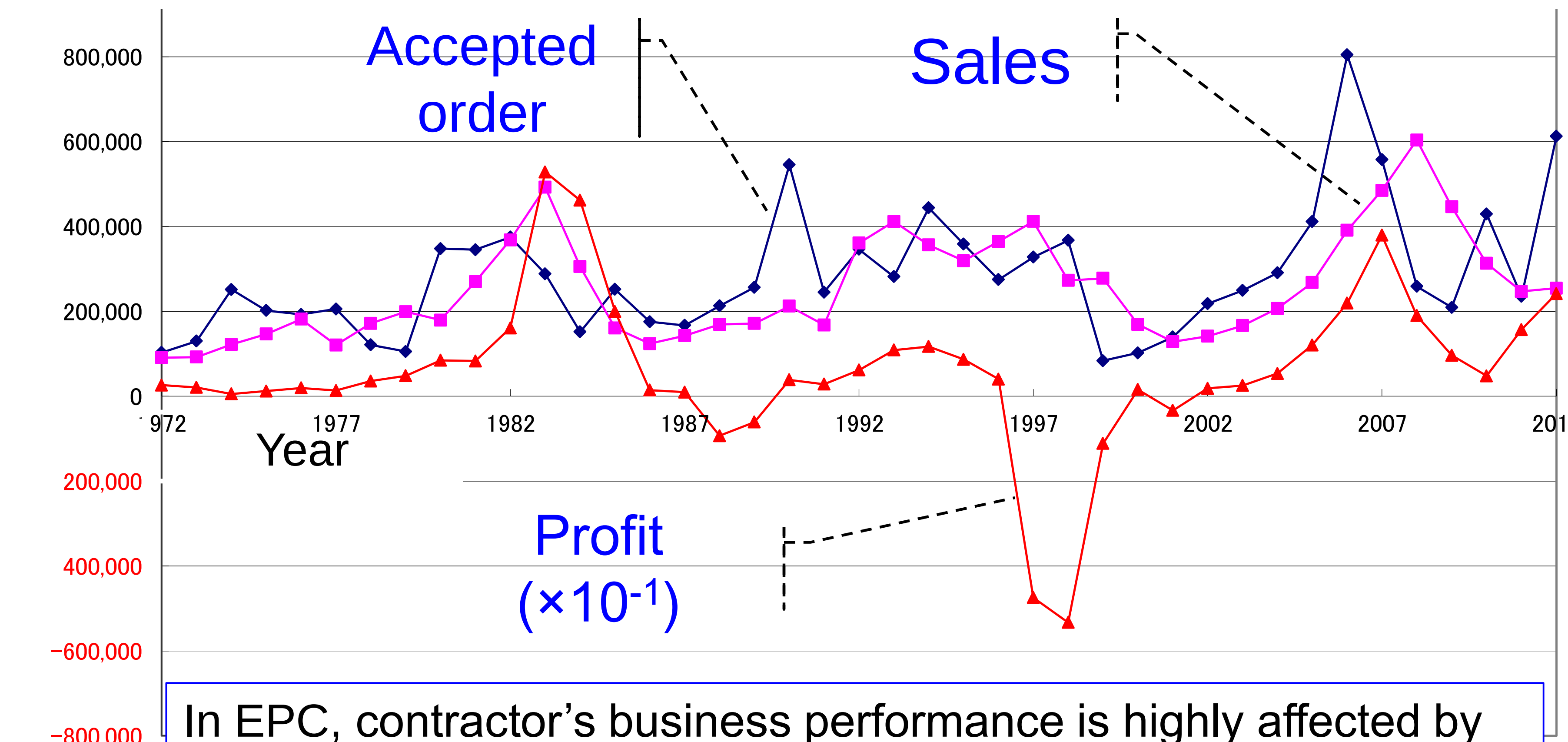
Background

＜Typical Example of EPC Project＞

Construction, Civil engineering, Plant Engineering, Information System Development, etc.

Background

Instability of EPC Contractor's Bisiness Financial Results



In EPC, contractor's business performance is highly affected by the market conditions and competitors' situations.
Stable profit is critical for any contractor to improve sustainability.

Background

For stabile profit, Contractor must determine the bidding price based on precise cost estimation

- In Case of Over Estimation (inaccurate estimation):
  - ✓ Contractor could not accept the order and hence obtain no profit.
- In Case of Under Estimation (inaccurate estimation):
  - ✓ Contractor would increase the chance of accepting the order.
  - ✓ However, the profit could be below the contractor’s expectation, and possibly suffers a loss on this order.

Background

For accurate cost estimation, experienced and skilled human resources, i.e., engineering MH (Man-Hour) for cost estimation, are required.

↕

MH allocation is a challenge for contractor to gain stable profit from EPC projects

The volume of total MH for cost estimation is limited.

Background

In addition;

In EPC Projects, just a few deficit orders would result in the significant reduction of realized profits when the number of accepted orders is limited.

↓

Adjustment of bidding price based on cost estimation accuracy & a relationship with bidders are critical.

Note, in this paper, that we refer to the order creating an eventual loss as a deficit order.

Background

Two Points to gain stable profit from EPC projects.

Requirements to bidding decision to gain stable profit from EPC projects.

① Appropriate allocation of MH for cost estimation to each order under the limited volume of total MH

② Bidding price adjustment based on cost estimation accuracy and competitors information

Most of the literature on bidding price in EPC projects does not consider the above points.

Research Objectives

Develop a bidding price decision algorithm to gain stable profit from EPC projects based on the requirements from background on EPC projects.

① Appropriate allocation of MH for cost estimation to each order under the limited volume of total MH

② Bidding price adjustment based on cost estimation accuracy and competitors information

Bidding price decision problem in EPC project

① A generic competitive bidding process

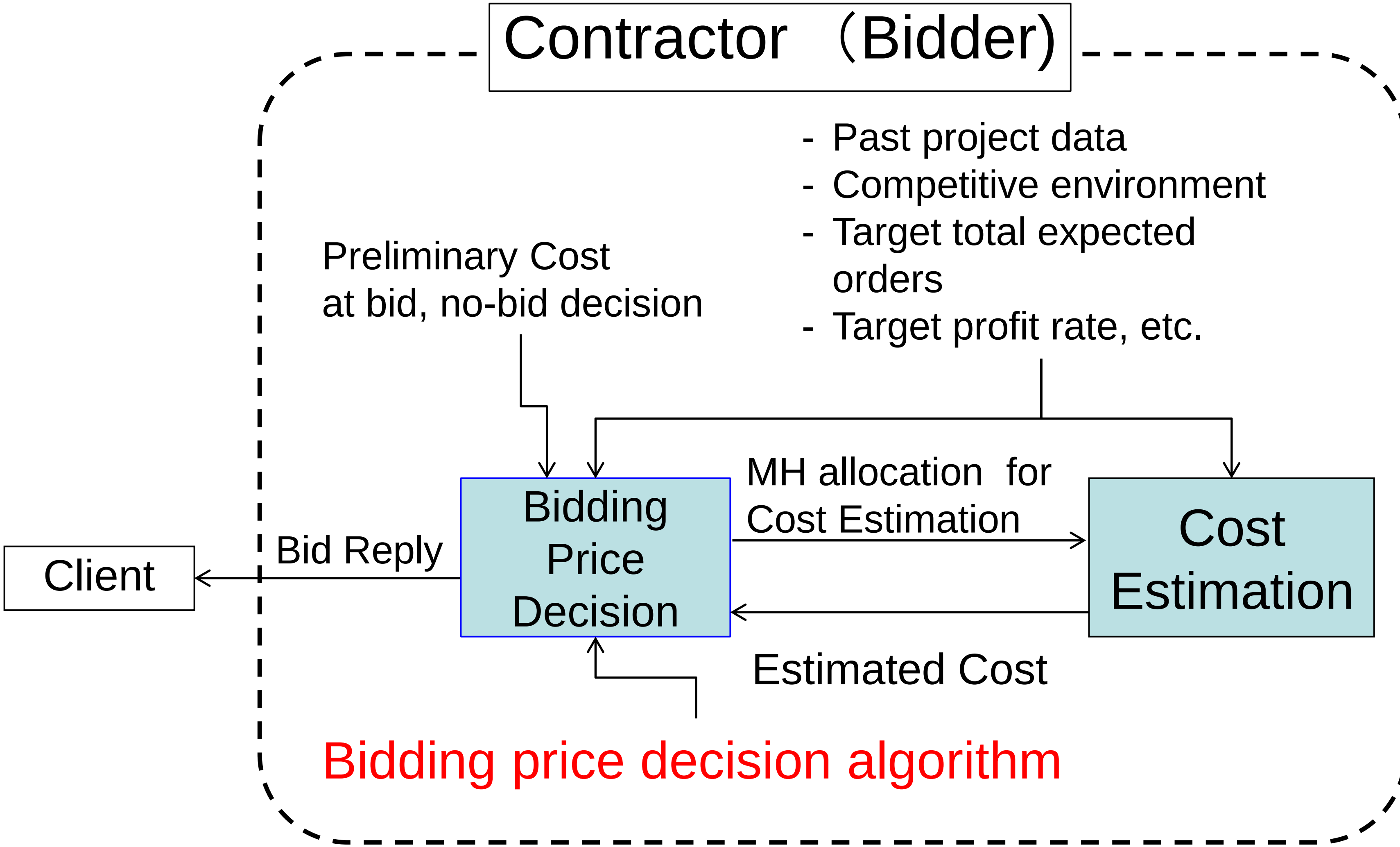
② Features of bidding price decision problem

a. Accuracy of cost estimation

b. MH allocation for cost estimation

c. Adjustment of bidding price

Relations among bidding price decision, related Information & Bidding price decision algorithm



Features of Bidding Price Decision Problem

(1) Accuracy of cost estimation

The bidding price is determined by adding the target profit to the estimated cost.

Contractor cannot estimate the precise cost because of limited information and restricted time.

The bidding price has a "probability distribution".

Features of Bidding Price Decision Problem

Cost estimation accuracy:
Standard deviation of the estimated cost
or the bidding price.

A lower deviation indicates a higher accuracy.

Features of Bidding Price Decision Problem

(2) MH allocation for cost estimation

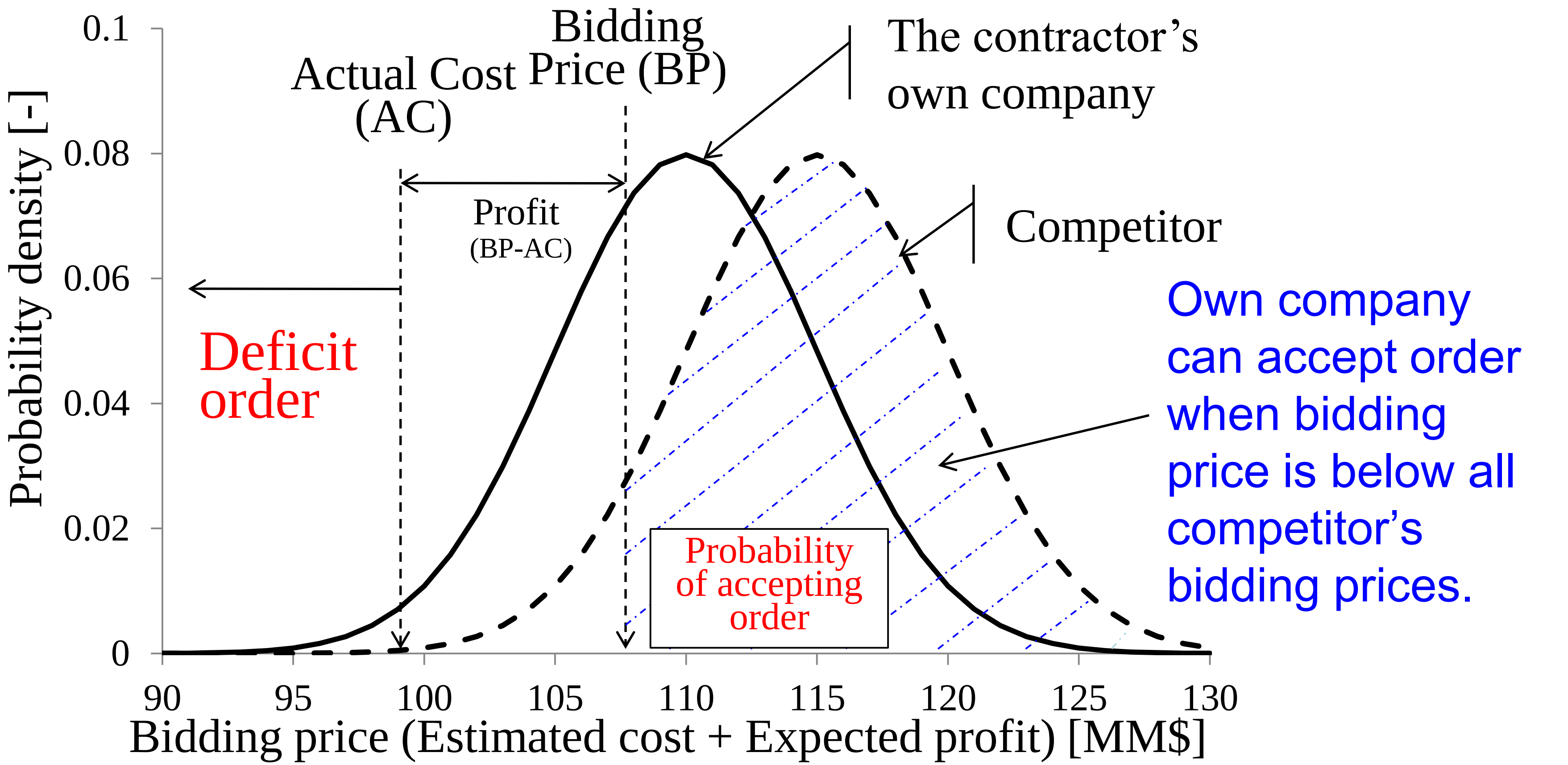
- ✓ The volume of MH for cost estimation affects its accuracy significantly
- ✓ MH of experienced engineers is limited
- ✓ Bidding conditions are different in each order

⇩

Contractor needs to **prioritize orders & allocate more MH to the potential orders** to improve the expected profits.

Features of Bidding Price Decision Problem

(3) Adjustment of bidding price



Contractor's expected profit can be maximized by adjusting the price under a competitive environment

A Mathematical Model on Bidding Price Based on Bidding Price Decision Process Model

Equations for using simulation:

① Cost Estimation Accuracy Model (E1. (1))
② Tentative bidding price (Eq. (2))
③ The expected volume of order (Eq. (3))
④ The expected profit (Eq. (4), (5))
⑤ The deficit order probability (Eq. (6), (5))

Cost Estimation Accuracy Model

<Assumptions of the logistic curve model> Eq. (1)

- Cost estimation accuracy is positively correlated with the volume of cost estimation MH.
- Marginal rate of cost estimation accuracy approaches zero according to the increase of the volume of MH.

Cost estimation accuracy

$$\sigma(TMH) = \frac{\sigma_{\min} \cdot \sigma_{\max}}{\sigma_{\max} + (\sigma_{\min} - \sigma_{\max}) \cdot e^{-C \cdot TMH}}$$

Volume of MH for cost estimation

Parameter

Lower σ

➔ Higher accuracy

Tentative (average) bidding price (Eq. (2))

Risk parameter to adjust bidding price

$$TBP_k^i = STD_i \cdot (1 + RC_k^i) \cdot (1 + e\_profit_k^i) \cdot rp_k^i$$

k: Contractor (*k*=1: Own company *k*>=2: Competitor)
i : Order
STD : Standard order cost
RC: Relative cost difference from *STD* in competitors
e_profit: Target profit rate
rp: Value of risk parameter

The expected volume of order (Eq. (3))

Expected value of bidding price

Probability of accepting order

$$\int_0^{+\infty} x_1^i \cdot p_1(x_1^i, TBP_1^i, \sigma_1^i) \cdot \prod_{k=2}^{n} \int_{x_1^i}^{+\infty} p_k(x_k^i, TBP_k^i, \sigma_k^i) dx_k^i \cdot dx_1^i$$

k: Contractor (*k*=1: Own company *k*>=2: Competitor)

i : Order

p : Probability density of the bidding price

x : Bidding price   *TBP* : Tentative bidding price

σ : Cost estimation accuracy

The expected profit (Eq. (4), (5))

Expected profit when order accepted

Probability of accepting order

$$\int_0^{+\infty}(x_1^i - STDR_1^i)\cdot p_1(x_1^i, TBP_1^i, \sigma_1^i)\cdot\prod_{k=2}^{n}\int_{x_1^i}^{+\infty} p_k(x_k^i, TBP_k^i, \sigma_k^i)dx_k^i \cdot dx_1^i$$

$$STDR_k^i = STD_i \cdot (1 + RC_k^i)$$

k: Contractor (*k*=1: Own company *k*>=2: Competitor)

i : Order

p : Probability density of the bidding price

x : Bidding price *TBP* : Tentative bidding price

σ : Cost estimation accuracy

STD : Standard order cost

RC: Relative cost difference from *STD*

The deficit order probability (Eq. (6), (5))

Probability of deficit — Probability of accepting order

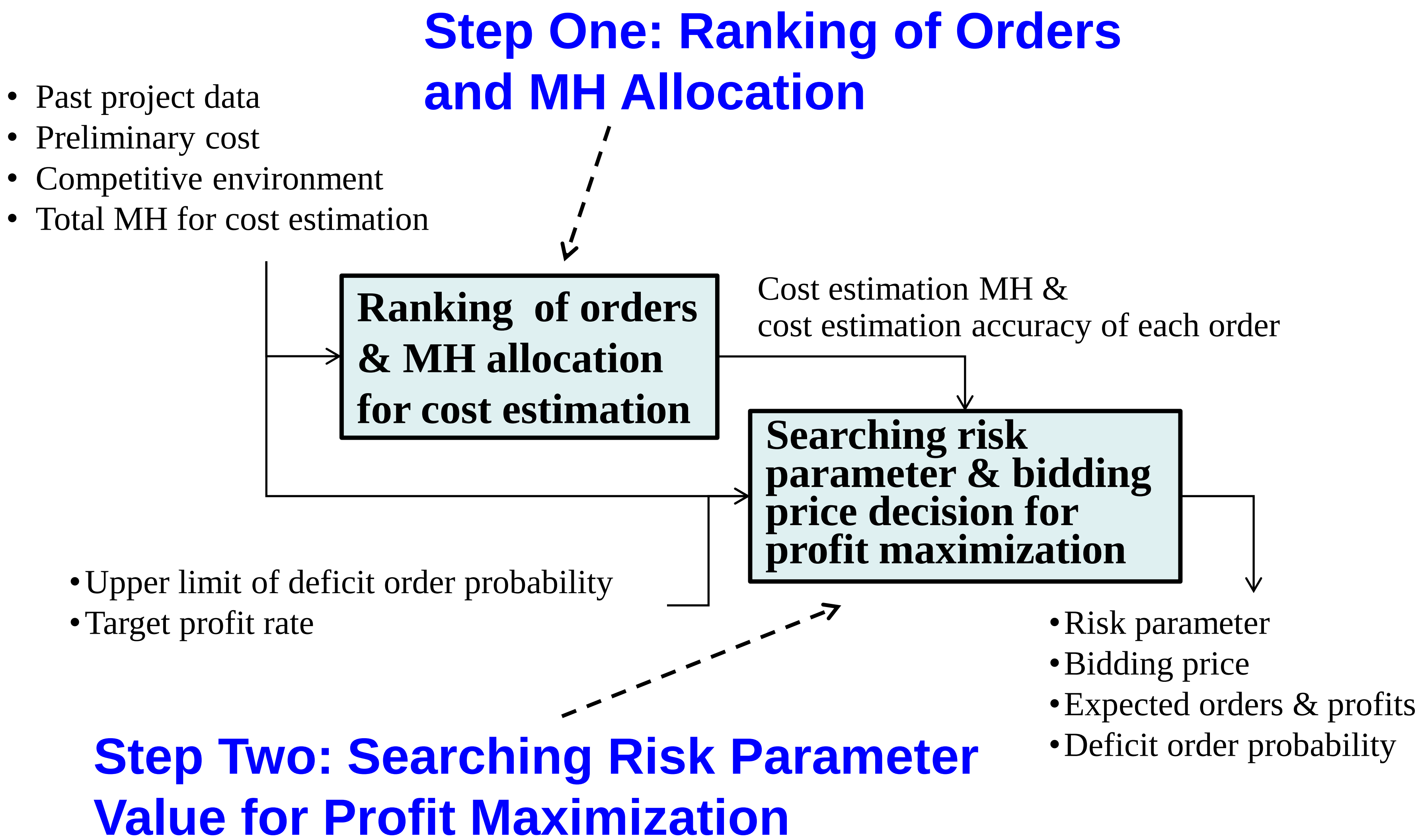
$$\int_0^{STDR_1^i} p_1(x_1^i, TBP_1^i, \sigma_1^i) \cdot \prod_{k=2}^{n} \int_{x_1^i}^{+\infty} p_k(x_k^i, TBP_k^i, \sigma_k^i) dx_k^i \cdot dx_1^i$$

$$STDR_k^i = STD_i \cdot (1 + RC_k^i)$$

k: Contractor (*k*=1: Own company *k*>=2: Competitor)
i : Order
p : Probability density of the bidding price
x : Bidding price σ : Cost estimation accuracy
STD : Standard order cost
RC: Relative cost difference from *STD*
e_profit: Target profit rate
rp: Value of risk parameter

A Two-Step Bidding Price Decision Algorithm Using A Mathematical Model on Bidding Price

A Two-Step Bidding Price Decision Algorithm



Step One: Ranking of Orders and MH Allocation

Ranking of Orders (Eq. (7), (8))

Define ranking score (*Score*) of order (*i*) as expected profit based on tentative bidding price (*TBPF*) estimated at *rp* =1.0.

Probability of accepting order

$$Score_i = TBPF_1^i \cdot \prod_{k=2}^{n} \int_{TBPF_1^i}^{+\infty} p_k(x_k^i, TBPF_k^i, \sigma_k^i) dx_k^i$$

$$TBPF_k^i = STD_i \cdot (1 + RC_k^i) \cdot (1 + e\_profit_k^i)$$

Note: we can modify the ranking score in consideration of multiple criteria besides the expected profit, such as technical feasibility, relationship with clients, and so on.

Step One: Ranking of Orders and MH Allocation

Overview of MH Allocation Procedure

- ✓Order with the high *Score* is ranked high because such an order is expected to generate a large profit.
- ✓Consider three grades of accuracy & Assign one of them to each order

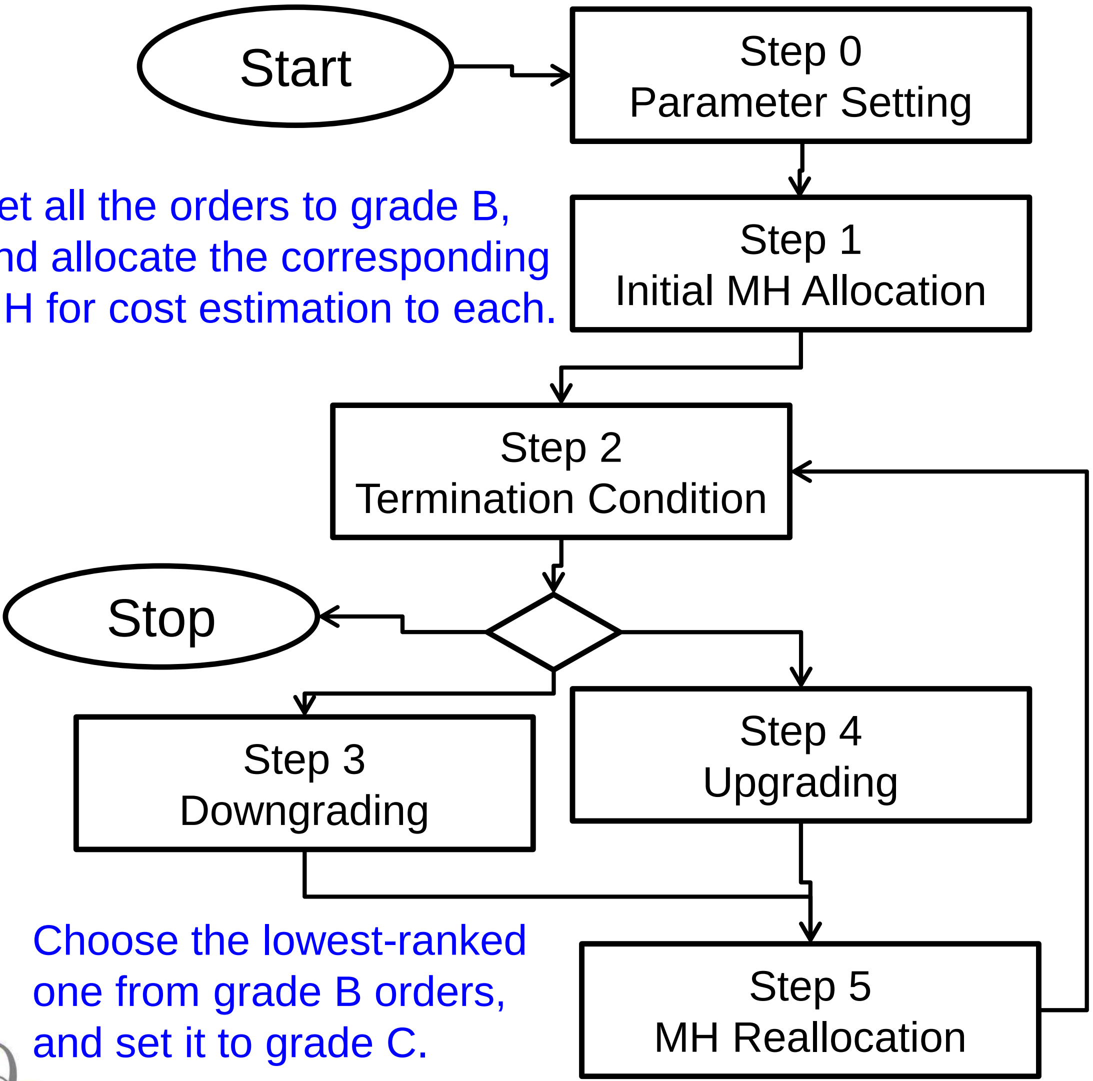
  Grade A (high accuracy)

  Grade B (average)

  Grade C (low accuracy)

Step One: Ranking of Orders and MH Allocation

Detailed MH Allocation Procedure



Set range of allowable total MH for cost estimation, and set accuracy level from (σ_{min}, σ_{max}) to each grade.

Set all the orders to grade B, and allocate the corresponding MH for cost estimation to each.

Calculate total MH (*TMR*).

- ✓If *TMR* is within the range of allowable total MH, stop the procedure with the current MH allocation.
- ✓If *TMR* is above the allowable range, go to Step 3.
- ✓If *TMR* is below the allowable range, go to Step 4.

Choose the highest-ranked one from grade B orders, and set it to grade A.

Choose the lowest-ranked one from grade B orders, and set it to grade C.

Reallocate MH for cost estimation to each order.

Step Two: Searching Risk Parameter Value for Profit Maximization

Search the value of *rp* by solving the following optimization problem based on MH allocation determined at Step 0ne.

Maximize Expected profit (Eq. (9))

$$\sum_{i=1}^{L}\int_{0}^{+\infty}(x_1^i - STDR_1^i)\cdot p_1(x_1^i, TBP_1^i, \sigma_1^i)\cdot\prod_{k=2}^{n}\int_{x_1^i}^{+\infty}p_k(x_k^i, TBP_k^i, \sigma_k^i)dx_k^i \cdot dx_1^i$$

subject to Constraint on deficit probability (Eq. (10), (11))

$$TBP_k^i = STD_i\cdot(1+RC_k^i)\cdot(1+e\_profit_k^i)\cdot rp_k^i \qquad (i=1,2,\ldots,L;\ k=1,2,\ldots,n)$$

$$\int_{0}^{STDR_1^i}p_1(x_1^i, TBP_1^i, \sigma_1^i)\cdot\prod_{k=2}^{n}\int_{x_1^i}^{+\infty}p_k(x_k^i, TBP_k^i, \sigma_k^i)dx_k^i \cdot dx_1^i \le rprob_i$$

$(i=1,2,\ldots.L)$

Upper limit of the deficit order probability

Bidding price (Eq. (12))

Given MH allocation for cost estimation & value of *rp*, bidding price is determined.

$$NET_i \cdot (1 + e\_profit_1^i) \cdot rp_1^i$$

NET: Estimated cost calculated by the allocated MH

i ： Order

e_profit: Target profit rate

rp: Value of risk parameter ➔ Gain from optimization problem

Numerical examples

Numerical examples

Analyze & discuss the performance of the two-step bidding price decision algorithm from the following perspectives:

① Relations between cost estimation accuracy and expected profit,
② Effectiveness of bidding price adjustment,
③ Effect of the upper limit constraint of the deficit order probability.

Setting of Cases (table 1)

Case	Value of Risk Parameter *(rp_1)*	Competitors' Cost Estimation Accuracy (k>=2)
Case 0	1.0	8% of STD_i
Case 1	To be searched	8% of STD_i
Case 2	To be searched	6% of STD_i
Case 3	To be searched	10% of STD_i

Cases 0 and 1 are set to show the effectiveness of bidding price adjustment by the risk parameter (*rp*).
Cases 2 and 3 are set to show the effects of the competitors' cost estimation accuracy on the expected profit & deficit of one's own company.

Other Parameter Values

- ✓ Competitors' risk parameter (rp_k): 1.0
- ✓ Relative cost difference (RC_k): 0.0
- ✓ Upper limit of the deficit order probability ($rprob_i$): 1.0
- ✓ Expected profit (*e_profit*): 0.1
- ✓ Bidding price: Follow normal distribution
- ✓ Rnge of allowable total MH for cost estimation [M MH] :

  (A) 70-80 (B) 80-90

  (C) 90-100 (D) 100-110

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Conditions of orders (Table 2)

Order id (i)	1	2	3	4	5	6	7	8
STD_i	100.0			200.0			300.0	
Number of bidders (n)	2	3	4	2	3	4	2	3
Order id (i)	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
STD_i		400.0			500.0		600.0	
Number of bidders (n)	4	2	3	4	3	4	3	4

Assume a midsize EPC contractor in the chemical plant engineering business, and consider the conditions of 16 orders in each case.

Parameter on Cost Estimation Accuracy (Eq. (1))

- C: 0.25*100/STD_i
- σ_{min} & σ_{max}: 0.5% & 30% of STD_i
- Cost estimation accuracy level for MH allocation procedure:

  Grade A: 5% of STD_i

  Grade B: 8% of STD_i

  Grade C: 15% of STD_i

Results of Numerical Calculations

Cost Estimation Accuracy and Expected Profit

Significant difference in total expected profits is caused by total MH for cost estimation for all the cases as shown in Table 3.

Example (Table 3)

Case [M MH]	Total expected profits [MM$]
Case 0.A (70-80)	28.8
Case 0.B (80-90)	46.3
Case 0.C (90-100)	51.7
Case 0.D (100-110)	61.5

Results of Numerical Calculations

Cost Estimation Accuracy and Expected Profit

- Cost estimation accuracy depends on MH for cost estimation
- Cost estimation accuracy affects expected profit significantly.

There is usually a limit to available MH for cost estimation.

Effective mechanism to allocate MH for cost estimation to each order under the limited volume of total MH is necessary in bidding price decision process.

Results of Numerical Calculations

Effectiveness of Bidding Price Adjustment by Risk Parameter

- Significant difference in expected profits between Case 0 & Case 1 as shown in Table 3

<Total expected profits in Case 0.A & Case 1.A>

Case	Total expected profits [MM$]
Case 0.A	28.8
Case 1.A	53.3

Results of Numerical Calculations

Effectiveness of Bidding Price Adjustment by Risk Parameter

- Affects expected orders & profit rate (Table 3)

Case	Total expected orders [MM$]	Profit rate [%]
Case 0.A	1858.2	1.54
Case 1.A	1141.6	4.67

About three times as high as that in Case 0.A.

Results of Numerical Calculations

Effectiveness of Bidding Price Adjustment by Risk Parameter

- Deficit order probability is significantly decreased by the adjustment of the bidding price as show in Table 4

<Range of deficit order probability>

- ✓ Case 0.A: Between 11.0% and 25.8%
- ✓ Case 1.A: Between 0.777% and 5.81%

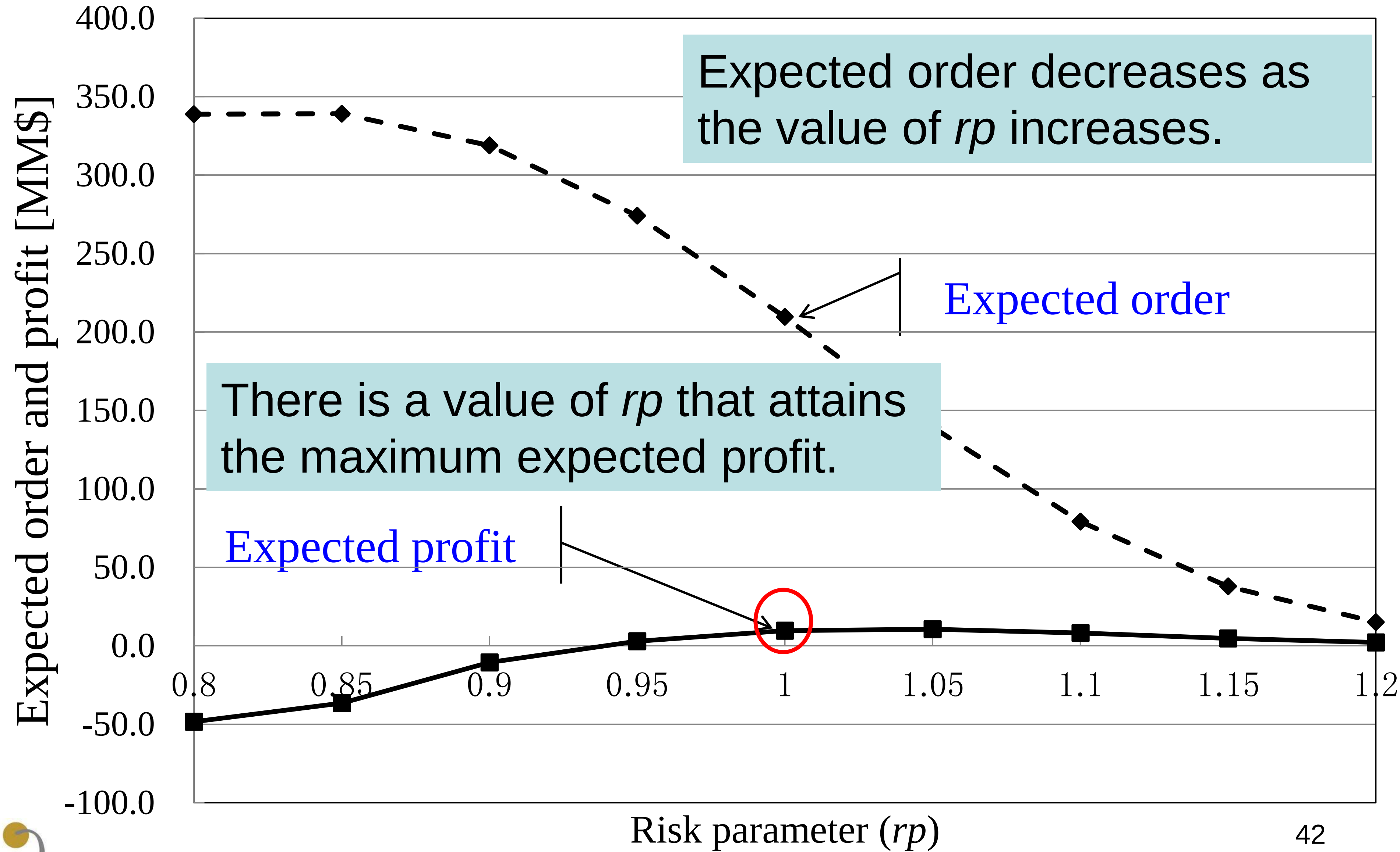
Results of Numerical Calculations

Effectiveness of Bidding Price Adjustment by Risk Parameter

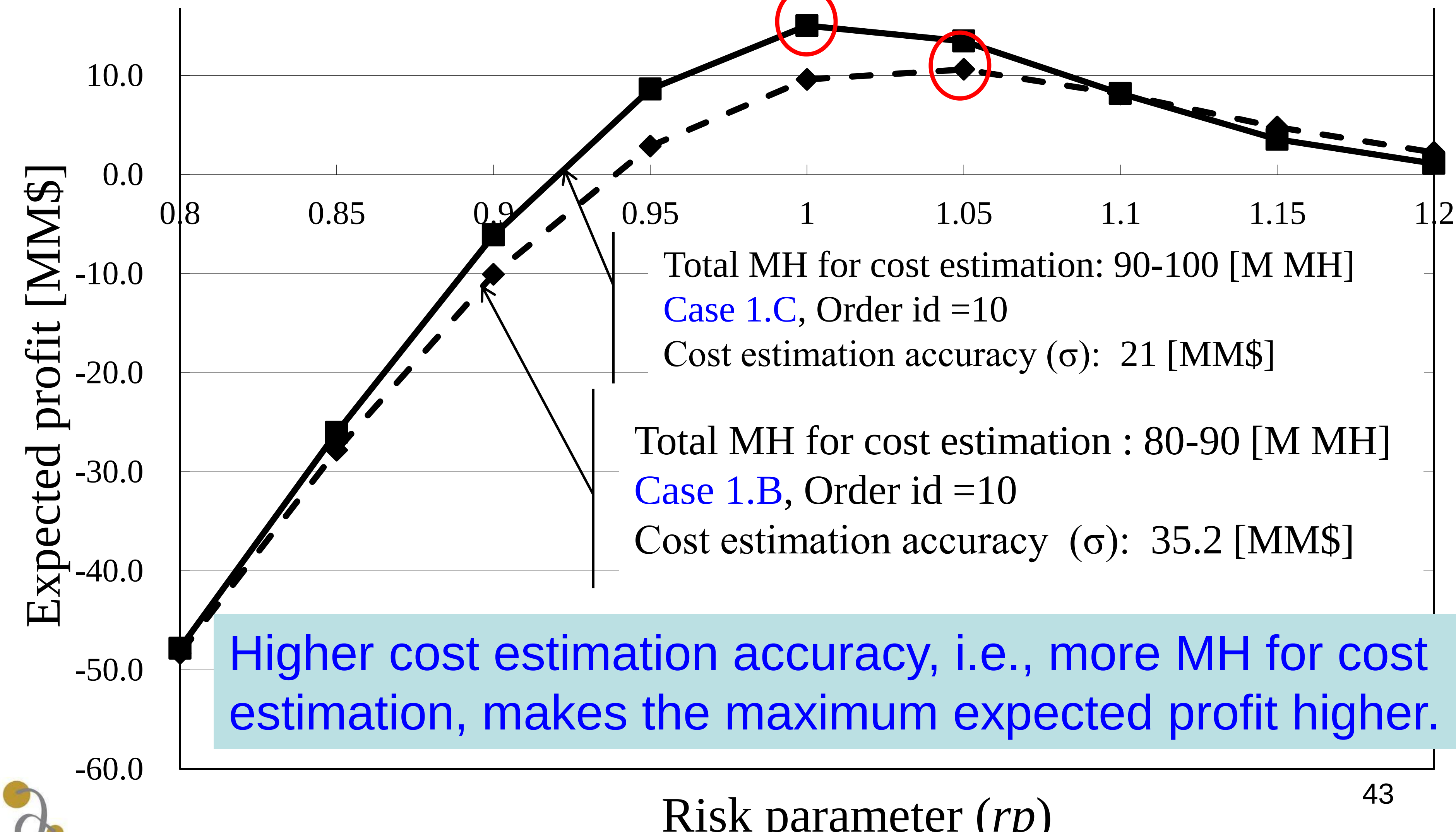
Range of deficit order probability (Eq. (6)) [%]. (Table 4)

	The range of allowable total MH for cost estimation [M MH]			
	70-80	**80-90**	**90-100**	**100-110**
Case 0	**Case 0.A**	**Case 0.B**	**Case 0.C**	**Case 0.D**
	11.0-25.8	**11.0-12.1**	**3.20-12.1**	**2.98-12.1**
Case 1	**Case 1.A**	**Case 1.B**	**Case 1.C**	**Case 1.D**
	0.777-5.81	**4.33-5.81**	**1.77-5.81**	**1.77-5.81**

Relations among expected order, expected profit, & risk parameter. (Case 1.B; Order id = 10) Fig. 3



Relations among expected profit, total MH for cost estimation, & risk parameter. (Case 1.B, Order id =10, Total MH for cost estimation: 80-90 [M MH]; and Case 1.C, Order id =10, Total MH for cost estimation 90-100 [M MH]) Fig. 4



Higher cost estimation accuracy, i.e., more MH for cost estimation, makes the maximum expected profit higher.

Results of Numerical Calculations

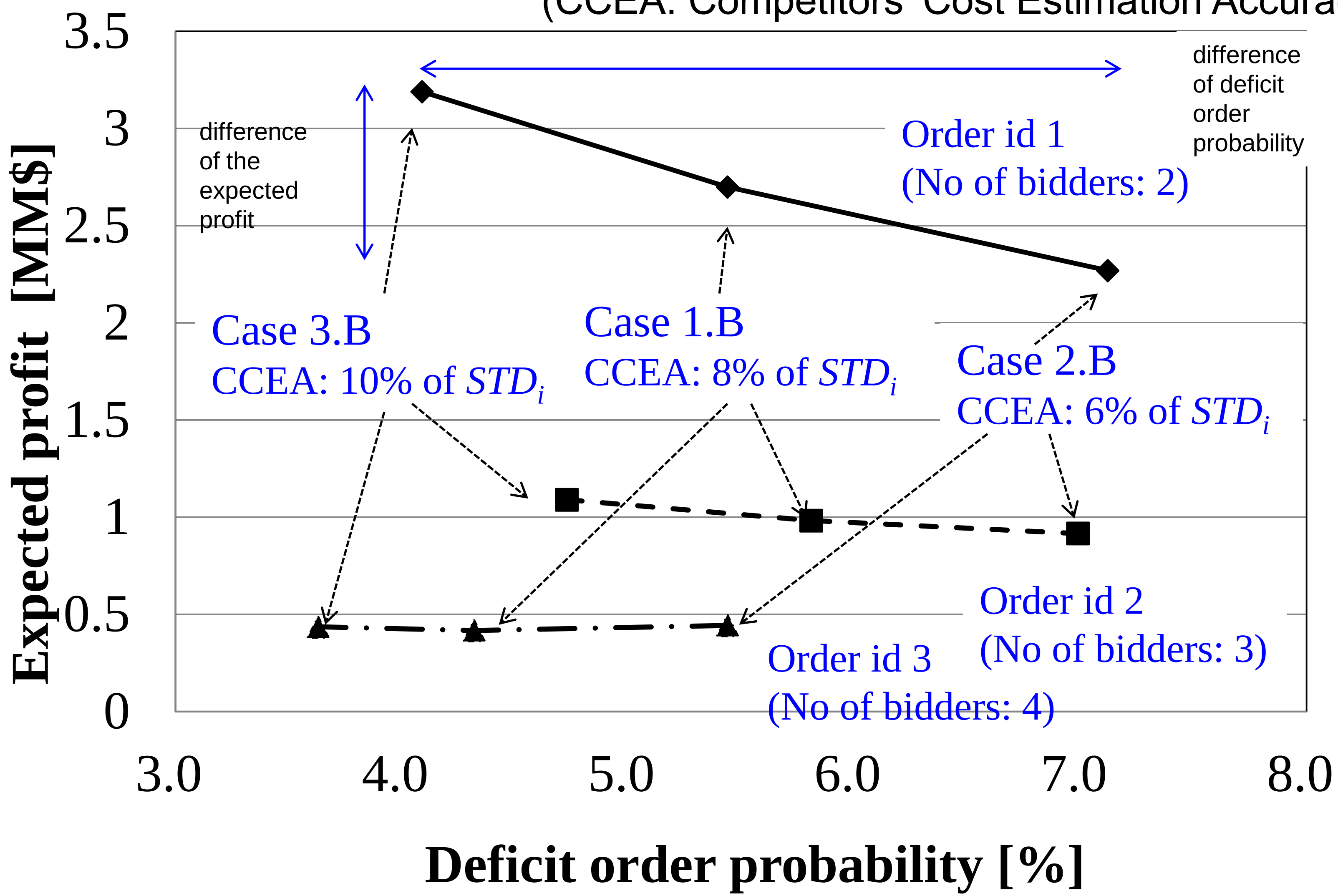
In summary, Bidding Price Adjustment by Risk Parameter:

- Bidding price adjustment by *rp* is effective to improve expected profit & reduce deficit from EPC projects.
- The optimization problem searches the value of *rp* to gain maximum expiated profit.

Effect of the Number of Bidders

Relations among expected profits and deficit order probability. (Fig.5)

(Case 2B, 1B, and 3B; Order id 1, 2, and 3)
(CCEA: Competitors' Cost Estimation Accuracy)



Results of Numerical Calculations

Effect of the Number of Bidders

- Effect of competitors' cost estimation accuracy on expected profit and deficit order probability becomes smaller as the number of bidders increases. (Fig. 5)

- ✓ In Order id 1, i.e., when the number of bidders is two, the difference of the expected profit between Case 3.B and Case 2.B is 0.87 [MM$].
- ✓ In Order id 3, i.e., when the number of bidders is four, the difference of the expected profit between Case 3.B and Case 2.B is 0.008 [MM$].
- ✓ The difference in the deficit order probability between Case 3.B and Case 2.B is also reduced from 3.03 [%] (in the case of Order id 1) to 1.81 [%] (in the case of Order id 3).

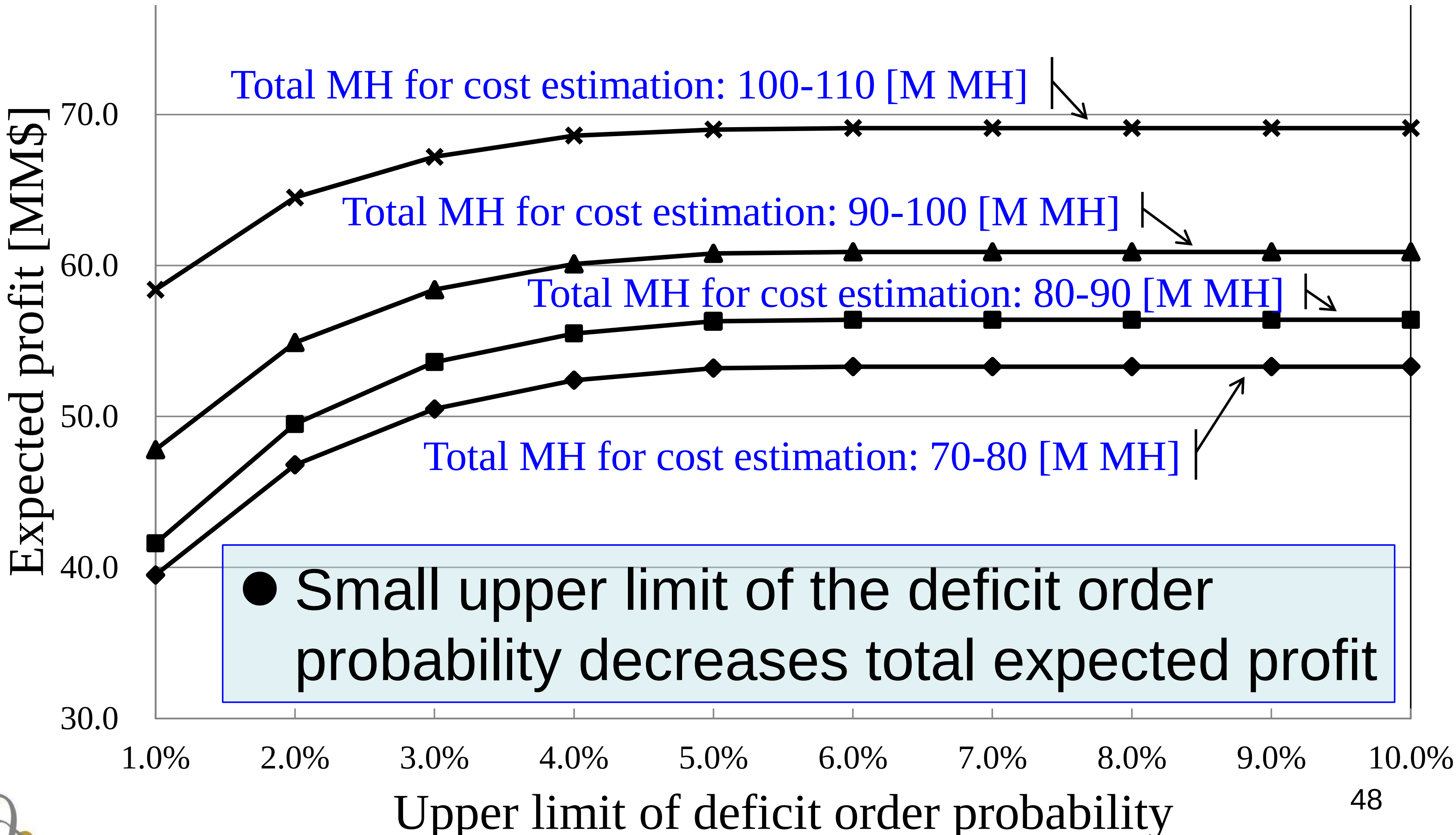
Results of Numerical Calculations

Effect of the Number of Bidders

- High degree of competition reduces the chance of accepting orders at high prices as well as at low prices regardless of the competitors’ cost estimation accuracy.
- Consequently, it reduces the effect of the competitors’ cost estimation accuracy on the expected profit and the deficit order probability.

Effect of Upper Limit Constraint of Deficit Order Probability

Relations among expected profits, total MH for cost estimation, and upper limit of deficit order probability (Case 1). Fig. 6



- Small upper limit of the deficit order probability decreases total expected profit

Results of Numerical Calculations

Effect of Upper Limit Constraint of the Deficit Order Probability

- Small upper limit of the deficit order probability decreases total expected profit
  - ✓ Deficit order probability can be reduced from 5.0% to 1.0% at the expense of the total expected profits of 10 to 15 [MM$].
- Our framework developed for EPC project will be helpful for any contractor to avoid large deficit from accepted orders.

Conclusions

①A two-step bidding price decision algorithm under limited MH in EPC projects is developed

②A mathematical model for simulating competitive bidding is developed

③Numerical results using the model show;

- ✓ Bidding price decision in consideration of the cost estimation accuracy & deficit order probability is essential for the contractor to make a stable profit in EPC projects
- ✓ Two-step bidding price decision algorithm is effective for making such bidding price decisions.

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Conclusions

There are several issues for further research

For example;

- The procedure for modifying the MH allocation and adjusting the bidding price dynamically in response to each order arrival is required for practical application
- The two-step algorithm does not consider the duration for estimating cost & for carrying out the project.
  - ✓ The MH allocation procedure should consider the time cost-trade-off and its implication on the cost estimation accuracy and profit.
  - ✓ It is also necessary to compare the performance of our procedure with other project scheduling methods dealing with the optimum allocation of resources for multiple projects.

Thank you very much
for your kind attention.