STRUCTURAL ANALYSIS OF HUMAN RESOURCE ALLOCATION IN ENGINEERING PROJECTS

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ABSTRACT

Each discipline manager has been entrusted for assigning his limited number of engineers to specified projects under a matrix organization. The managers, however, have no efficient decision methods except their experienced guesses. In this paper, the result of in-depth analyses of human resource allocation problem in engineering projects is presented with respect to engineers' quality and their work volumes. The problem is stated in a Linear Programming (LP) form of man-hour allocation problem and is solved by applying an analytical solution method that makes possible essential understanding of the optimal solution space of the problem. Some heuristics for the man-hour allocation problem are also introduced through this analysis.

INTRODUCTION

Methodologies of resource allocation have been presented in numerous papers[1][2], and mostly applied to job-shop scheduling problems such as resource leveling, resource-constrained project scheduling, and resource allocation heuristics.[4][6] They give the optimal solution based on single or uniform resource and single task of a given work volume. However, as in chemical process industries and the related engineering firms, the human resources in actual organization comprise various discipline engineers with different quality-levels based on their experiences and knowledge. A task is also divided into sub-tasks according to difficulty grades of the given work volume. Therefore, allocation and assignment of human resources must be concerned with the quality levels of engineers and the difficulty grades of work volumes at the individual stages of project life cycle.[10]

The concept of the project management is extended to all work in an enterprise[3] and core tasks are strategically defined as projects to achieve the specific objectives. The corporate resources must be effectively allocated to projects and be efficiently managed to accomplish the tasks within the constraints of quality, cost and time. The capability and adaptability of human resources become significant in responding to the changing requirements for project tasks along the project life cycle. The human resources allocation and assignment must be done by taking the quality levels of engineers and the degrees of difficulty for grades of work volumes at each stages of project life cycle. In practical situation, a capable class of engineers can be assigned to both single graded-work volume and multiple graded-work volumes. It is necessary to mobilize the available human resources flexibly and adaptively considering the effectiveness of multiple assignments under severe constraints.

In this paper, the authors present a practical model of human resource allocation to multiple assignments accounting for the various quality-classes of engineers and the degrees of difficulty for grades of work volumes. Based on the model, the optimal solutions of assignment are analytically obtained and the heuristics on human resource allocation are derived from the optimal solution space.

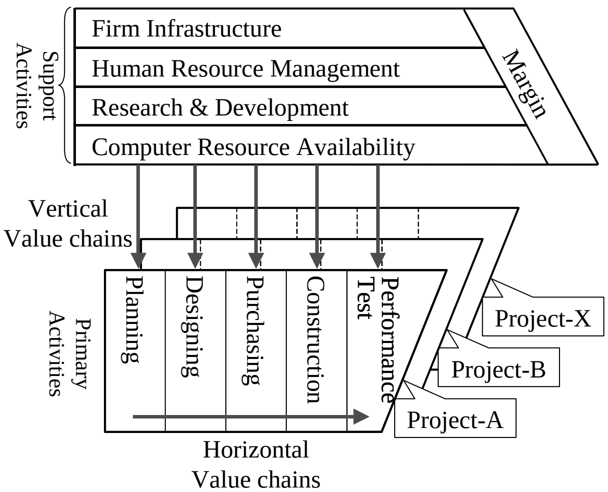

Fig. 2.1 Typical Value Chain of Project Lifecycle

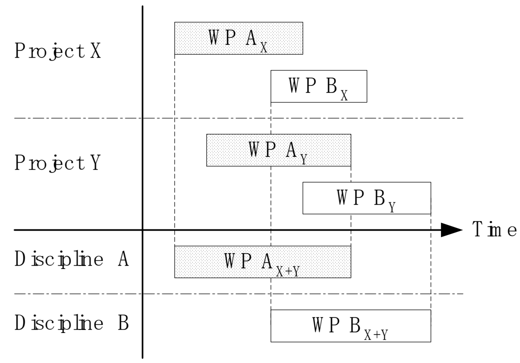

Fig.2.2 Task Integration based on Work Packages

PROBLEM STATEMENT

A typical project activity in an engineering firm is shown in Fig. 2.1 in a form of M. E. Porter's value-chain.[8] Each project is managed by the horizontal linkage along with its own project lifecycle. The engineering firm manages all projects with vertical linkages that regulate the volumes of available resources, such as human resources, technologies and IT systems. The value added activities of each stage may be evaluated according to the project strategy and every value added activity must be controlled with the corporate strategy to gain the higher margin of the enterprise.[11]

A work breakdown structure (WBS) is the key part to create the margin in the project work. It defines the work to be performed, specifies the required engineering type and level, and settles a base for controlling project schedule and responsibility.[9] The matrix organization provides efficient project execution environment with emphasis on the functionality of each discipline.[5] Under the matrix organization, all project tasks in WBS are assigned to each discipline through work packages which are basic control units of the project management, and strictly specify the scope, schedule, cost, deliverables and work volumes. Since a discipline team carries out multiple project jobs in general, the discipline manager must strategically assign human resources to ongoing and future projects. Fig.2.2 shows an illustrative example to perform the scheduled work packages for multiple projects. Considering a certain span of the time schedule, those work packages can be integrated and assigned to the appropriate quality-levels of discipline engineers according to the integrated work packages.

In the content of work packages, several grades of works are involved according to the degrees of difficulty. Generally, high or low quality class of engineers must be assigned to higher-grade or lower-grade works, respectively. In a practical situation, however, under the severe time constraint, it is often required that an engineers' class, especially middle class of engineers, must carry out the multiple grade works in parallel including the support works of higher and/or lower grade works. The multiple assignments can be effective to minimize the total man-hours and to mobilize the available engineers in a discipline team. Therefore, it is important for the discipline manager to find out a way of the human resource allocation along with the quality-levels of engineers to meet the graded work volumes.

Optimal allocation of human resources at planning phase may be changed at the actual phase of project life cycle, if the pre-determined conditions such as work volumes of the task and/or work efficiency of the assigned engineers are different from the initial estimation. Reallocation of the resources is often required to find the alternative optimal point and parametric studies of the work volumes and the efficiencies must be required to evaluate the alternatives under the actual conditions. Some heuristics are needed for a discipline manager to make decision on the assignment of capable engineers.

HUMAN RESOURCE ALLOCATION MODEL

Tasks associated with the work volume are specified in the work package. After each task is divided into several sub-tasks to meet available human resources in the discipline, the progress of the task is measured by man-hours consumed. The following assumptions are made for resource allocation problem.

1) A task in the work package can be divided into multiple grades of sub-tasks, and the work volumes are specified to the graded sub-tasks.
2) Discipline engineers can be classified into engineer's classes based on their engineering experiences and capabilities.
3) The work efficiencies of the graded sub-task can be defined for corresponding engineer's classes, respectively. There exist differences of work efficiency between primary engineer's class and support engineer's class against the assigned sub-task.
4) When an engineer charges some parts of work to the lower grade of support sub-task, the engineer should perform additional tasks, such as administrative work and/or clerical work.

Taking the above assumptions into consideration, a task execution model for a discipline engineers' class can be simplified as follows.

1) Man-hour of the class (i) engineer is allocated to three grades (M, N and X) of sub-tasks.
2) The class (i) engineer is an adequate for the grade (M) of sub-task and charged for the lower grade (N) of sub-task.
3) The engineer additionally has to handle the grade (X) of sub-task associated with the grade (M) of sub-task.

Considering the discipline operation, the following assumptions are added to describe the resource allocation problem:

1) All tasks are graded into the three grade, such as A, B and C, and all engineers are also classified into three class according to the task grade.
   First class engineer: He / She is assigned as a chief discipline engineer from the project and is in charge of the grade A tasks, such as approving task of the deliverables and correspondences.
   Second class engineer: He / She is a real workforce and is assigned as a lead engineer from the discipline manager and is in charge of the grade B tasks, such as engineering work. He / She also has a capability of a first class engineer.
   Third class engineer: He / She is a supporting staff and is in charge of the grade C of tasks, such as engineering support-work and engineering administration.
2) The first and second class of engineers are complementary to each other for the grade A and B tasks. On the other hand, the third class engineer cannot be assigned to the grade A and B tasks.

The resource allocation problem in the discipline, therefore, is summarized as a man-hour allocation model shown in Fig. 3.1 and the resource allocation problem is described by:

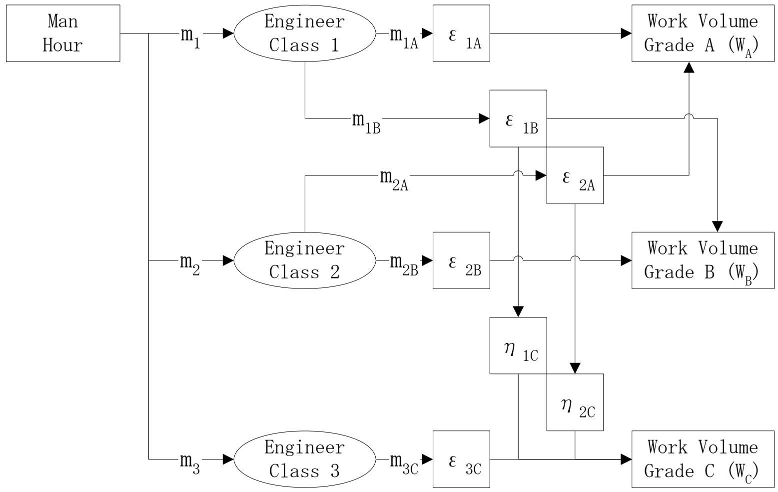

Fig. 3.1 Man-hour Allocation Model

Remarks:
m_i: Man-hours for the class (i) engineer
m_{iL}: Man-hours comsumed for the grade L task by the class (i) engineer, L=A, B, C
W_L: Work volume of the grade L task
ε_{iL} : Work efficiency of the class (i) engineer when he performs the grade L task
η_{iL} : Compensation factor of work efficiency for the class (i) engineer when he performs the grade L task as a side-work

Minimize $$Z^* = c\sum_{i=1}^{3} m_i \quad \text{or} \quad Z = \sum_{i=1}^{3} m_i \tag{1}$$

Subject to:

$$m_1 = m_{1A} + m_{1B} \tag{2}$$

$$m_2 = m_{2A} + m_{2B} \tag{3}$$

$$m_3 = m_{3C} \tag{4}$$

$$\varepsilon_{1A} \cdot m_{1A} + \varepsilon_{2A} \cdot m_{2A} = W_A \tag{5}$$

$$\varepsilon_{1B} \cdot m_{1B} + \varepsilon_{2B} \cdot m_{2B} = W_B \tag{6}$$

$$\varepsilon_{1B} \cdot \eta_{1C} \cdot m_{1B} + \varepsilon_{2A} \cdot \eta_{2C} \cdot m_{2A} + \varepsilon_{3C} \cdot m_{3C} \geq W_C \tag{7}$$

The objective function Z^* is total man-hour cost, where *c* in equation (1) is man-hour cost for an engineer class, and assumed to be constant for all engineer classes in the discipline. Then, *c* is omitted in the following discussion on optimal conditions. The optimal solution can be derived as the function of work efficiencies of different engineer classes and the graded work volumes.

ANALYSIS OF OPTIMAL SOLUTION SPACE FOR HUMAN RESOURCE ALLOCATION

The approach proposed herein centers on a problem in the form of Linear Programming (LP). The problem is solved by applying an analytical solution method for the LP problem, which enables possible essential understanding of the solution space for the problem.[7] The analysis of optimal solution space derived by the analytical solution method gives the following three results:

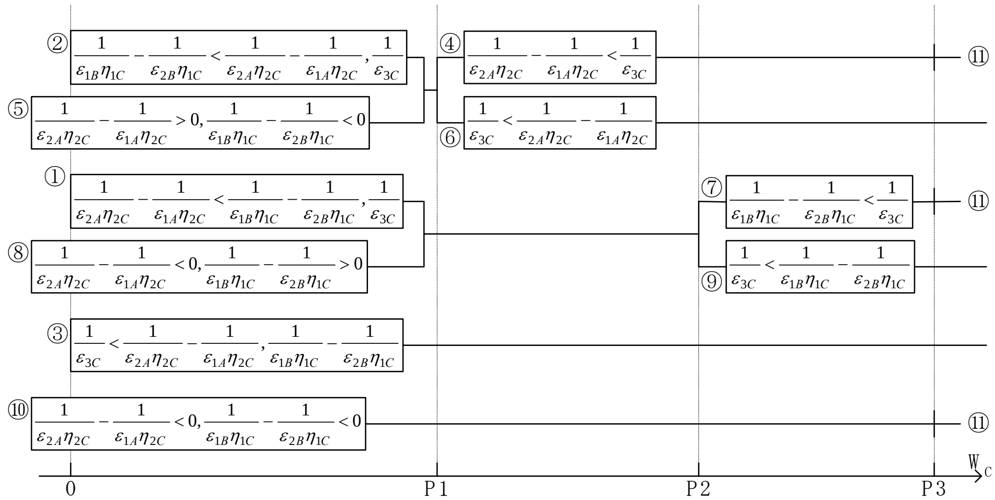

Fig. 4.1 Optimal Solution Space for Man-hours Allocation Problem (Space 1: P1 < P2 < P3)

1) Infeasible combination of basic variables
2) Combination of variables that cannot be optimal
3) Optimal allocation and condition for human resource allocation problem

In accordance with the analytical solution method, the set of combinations of feasible solutions is shown in Table 4.1, where 11 feasible solutions are listed. The solution number 3 shows an ideal assignment where each class of engineers has only charge of their own task. The optimal region of each feasible solution is depending on the following three transition points with respect to W_C.

$$\mathrm{P1} = \eta_{1C} W_B \tag{8}$$

$$\mathrm{P2} = \eta_{2C} W_A \tag{9}$$

$$\mathrm{P3} = \eta_{2C} W_A + \eta_{1C} W_B \tag{10}$$

P1, P2 and P3 define two solution spaces (P1 < P2 < P3 for Space 1 and P2<P1<P3 for Space 2), where each feasible solution is mapped in its feasible region. From the solution space 1 shown in Fig. 4.1, it is understood that the solution number 1, 3, 4, 6, 8 and 10 are feasible solutions in the range of P1 < W_C < P2. Optimal solution can be obtained according to the value of ε and η. Considering P1 < P2 < P3 as a practical condition, the optimal solution space is defined as shown in Fig. 4.1. Using this diagram, it is easily recognized the feasible and optimal conditions of each solution in the whole solution space. For

Table 4.1 Sets of Combination of Basic Variables

Soln. No.	m_{1A}	m_{1B}	m_{2A}	m_{2B}	m_{3C}	λ
1	1	0	1	1	0	0
2	1	1	0	1	0	0
3	1	0	0	1	1	0
4	1	1	1	0	0	0
5	1	1	0	0	0	1
6	1	1	0	0	1	0
7	0	1	1	1	0	0
8	0	0	1	1	0	1
9	0	0	1	1	1	0
10	0	1	1	0	0	1
11	0	1	1	0	1	0

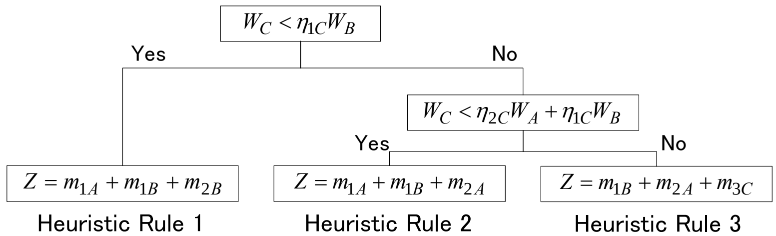

Fig.5.1 Rational Decision Tree for Human Resource Allocation Problem

example, if the solution number 5 is the optimal solution in the range of W_C < P1 and the work volume of grade C is changed from W_C < P1 to P3 < W_C under the following condition in equation (11), the optimal solution is transferred from No. 5 to No. 4 at the point P1, and No.4 is transferred to No. 11 at the point P3.

$$\frac{1}{\varepsilon_{2A}\eta_{2C}} - \frac{1}{\varepsilon_{1A}\eta_{2C}} < \frac{1}{\varepsilon_{3C}} \quad (11)$$

DERIVATION OF HEURISTIC RULES FOR RATIONAL DECISION

To derive heuristics for solutions, the following conditions are introduced to practically reflect the performance differences among each engineer's class.

1) Work efficiency of class 1 engineers for graded work B is higher than that of class 2 for work A. That is $\varepsilon_{1B} > \varepsilon_{2A}$.
2) Work efficiency of class 1 engineers for graded wok A is higher than that of class 2 for work B. That is $\varepsilon_{1A} > \varepsilon_{2B}$. Then,

$$\frac{1}{\varepsilon_{1B}} - \frac{1}{\varepsilon_{2B}} < \frac{1}{\varepsilon_{2A}} - \frac{1}{\varepsilon_{1A}} \quad (12)$$

3) Supposing that $\eta_{1C} > \eta_{2C}$ and $\varepsilon_{2A}\eta_{2C} > \varepsilon_{3C}$, then above conditions are summarized as the following equation:

$$\frac{1}{\varepsilon_{1B}\eta_{1C}} - \frac{1}{\varepsilon_{2B}\eta_{1C}} < \frac{1}{\varepsilon_{2A}\eta_{2C}} - \frac{1}{\varepsilon_{1A}\eta_{2C}} < \frac{1}{\varepsilon_{3C}} \quad (13)$$

Applying the above condition, the solution No. 2, 4 or 11 controls the optimal solution space shown in Fig. 4.1, and the following heuristics between the work volumes and the man-hours can be derived:

Heuristic rule 1:

If the work volume of grade C is less than P1,
then the class 1 engineer should perform the grade A task and share the grade B task with the class 2 engineer and
the class 2 engineer should concentrate on the grade B task and the grade C may be performed as the side-work of the class 1 engineer.

Heuristic rule 2:

If the work volume of grade C is greater than P1 and less than P3,
then the class 1 engineer should perform the grade A task and the grade B task and
the class 2 engineer should support the class 1 engineer and share the grade A task and the grade C task may be performed as the side-work of the class 1 and the class 2 engineers.

Heuristic rule 3:

If the work volume of grade C is greater than P3

then the class 1 engineer should support the class 2 engineer to follow the grade B task and the class 2 engineer should act as the chief engineer to perform the grade A task and the grade C task should be performed by the class 3 engineer under the support of the class 1 and 2 engineers.

As the summary of the above heuristics, a decision tree is presented in Fig. 5.1. In a discipline team, human resource on hand may be limited and all the jobs should be performed within the specified term. The discipline manager must make decision to assign suitable engineers or clerks according to their quality and quantity. Once the work efficiency ε and the factor η are registered for individual engineer and clerk, optimal solution can be identified by use of Fig.5.1. In this approach, decision maker can efficiently assign the appropriate engineers and clerks with the consideration of minimum man-hours or man-hour cost.

DISCUSSIONS AND CONCLUDING REMARKS

The proposed method can be applied to the planning stage and also to the actual phase of human resource allocation at the individual stage of project lifecycle. Traditional approach is too idealized and simplified to apply the actual resource allocation with different quality levels of engineers to perform various grades of given work volumes. In the competitive environment, the multiple assignments to several graded works must be considered to take an advantage of effective human resource allocation.

Though the above analytical approach may be limited to the size of the problem, it will be sufficient in a practical use to categorize the three classes of engineers and three grades of work volumes as described in the proposed model. The numerical approach can also be applied even if the problem is formulated in detailed LP model. However, the results are merely one point of optimal solution. If the decision maker wants to know the reason of optimal points or the sensitivity of the parameters such as work efficiency, some numerical case studies by repeated computations must be required to find the behavior of optimal solutions. On the other hand, the analytical approach proposed in the paper can suggest the solution behavior based on the whole solution space with the values of parameters at actual conditions. The reason of optimality can be clarified to see the local region of solution space or the change of optimal solution along with transition points as shown in Fig.5.1. The analytical approach also gives the theoretical reasons deriving the heuristic rules for optimal human resource allocation.

Further applications of the proposed method can be considered as follows:

1) In the viewpoint of enterprise project management, required quality and quantity of human resources in a firm can be evaluated for the whole project jobs including expected future projects. The graded work volumes in a certain future term are estimated as the summary of individual project jobs. Supposing the required class of engineers with expected work efficiency to perform the graded work volume, the required man-hours of individual engineers' class can be obtained, referring to Fig 4.1. The results can be used to make the firm's policy of human resources with future perspective.
2) If the specified work volumes are revised with the progress of projects, appropriate classes of engineers must be assigned according to the change of transition point.
3) If delay of project works is found and the actual efficiency of certain engineer class is lower than the expected one, the assignment must be changed according to the change of work efficiency in optimal solution space. The delayed work volumes must be added to keep the schedule.

CONCLUDING REMARKS

The model of human resource allocation is proposed to handle the assignment of different quality levels of engineers associated with the graded work volumes. Though the detailed description is omitted here due to the space limitation, the proposed method can be applied to various cases encountered in practice, such as the case with a specified work volumes being revised or the delay of project works being found. Though the above analytical approach may be limited to the size of the problem with three classes of engineers and three grades of work volumes, it will be sufficient in practice. Unlike the numerical approach to the LP problem-solving with the sensitivity analysis of parameters change and without knowing the reason of optimal points, the analytical approach proposed in the paper can suggest the solution behavior on the whole solution space with the values of parameters at actual conditions. The reason of optimality can be clarified to see the local region of solution space or the change of optimal solution along with transition points as shown in Fig.5.1. The analytical approach also gives the theoretical reasons deriving the heuristic rules for optimal human resource allocation.

ACKNOWLEDGMENT

This research was partially supported by the Ministry of Education, Science, Sports and Culture, Grant-in-Aid for Scientific Research (B), No.11680451 (2005), titled "Innovation for business strategy based on integrated PLM".

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