Resource Flow based Order Selection Method in Project Cost Estimation Process

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Abstract: Since the project price is fixed in EPC (Engineering, Procurement, and Construction) projects, the contractor should devote significant resources to the cost estimation process to realize the accurate cost estimation and then accept profitable projects from clients in competitive bidding situations. However, it is impossible for any contractor to devote sufficient resources to all the orders because of the resource constraints. In this study, a multistage project cost estimation process model, consisting of pre-evaluation, order selection, man-hour allocation, and a series of cost estimation steps, is developed. Then, this study devises a resource flow based order selection method and man-hour allocation method to provide successful results to clients and to maximize the contractor's profits under the limited resources. Specifically, those methods dynamically select orders to estimate cost at each order arrival and allocate the resources to the selected orders, respectively. The effectiveness of our method is demonstrated through simulation experiments using the developed model.

1 INTRODUCTION

EPC (Engineering, Procurement, and Construction) projects (Pritchard and Scriven, 2011) correspond to the execution process of industrial projects, such as process plants, structures, and information systems. Those projects start after the final investment decision by the clients, and are complete when the contractor delivers facilities based on the client's requirements for a limited period of time under a lump sum turnkey basis. Since any EPC project includes unique and non-repetitive activities, many uncertainties exist in the project execution process. Furthermore, since the project price is fixed before the start of the project, the contractor often faces eventual loss of profit in EPC projects. Thus, it is necessary for any contractor to precisely estimate the project cost in order to determine the bidding price. Namely, the cost estimation process in an EPC project is critical for any contractor who seeks to increase profits and reduce the possibility of realizing a loss, i.e., a deficit risk, due to cost estimation error.

Cost estimation is also crucial for ensuring the proper volume of accepted orders. Inaccurate cost estimation could not only lead to deficit orders but could also exhaust the contractor's resources, which are necessary to carry out long-term deficit projects, as Ishii et al. (2014) stated. Moreover, a contractor's deficit order would have severely harmful effects on the client's business. For example, it would generate an additional cost and/or delay to the project delivery date, thus the client would miss a business opportunity.

Since the quality and quantity of the data available for cost estimation determine the accuracy of the estimated cost, a significant amount of high-quality data is required to improve accuracy. In process plant engineering, for example, the data and methods required to attain the target accuracy of project cost estimation have been studied (AACE, 2011). In any cost estimation method, such as parametric, analogy, and engineering (Kerzner, 2013), higher accuracy requires more data and, accordingly, more engineering man-hours (MH) to acquire and analyse the data for cost estimation.

Thus, experienced and skilled human resources who can acquire data for cost estimation and create project plans are required for accurate cost estimation. Those resources, however, are limited for

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any contractor. Furthermore, once the orders are successfully accepted, the corresponding project execution will also need considerable human resources. For these reasons, the contractor should realize appropriate selection of orders and allocation of MH for cost estimation of each selected order to maximize the total expected profit under the constraint of the total MH.

Based on the above observations, this paper examines the cost estimation process of EPC projects in dynamic order arrival situations. Namely, activities of the project cost estimation process are identified, and a model of the multistage project cost estimation process that divides the cost estimation process into four phases, i.e., pre-evaluation, order selection, MH allocation, and a series of cost estimate steps, is developed.

We next devised an order selection method based on resource flows for dynamically selecting orders to estimate cost at each order arrival through the pre-evaluation and the order selection in the developed model. In addition, we use MH allocation rules for allocating the limited resources to the selected orders in the MH allocation. The resource flow based order selection method selects orders on the basis of the flow rate of the contractor's MH for estimating cost and that of the expected profits from the orders. MH allocation rules prioritize orders in the queue waiting for allocating MH for estimating cost, and then it allocates MH to the orders based on the priority. We finally analyse the effectiveness of our developed methods through numerical examples by using the discrete-event simulation model of the multistage project cost estimation process.

2 RELATED WORK

A variety of studies have been conducted on project cost estimation from the viewpoints of cost estimation accuracy, MH allocation for cost estimation, order selection, and so on. For example, AACE (2011), Humphreys (2004), and Towler and Sinnott (2008) demonstrated the relationship of cost estimation accuracy and the methods and data used for cost estimation in the field of process plant engineering projects. Furthermore, they suggested that cost estimation accuracy is positively correlated with the volume of MH for cost estimation. However, only a few of studies have examined management issues on the project cost estimation process that uses the methods and data for cost estimation.

Regarding MH allocation in the cost estimation process, Ishii et al. (2016a) developed an algorithm that determines the bidding prices under the limited MH for cost estimation. Their algorithm allocates MH to maximize expected profits based on the cost estimation accuracy determined by allocated MH. In addition, Takano et al. (2014) developed a stochastic dynamic programming model for establishing an optimal sequential bidding strategy in a competitive bidding situation. Their model determines the optimal markup in consideration of the effect of inaccurate cost estimates. Takano et al. (2016) also developed a bid markup decision and resource allocation model that determines the optimum bid markup and resource allocation simultaneously. Furthermore, Takano et al. (2017) developed a multi-period resource allocation method for estimating project costs in a sequential competitive bidding situation. Their method allocates resources for cost estimation by solving a mixed integer programming problem that is formulated by making a piecewise liner approximation of the expected profit functions. Those studies, however, assume the order arrivals in advance, and thus they cannot deal with dynamic order arrival situations.

Regarding the order selection in the cost estimation process, Shafahi and Haghani (2014) proposed an optimization model that combines project selection decisions and markup selection decisions in consideration of eminence and previous works as the non-monetary evaluation criterion used by owners for evaluating bids. In addition, Ishii et al. (2016b) developed the threshold function method (TFM) for deciding bid or no-bid on newly arrived orders based on the threshold function of MH utilization with respect to the expected profit of orders. In TFM, the threshold function is determined through simulation experiments under a set of averaged conditions for estimating cost. They show that TFM increases the expected profits from orders compared to the case of no order selection by simulation experiments. In TFM, however, the contractor needs to build a simulation model of the cost estimation process and certain computational loads to obtain the threshold function. In addition, a long-term and stable cost estimation conditions, such as order arrivals, expected profits from orders, and so on, are assumed in advance to determine the threshold function through simulation runs. Thus, TFM could not deliver good performance in practical situations where the cost estimation conditions are unstable and change dynamically.

Based on the above literature review, we found that most of the studies have paid little attention to the project cost estimation process in practical situations. More specifically, in practice, the contractor needs to select orders to bid and allocate MH for cost estimation dynamically to each selected order which has different characteristics. In light of these facts, this paper develops a method for selecting orders and determining MH allocation in consideration of the contractor's available MH and the orders' profitability under the dynamic order arrival conditions as is the case in practical situations.

3 A MULTISTAGE MODEL OF PROJECT COST ESTIMATION PROCESS

3.1 Project Cost Estimation Activities

The project cost estimation process can be recognized as a series of activities that starts with the arrival of bid invitations from the client and closes by the date of bidding (Ishii et al., 2016b). A variety of orders arrive, and the contractor selects orders to estimate the project costs through the cost estimation process. Then, the contractor determines the accuracy of cost estimation by allocating MH to the cost estimation activities of selected orders in consideration of the MH availability, expected profits, competitive bidding situations, and so on. When the available MH is not sufficient to estimate cost accurately, the contactor must allocate fewer MH, thereby reducing expected profit due to inaccurate cost estimation, or no-bid on the order.

3.2 Overview of the Model

Based on the above observations, we propose a multistage model of the project cost estimation process which consists of pre-evaluation, order selection, MH allocation for cost estimation, and a series of cost estimation steps, as shown in Figure 1, by referencing the model developed by Ishii et al. (2016b). In the model, we assume that the cost is estimated through the cost estimation steps: E1, E2, and E3 estimate. Each step needs MH and a period of time for cost estimation, and the accuracy of the estimated cost increases through the cost estimation activities in each step.

The cost estimate manuals, such as AACE classification matrix (AACE, 2011), the classes of estimates by Kerzner (2013), and so on, can be used for reference of the cost estimation accuracy and for the required MH in each step. For example, AACE classifies cost estimation into five classes and indicates the methods, data, and the accuracy of cost estimation in each class. Two of the classes in AACE are in the order of magnitude type estimation for a project feasibility study. Thus, the developed model divides the cost estimate activities into three steps in reference to the AACE system. Namely, we assume that the project cost is estimated through a series of three cost estimation steps, and the accuracy of the estimated cost is improved in accordance with the steps.

In the model, the pre-evaluation and the order selection determine whether to select and bid the newly arrived order or not. Specifically, the pre-evaluation evaluates the resource flow of the process if the newly arrived orders are selected as explained in section 4.1. The order selection determines whether to select orders for estimating costs or not from the viewpoint of changes of the resource flow, the volume of orders to be accepted, the expected profits, MH availability for cost estimation, and so on.

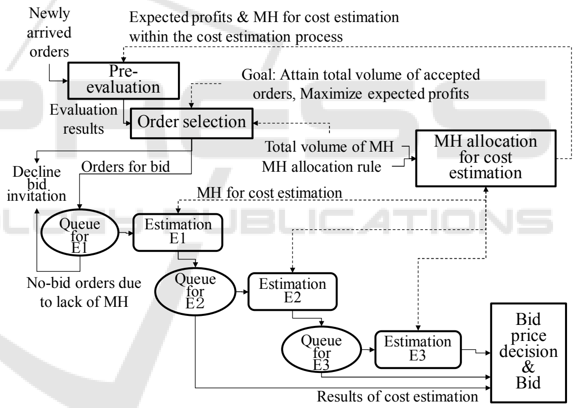

Figure 1: A model of multistage project cost estimation process.

The selected order is first filed in the queue for the E1 estimate and waits to be assigned the MH for cost estimation by the mechanism of MH allocation for cost estimation. If any MH is not assigned to the order until the bidding date, the contractor does not bid for it due to the lack of MH. If the MH is assigned to the order, its project cost is estimated with the accuracy of the E1 estimate. This order is then filed in the queue of the E2 estimate and waits for MH assignment for the E2 estimate. If the MH is not further assigned to the order until the bidding date, the contractor determines the bidding price based on the accuracy of the E1 estimate. By contrast, if the MH is assigned to the order waiting in the queue of the E2 estimate, its project cost is estimated with the accuracy of the E2 estimate, and filed in the queue of the E3 estimate. The same decision is made for the orders in the queue of the E3 estimate.

The project cost estimation problem, addressed in this paper, is a kind of dynamic scheduling problem that determines the processes dynamically for each order arriving at a system. In our problem, however, orders and the volume of resources for cost estimation are determined dynamically under the conditions of resource availability and due date of the order in order to maximize the total expected profits from orders. On the contrary, in the standard scheduling problems (Jacobs et al. 2011), orders and the volume of resources are predetermined, and the orders are scheduled so as to minimize the makespan and/or reduce tardy jobs. From this perspective, we believe that the project cost estimation problem in this study can be recognized as a novel dynamic scheduling problem.

4 METHODS OF ORDER SELECTION AND MAN-HOUR ALLOCATION

This section shows the two methods, i.e. order selection and MH allocation for cost estimation, that are used in the project cost estimation process shown in Figure 1.

These two methods are developed based on the following assumptions:

Assumptions:

1) Orders for cost estimation arrive randomly;
2) Expected profit, required MH and periods for cost estimation of each estimate step are predetermined;
3) Probability of a successful bid of each order, i.e. accepted order, is predetermined.

4.1 Resource Flow based Order Selection Method

For the order selection through the pre-evaluation and the order selection shown in Figure 1, we develop a resource flow based order selection method (RFSM) that decides estimating cost or declining bid invitation on arrived orders according to the changes of *MHR* and *EPR* by the arrived orders. *MHR* and *EPR* are the flow rate of MH for cost estimation and the total expected profits from orders, respectively, within the cost estimation process. Those are determined as Eqs. (1) and (2).

For explaining the basis of RFSM, in this section, we assume that the project costs of at least step E2 are estimated in all the selected orders.

$$MHR = \sum_{i \in UE} MH_i / D_i \tag{1}$$

$$EPR = \sum_{i \in UE} EP_i / D_i \tag{2}$$

where i is order under estimating cost in the process. MH_i, EP_i, and D_i are the volume of cost estimation MH, the expected profit, and period for cost estimation of order i, respectively. In addition, UE is a set of orders within the cost estimation process.

Now, assume that $P_{E3}(MHR_{E3}, EPR_{E3})$ indicates the coordinate point where costs of all the orders are estimated to E3, $P_{E2}(MHR_{E2}, EPR_{E2})$ indicates the coordinate point where costs of all the orders are estimated to E2, and MHR_{CP} is the maximum flow rate of MH available in the cost estimation process.

Then, the rate of maximum expected profits EPR_{max} is calculated based on the magnitude relationship between MHR_{E3} and MHR_{CP} as Eqs. (3) or (4).

1) If $MHR_{E3} \leqq MHR_{CP}$:

$$\text{EPRmax} = \text{EPRE3} \tag{3}$$

2) If $MHR_{CP} < MHR_{E3}$:

$$EPR_{\max} = \frac{EPR_{E3} - EPR_{E2}}{MHR_{E3} - MHR_{E2}} \cdot MHR_{CP} + \frac{MHR_{E3} \cdot EPR_{E2} - MHR_{E2} \cdot EPR_{E3}}{MHR_{E3} - MHR_{E2}} \tag{4}$$

Eq. (4) assumes that there is linearity between P_{E3} and P_{E2}, then EPR_{max} exists where $MHRcp$ intersects the line connecting the points of P_{E3} and P_{E2} as shown in Figure 2.

Next, if the new order *nwd* has arrived for cost estimation, $P'_{E3}(MHR'_{E3}, EPR'_{E3})$ and $P'_{E2}(MHR'_{E2}, EPR'_{E2})$, which indicate the coordinate points including *nwd*, are calculated in Eqs. (5) to (8).

$$MHR'_{E3} = R \cdot MHR_{E3} + MHR_{E3}^{nwd} \tag{5}$$

$$EPR'_{E3} = R \cdot EPR_{E3} + EPR_{E3}^{nwd} \tag{6}$$

$$MHR'_{E2} = R \cdot MHR_{E2} + MHR_{E2}^{nwd} \tag{7}$$

$$EPR'_{E2} = R \cdot EPR_{E2} + EPR_{E2}^{nwd} \tag{8}$$

where MHR^{nwd} and EPR^{nwd} indicate MHR and EPR of a newly selected order for cost estimation, respectively, in steps E2 and E3. In addition, R is a coefficient to discount the flow rate by the next order arrival if the newly arrived order is not selected. It is calculated by Eq. (9) by the average cost estimation period of orders within the cost estimation process ED and the number of orders within the process NE, where R=0 if NE=0.

$$R = (ED - ED / NE) / ED = 1 - 1 / NE \quad (9)$$

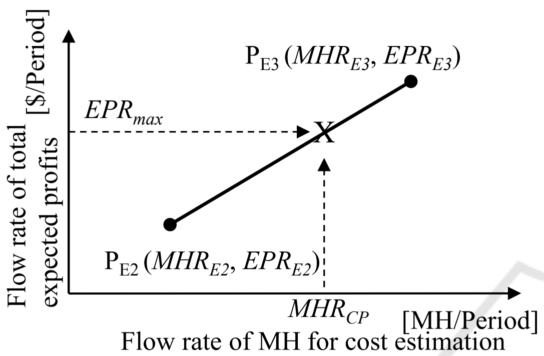

Figure 2: Relations between *MHR* and *EPR*.

Then RFSM evaluates EPR'_{max} indicating the flow rate of maximum expected profits if *nwd* is selected by Eqs. (10) or (11). Eq. (11) calculates the value where $MHRcp$ intersects the line connecting the points of P'_{E3} and P'_{E2} based on the assumption that there is linearity between P'_{E3} and P'_{E2} as is the case of Eq. (4).

1) If $MHR_{E3} < MHR_{CP}$:

$$\text{EPR'max} = \text{ERP'E3} \quad (10)$$

2) If $MHR'_{E2} < MHR_{CP} < MHR'_{E3}$:

$$EPR'_{\max} = \frac{EPR'_{E3} - EPR'_{E2}}{MHR'_{E3} - MHR'_{E2}} \cdot MHR_{CP} + \frac{MHR'_{E3} \cdot EPR'_{E2} - MHR'_{E2} \cdot EPR'_{E3}}{MHR'_{E3} - MHR_{E2}} \quad (11)$$

Finally, the order *nwd* is selected for cost estimation in the case of $R \times EPR_{max} < EPR'_{max}$ or $MHR'_{E3} < MHR_{CP}$.

The former condition means that the flow rate of expected profit EPR'_{max} gained by selecting *nwd* for cost estimation is higher than the flow rate of expected profit $R \times EPR_{max}$ gained by cutting *nwd*. The later condition means that the flow rate of MH for cost estimation including *nwd,* i.e., MHR'_{E3}, is less than the maximum flow rate available in the process.

4.2 Man-Hour Allocation Method

For the allocation of MH for cost estimation under dynamic order arrival situations, we use a dispatching method, as is the case of the dynamic scheduling problem in production systems (Jacobs et al., 2011) because the project cost estimation is similar to the production.

Specifically, when MH is released from the cost estimation of an order, this method selects an order based on the MH allocation rules, which prioritize orders in the queue of each estimate step. The selected order is subsequently assigned the required MH for its cost estimation step. If the required MH is more than the MH available, the selected order waits in the queue until the required MH is released.

Table 1 shows potential rules that could be applicable for dynamic MH allocation in the project cost estimation problem.

Table 1: Potential MH allocation rules.

Rule	Description
FIFO	First-In First-Out: Order is selected on a first-in first-out basis.
SDUF	Shortest DUe date First: Order remaining with the shortest estimation period is selected.
SET	Shortest Estimation Time: Order having the shortest estimation period is selected.
HEPF	Highest Expected Profit per MH First: Order having the highest expected profit per MH for cost estimation is selected.

5 NUMERICAL EXAMPLES

This section evaluates the performance of the developed methods for managing the project cost estimation process effectively by simulation experiments. We use a general-purpose simulation system AweSim! (Pritsker and O'Reilly, 1998) for building a simulation model of the multistage project cost estimation process.

5.1 Design of Simulation Experiments

In our simulation experiments, the performance of the two order selection methods, i.e., the developed method in this paper RFSM, and the existing method TFM (Ishii et al., 2016b), are compared as two basic cases shown in Table 2. Namely, 100 simulation runs of a 120 period simulation length are performed by each method, and the average expected profits per 12 periods are compared.

Table 2: Basic simulation case.

	Order selection method	MH allocation rule
Case A	RFSM	HEPF
Case B	TFM	

The total volume of MH for cost estimation is set as 16,000 [MH/Period] in reference to a mid-size process plant EPC contractor. Furthermore, as the MH allocation rule, the HEPF rule is used throughout all the simulation experiments, because it is reported that the higher expected profit is gained by HEPF rule (Ishii et al., 2016b))

Three order arrival scenarios— scenario S1, scenario S2, and scenario S3— based on the order arrival intervals defined by the triangular distribution, as shown in Table 3, are determined. In each scenario, orders of the three sizes, i.e., Small, Medium, Large, arrive dynamically. The total periods for cost estimation, periods for cost estimation in each step, and the volume of MH for cost estimation are set as shown in Table 4. In addition, two scenarios of expected profit of accepted orders, i.e. scenarios I and II, are set as shown in Table 5. Furthermore, as the probability of order acceptance, the arrived orders are sorted into grade H: 70%, M: 40%, and L: 10%. Regarding the rate of the grade, grade M is set as 40%, and grade H changes from 0% to 60%, and thus it changes from 60% to 0% in grade L accordingly in each simulation experiment. The expected profit of each order is computed by multiplying the value in Table 5 by the probability of order acceptance. For example, if the arrived order's grade is M (40%) and the expected profit of the accepted order is 20 [MM$], the expected profit is 8 [MM$].

Regarding the threshold function used for selecting orders in TFM, the order with the expected profit per MH 35.0 [$/MH] and the volume of MH under estimating cost 6,000 [MH] are set, i.e., the threshold function P(350, 6000), by using the algorithm developed by Ishii et al. (2016b), under cost estimation conditions as follows;

1) order arrival interval: S2,
2) the expected profit of orders: I,
3) the rate of probability of order acceptance in each grade: H:30-M:40-L:30 [%].

Namely, the newly arrived order is selected for estimating cost by the threshold function in TFM when its expected profit per MH is higher than 35.0 [$/MH] and MH under estimating cost is less than 6,000 [MH].

Table 3: Order arrival interval [Orders/Period].

Scenario of order arrival	Parameters of triangular distribution	Order size: Small	Medium	Large
S1	Min.	1.05	2.70	3.15
	Mode	1.50	3.00	4.50
	Max.	1.95	3.90	5.85
S2	Min.	0.84	1.68	2.52
	Mode	1.20	2.40	3.60
	Max	1.56	3.12	4.68
S3	Min.	0.70	1.40	2.10
	Mode	1.00	2.00	3.00
	Max	1.30	2.60	3.90

Table 4: Cost estimation conditions.

		Order size: Small	Medium	Large
Total periods available for cost estimation		Triangular distribution (Min.: 4.0, Mode: 7.5, Max.:9.0)		
Periods for cost estimation	E1	1.0	1.0	1.0
	E2	1.5	1.5	1.5
	E3	2.0	2.0	2.0
MH for cost estimation [M MH]	E1	1.0	2.0	3.0
	E2	2.0	3.0	4.0
	E3	3.0	4.0	5.0

Table 5: Expected profit of accepted orders [MM$] (Mode of triangle distribution. Min. & Max. are -/+ 10% of the mode value.)

Scenario of expected profit		Order size: Small	Medium	Large
I	E1	1	2	3
	E2	10	20	30
	E3	20	40	60
II	E1	1	2	3
	E2	15	30	45
	E3	20	40	60

5.2 Results of Simulation Experiments

As shown in Figures 3 and 4, RFSM gains almost the same or higher expected profit than that by the existing TFM. Especially, RFSM performs well when the rate of probability of order acceptance on grade L is large. For example, in the case of 0-40-60% in the rate of probability of order acceptance, the expected profit by RFSM is increased 17.1% compared to that by TFM as shown in Figure 3. On the other hand, in the case of the expected profit by TFM being better than RFSM, its difference is less than 5.0% as shown in Figure 3 and 4. TFM uses the fixed threshold function determined under the cost estimation conditions shown in section 5.1 throughout the simulation experiments. We can say that TFM could not maintain the performance when the cost estimation conditions change dynamically.

In addition, RFSM has almost the same or higher expected profit than that of TFM at all the rate of probability of order acceptance in the scenario S1.I where orders arrive less than the scenario S2.I. as shown in Figure 5. For example, in the case of 0-40-60% in the rate of probability of order acceptance, the expected profit by RFSM is increased 23.8% compared to that by TFM.

It is also obvious that the expected profit gained by RFSM is expanded compared to that of TFM when the conditions of the expected profit in each step are changed to the scenario II as shown in Figures 6 and 7. For example, in the case of 0-40-60% in the rate of probability of order acceptance, the expected profit by RFSM in scenario S2.I is increased 17.1% compared to that by TFM as shown in Figure 3, however it is 24.0% in scenario S2.II as shown in Figure 6. In these cases, TFM cuts too many orders because of the higher ratio of low profit orders compared to the cost estimation conditions that determines the threshold function of TFM.

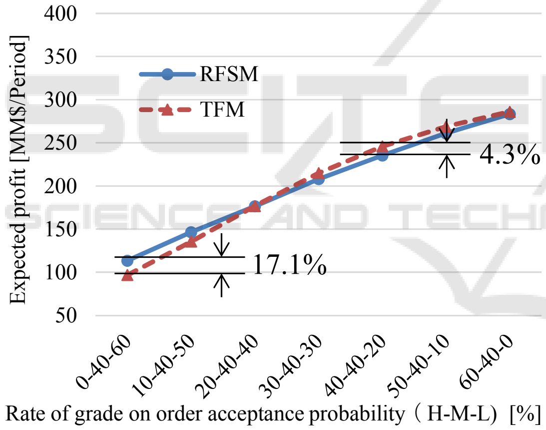

Figure 3: Expected profits in scenario S2.I.

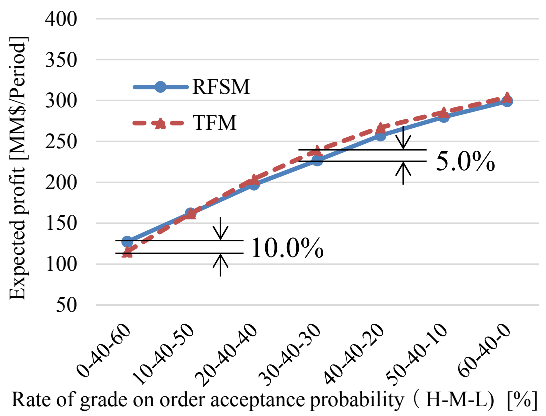

Figure 4: Expected profits in scenario S3.I.

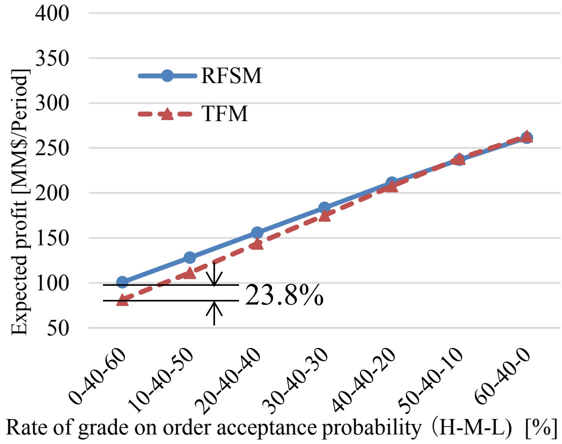

Figure 5: Expected profits in scenario S1.I.

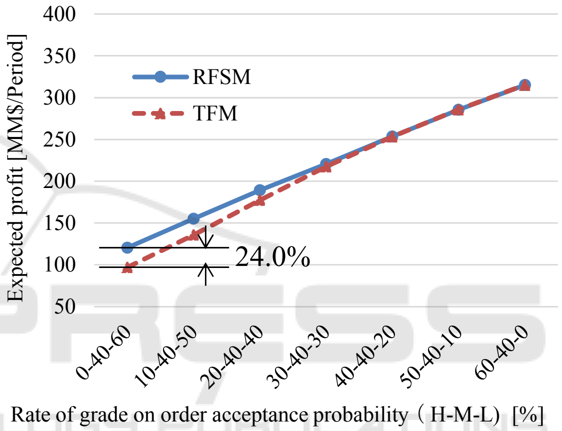

Figure 6: Expected profits in scenario S2.II.

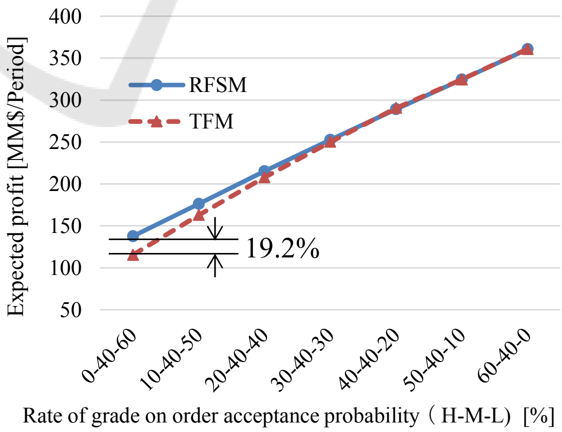

Figure 7: Expected profits in scenario S3.II.

Furthermore, since RFSM determines the order selection based on the changes of the resource flow rate, which reflects the conditions of the cost estimation process, we can say that the resource flow based method is effective for the selecting order, especially when the conditions of cost estimation, such as order arrival intervals, the expected profit of accepted orders, and so on, change dynamically.

In addition, RFSM needs no complicated mechanism to determine the order selection rules as TFM requires. Thus, RFSM can work by lower computational loads than that of TFM. We can say that the RFSM is simple and sufficient to be implemented as an order selection mechanism in the project cost estimation process in practical situations.

6 CONCLUSIONS

This paper explores the project cost estimation process of EPC projects in dynamic order arrival situations, and then it develops a model of multistage project cost estimation process. Based on the process, we develop a resource flow based order selection method. It selects orders for cost estimation at each order arrival according to the changes of the flow rate of the contractor's man-hours for estimating cost and that of the expected profits from the orders to maximize the total expected profits from orders. We analyse the effectiveness of the developed method in terms of the expected profit through numerical examples.

The following conclusions can be drawn from the analysis of the numerical examples:

- For increasing the total expected profits from orders in EPC projects, the resource flow based order selection method is effective as an order selection mechanism in the cost estimation process.
- The performance of the resource flow based order selection method is obvious, especially, in the cases where the cost estimation conditions change dynamically.

Several issues require further research. For example, a generalized algorithm of resource flow based order selection method that extends the coordinate points of cost estimate more than three to correspond to the number of cost estimation steps should be developed. Regarding the expected profits from orders, the interrelationship of the order selection method and the MH allocation rule should be explored. Management technologies for an advanced model of the cost estimation process that changes the total volume of MH associated with the backlog of orders should also be explored.

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