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OPTIMAL PROJECT ORGANIZATIONAL STRUCTURE FOR CONSTRUCTION MANAGEMENT

By Min-Yuan Cheng¹, Associate Member, ASCE, Cheng-Wei Su²,
and Horng-Yuh You²

ABSTRACT: This study relies on Trend Model to investigate various modes of coordination among team members of construction projects. According to the project network developed based on the characteristics of a project, Trend Model establishes an Activity Relationship Matrix (ARM) to identify the activity relationships within the construction process. ARM is used to construct an organizational structure for project management and a Communication Resistance Matrix (CRM) that shows the efficiency of communication and coordination among the members of the project team. In order to evaluate various organizational structures and their coordination efficiencies, this study utilizes the Analytical Hierarchy Process (AHP) to quantify the strength of an organizational structure and identify the optimal structure for project management. Through quantitative modeling of communication efficiency among organizational team members, an objective function for calculating the total resistance index is used to determine the optimal organizational structure available to execute the project. This study demonstrates how Trend Model may be applied in the future for evaluating the coordination efficiencies of various organizational structures.

¹Prof., Dept. of Construction Engineering, National Taiwan University of Science and Technology, Taiwan

²Research Assistant, Dept. of Construction Engineering, National Taiwan University of Science and Technology, Taiwan

Key Words: project organization, organizational structure, optimal organization, Trend model, trend analysis, analytic hierarchy process, organization communication, communication resistance

INTRODUCTION

Increase in construction project scale and complexity induces difficulty in project control. The scope of work, contents, and interfaces among different levels of the project team will certainly be increased. The key element for smooth execution of a huge construction project is a suitable project organizational structure, which will improve the efficiency of communication between different groups of project members. The duration of a construction project is quite long and during this period, coordination between different members of the construction team is vital for smooth project execution. The main issue of this paper is discussion of how to establish a well-organized structure with high working efficiency in order to expedite smooth project execution.

In the past, smooth progress control of a construction project relied on the development of the project network and analysis & control of the operation resources. It was expected that completion of a construction project within a certain time frame could be achieved through the application of the scheduling control technique. There are some articles discussing the influence of the organizational structure on the project's progress (Bennigson, 1971; Barrie, 1992). However, the degree of its influence and selection of the best organization structure for the project execution has not yet been addressed. Up until now, there has been no quantitative modeling used for the evaluation of a project's communication efficiency under different organizational structures. The purposes of this study are as follows: (1) Investigate the feasibility of establishing the organizational structure for a construction project by using the Trend Model method, (2) Establish a model for evaluating the communication resistance among the team members of a construction project through the application of an Analytical Hierarchy Process (AHP), and (3) Realize the optimal organizational structure for a construction project based on the quantitative evaluation results from the resistance matrix calculation.

Basic Assumptions

Due to the large number of uncertainties and breadth of information included in the

planning process, it is necessary to explore several assumptions before a model can be developed.

The basic assumptions of this study are described as follows:

(1) The optimal project organizational structure can be established only under the condition that the project network has been determined.

(2) The maximum number of the organization layers among the members of the construction project will be limited to three only and that which is consistent with current practice. In other words, there can only be three layers under the Construction Manager (C.M.). The members of the construction teams are classified into three categories, based on their characteristics, magnitude and expertise. The relative positions of these members in the organizational structure will be defined and restricted accordingly. These three layers are defined as: a. main contractor, b. intermediate contractor, and c. specialty contractor. The restrictions imposed on these three different layers of the construction members are explained as follows:

a. Main Contractor: Since there can only be three layers of working teams under the C.M., there are only a maximum of two layers of working members under the contractor in this layer. The main contractor is allowed to carry any type of work in all layers of the construction project. As one of the main contractors, General contractor is restricted to placement in the first layer of the construction team.

b. Intermediate Contractor: The contractors placed in this layer are generally smaller in company scale; there can only be one layer of working members under this type of contractor.

c. Specialty Contractor: The contractors listed in this layer are not allowed to have subcontractors, they are contractors with special skills or relative smaller company scale. They are considered the bottom line of the organizational structure and thus there are no layers of working member under them.

(3) Since the operational activity characteristics will be directly reflected in the activity time and the environmental & human factors are too complicated to be predicted during the work execution, these factors will not be considered in this study. This study will concentrate on the formation of organization structure under normal working conditions.

Scope of the Study

- (1) The organization of the construction team can be divided into two different types:
 - a. Administration Control Team: The main job of the administration control team is to handle the daily management work of all activities related to the construction work.
 - b. Construction Execution Team: The execution team is composed of the members involved in field construction work, such as the main contractor, intermediate contractor and specialty contractor. They work on a contract basis and their positions in the organizational structure are defined according to their assignment in the construction work and the organization chart established by Work Breakdown Structure (WBS).

This paper will concentrate on studying the organizational structure of the construction execution team. In addition, the organization and coordinating relationships between different members of the project, based on the differences and interfaces of the contracts, will also be analyzed.

- (2) As the optimality of the organizational structure is influenced by the project network, any change in the network will require the re-computation of the optimal organizational structure. However, any change in the organization structure after the contract has been signed will result in contractual problems. Such changes are considered to be beyond the scope of this work. This study focuses on developing the optimal organizational structure for the project during the construction planning phase - prior to the signature of related contracts. It can specifically assist with the following issues:

- a. Sensitivity analyses for the planning work under a definite network.
- b. Tendering operation under a clearly defined working sequence.

- (3) A port construction project is selected as the case study of this approach, thus the similar processes and flow diagrams could be adopted to other construction projects of a different nature.

- (4) A Trend Model is adopted for analysis of the relationships and niche positions among different members of the project team.

TREND MODEL

Trend Model was proposed by Bennigson in 1971, and is used for the establishment of the organization framework for a construction project. The model is constructed based on the scope and nature of the project. The probable organizational structure of the project team is investigated to reflect the interfaces due to subcontract relationships among the members of the project team. The niches and interfaces between the members of the project team are also analyzed in the model. The original functions of the Trend Model include: (1) Clearly define the relationship between different members of the project team during the execution of the project, (2) Predict the interface and mutual relationships between the members of the project team and the probable problems that will be encountered during the project execution, and (3) Establish the project control system within the required time frame. The following passage introduces the basic ideas of the Trend Model:

Analysis Concept of the Trend Model

Trend Model could analyze operation of the project team based on concepts such as mutual reliance, uncertainty and niche positions in the operation.

(1) Mutual reliance: Relationships between the members of the project team can be classified into the following categories: a. independent, b. sequential, and c. mutual reliance. Independent relationship indicates that the operation could be carried out through a standard procedure independently. Sequential relationship means that this particular operation could only be carried out after the completion of certain preceding operations, and the degree of reliance between these operations could be classified as medium. The conflicts among the sequential operations could be minimized through proper planning and coordination in advance. As for the mutual reliance, the degree of reliance is the highest among all the operations, thus the job could only be completed through good coordination between the related parties. Therefore intensive coordination should be practiced to have a unified goal and decision prior to commencement of the work.

(2) Uncertainty: During project execution, the risk and the impact from the external environment

of each work item will not be the same. Consequently, the uncertainty of the activity time is generated and the impact to the whole construction duration is classified as low, medium or high. For example, for the construction of a breakwater, the underwater leveling work of the caisson foundation and towing of the caisson are heavily dependent on sea and weather conditions. Variation in the activity duration of such work will be much higher than casting of the caisson in the dock, so uncertainty of these works will be higher than other work items in the project.

(3) Niche position: The respective working contracts and their roles in the construction sequence determines the relative positions of members in the project's organization structure. The influence of each work item on the progress of the project could be determined through analysis of the conflicts and mutual relationship between the project members (Bennigson, 1971). For example, if a work item carried out by the main contractor can only be started after completion of the subcontractor's work, due to its contractual restriction, the subcontractor should pay much more attention to finishing his job in order not to cause any delay to the main contractor. If the situation is reversed, the main contractor should pay less attention to that work for in interest of the subcontractor.

As only the mutual reliance within the operation and the influence of niche positions to the project are considered here, those factors that could not be clearly defined are beyond the scope of this study. However, the impact of uncertainty factors to the construction timeframe can be studied through probability or process simulation analysis. A worthwhile study would be to integrate this subject with project organizational planning in order to assist project managers in the decision-making process.

Trend Model's Analysis Procedure

In the process of establishing the Trend Model, the Trend Analysis procedure is adopted to define the working procedure for the model and illustrated as follows: (1) Clearly understand the content and characteristics of the work; (2) Plot the project network according to the relationship between the work items; (3) Estimate the uncertainty of each work item; (4) Draw

the diagrams of all possible organizational structures according to the clauses stipulated in the respective contracts; (5) Set up mutual relationships among the members of the project team; (6) Establish the Trend Map to facilitate analysis of the problems associated with the communication, coordination and mutual understanding between the project members. The conflicts between the members should also be analyzed and a solution will be brought out accordingly; and (7) Propose adjustments to the project organizational structure and conduct alternative analyses.

MODEL DEVELOPMENT

Based on the seven steps of the Trend Analysis, this study combines several steps and adds in the resistance value and matrix calculation in developing a new analysis model. With the application of Trend Model, the project network that represents the contents and characteristics of the work items is developed first. The Activity Relationship Matrix (ARM) is then developed accordingly to show the relationship between the project members. A Communication Resistance Matrix (CRM), which displays the resistance between the members of the project team, is developed according to the result of the ARM. AHP is adopted to quantify the resistance values between different layers of the project organization and the ideal organizational structure for the project can then be determined based on the results from the above mentioned procedures. The new model also includes seven steps, which are illustrated by a simple example as follows:

Clear Understanding of the Contents and Characteristics of the Project

Prior to finalizing the strategy for tendering operation, a thorough study of the project details, including content, quantity, scale, construction method, construction condition and field situation, should be done to provide the basic reference data for selecting the members in the project team and determining the optimal organizational structure.

Plotting of Project Network

The first step towards developing the project network is to create a Work Breakdown

Structure (WBS). The WBS is designed to describe the work elements of a project in a logical hierarchy that can be applied at various levels to structure schedule planning and organizational charts. For subcontracting purposes, the hierarchy of the WBS is developed in three levels according to the basic restrictions for the establishment of the organizational structure as discussed in assumption 2. The proper level of detail will depend upon the size, importance, and difficulty of the project as well as the specific scheduling and contracting principles that are adopted. Further, it is important to keep in mind that the tasks defined will serve as the basis for scheduling, for communicating the construction plan and for subcontracting. Although detailed task definition can be quite helpful, further details are only valuable to the extent that the resources required, durations, and activity relationships are realistically estimated for each activity.

Referring to assumption 1, the methodology applied in this study is valid only after the basic WBS and project network are fixed. Hence, after the completion of WBS, the relationship between activities and the whole construction sequence should be specified and shown on the network drawing to facilitate development of the ARM. The establishment of ARM in this study utilizes a modified PERT technique (Kaiser, 1971). The following example shown in Fig. 1 illustrates this process. The activities as well as the operation units required to facilitate the construction of ARM, are shown in the network.

<insert FIG. 1. here>

Node 2 of the drawing shows that member II can only start work after the completion of the work assigned to member I, and so as with member III. Node 3 indicates that member IV can start his work after member II has finished. Node 4 shows that member II can only start work after member III finishes. Node 5 shows that member III can only resume work after both member II and IV have finished their work. Node 6 indicates that member I can only start work after member III has finished. Node 7 indicates that member II can only start work after member I finishes.

Establishment of the Activity Relationship Matrix

From the construction sequence shown on the network, the number of hand-overs between the members can be found and presented in a matrix. Fig. 1 shows sequential connection between the members, where member II receives work from member I twice, and member I never receives any work from member II, thus member I never continues his work after member II. After inserting all these numbers into Table 1, the ARM of the project is completed.

<insert TABLE 1. here>

Drawing the Organizational Structure

It is supposed that under restrictions imposed by contracts, all possible organization structures together with their subcontractor structures should be drawn for further evaluation. This is a time-consuming process and probably too intricate for practical use. Thus some screening work is first preformed to complete the drawing work in an economical and practical manner. In order to enhance the feasibility of a better organizational structure and minimize the difficulty in communication at the early stages of the project, the following three principles are applied as the basis for the study.

- (1) To prevent over complexity of the structure, the layers will be limited to three only (referred to the assumption 2).
- (2) There are three different types of contractors under the C.M., which are categorized as the main contractor, intermediate contractor and specialty contractor according to their working characteristics, business scale and working capability as defined in the basic assumptions.
- (3) Evaluation of the structure is based on the working sequence of the contractor. In most cases, demand for communication and coordination between different contractors develops when work is passed on between them. The layer relationship between contractors only exists when these two parties work in a sequential relationship. The layer relationships are classified into two categories in this study:

Probable Layer Relationship. Should two work procedures in the project have to be

done in a sequential manner, then their relationship in the Trend Model is defined as “sequential relationship” with medium degree of reliance. In the analysis carried out by the Trend Model, these two members are assumed to exist in a probable layer relationship. In Fig. 1, for member I, the preceding worker is member III and the succeeding worker is member II. In consideration of the layer relationship, only members III and II are considered as the superior or sub contractors of member I. The relationship shown in Fig. 1 is tabulated in Table 2. Using Table 2, the potential superior or sub contractors of a particular member are identified in Table 3.

<insert TABLE 2. here>

<insert TABLE 3. here>

Definite Layer Relationship. If the preceding and succeeding workers of a member are of the same operation with extensive interfaces, then in the Trend Model they are defined as a mutual reliance relationship with a high degree of reliance. These two members will be put into definite layer relationship status. As shown in Table 2, both the previous and succeeding positions around of member I are member III, thus then it could be assumed that these members are in the definite layer relationship. Through the above-mentioned process, all possible organizational structures of the project can be identified for the further evaluation. (details are explained in the example)

Developing the Organizational Structure’s Communication Resistance Matrix

Survey of Experts

The communication resistance value between two members of different layers of the organizational structure is represented as K_i (as shown in Fig. 2). Resistance coefficient K_i is the basic variable used to represent the degree of communication ease in the project. In order to estimate the weight of K_i , a questionnaire survey was objectively conducted using the AHP method. Fifty questionnaires were sent and 30 responses were valid, showing a recovery rate of 60 percent. The samples obtained represent different construction phases, including 2 owners, 4 construction managers, 5 government employees, 8 engineers, 4 site managers, 4 field

supervisors, 1 construction team leader and 2 others for a total of 30 people. The averaged working experience of the respondents was 11 years.

Example Resistance Coefficient Evaluation of Questionnaire

Introduction: The purpose of this survey is to investigate the relative weight of communication resistance value (K_i) between two members at different levels of the organizational structure (as shown in Fig. 2). According to the respective working contracts and their roles in the construction sequence, the relative positions of members in the project's organization structure are determined. Members in different layers may have different degrees of communication ease to the related parties in higher or lower layers. Resistance coefficient K_i , a one-way communication index, is used to evaluate the ease of communication for solving disputes, conflicts or coordination problems between related parties in different layers. The basic assumptions of this survey are: (1) Only mutual reliance within the operation and each party's niche position in the project's organizational structure are the factors considered for evaluating the K_i value. (2) Only members in adjacent layers have a contractual relationship. For example, member I has direct contractual relationships with his higher layer CM and lower layer members II and III. Member IV has no direct contractual relationship with member I. (3) Due to contract restrictions, members at the lower layer would pay much more attention to job completion in order not to cause any delay or conflict with members at the higher layer. Further, the reverse relationship also holds - members at the higher layer will pay less attention to that work for in interest of the members at the lower layer. As a result, different directions of communication have different degrees of communication ease. The definitions of K_i values are as follows:

<insert FIG. 2. here>

Here K_1 : the resistance of the C.M. to the members of the first layer; K_2 : the resistance of members of the first layer to those in the second layer; K_3 : the resistance of members of the second layer to those in the third layer; K_4 : the resistance of members of the third layer to those in the second layer; K_5 : the resistance of members of the second layer to those in the first layer;

K6: the resistance of members of the first layer to the C.M.

Survey Questions:

1. Based on your personal experience and understanding of construction projects, please rank the K_i values from 1~6.

K1 = _____ , K2 = _____ , K3 = _____ , K4 = _____ , K5 = _____ , K6 = _____

2. All the resistance values K_i shown in Fig. 2 were determined on a pair-wise comparison basis. For example, in Table 4, if you think the communication resistance of members of the first layer to the second layer (K2) is more difficult than the communication resistance of the CM to the members of the first layer (K1), the difficult column is checked.

<insert Table 4. here>

3. Please write your name, age, comprehension level (percent) of this survey, academic degree, working description, working experience, and position.

Name: _____

Age: ___ below 19, ___ 20~29, ___ 30~39, ___ 40~49, ___ 50~59, ___ above 60

Comprehension level (percent) of this survey: ___100% ___80% ___60% ___40% ___20%

Academic degree: ___ Ph.D., ___ MS, ___ BS, ___ Senior High, ___ the other

Working description: ___ planning, ___ design, ___ construction, ___ the other

Working experience: _____ years

Position: _____

After transforming the linguistic items in Table 4 to the represented values, all questionnaires underwent a consistency test to ensure that they were logically correct. The average and variance of K_i values derived from the effective answer sheets are shown in Table 5. The data, suitable for general construction projects, is used as the basis for quantitative evaluation of the optimal organizational structure in the following case study.

<insert Table 5. here>

Developing the Communication Resistance Matrix

The communication is assumed to be transferred through the layer structures as shown in Fig. 2, thus messages passed from member II to member III should go through member I and member I passes messages received from member II to member III. Based on this assumption, resistance should be accumulated, thus resistance from member II to member III is the sum of the resistance value from member II to member I and from member I to member III. Likewise, the resistance from II to IV includes that from II to I, I to III and III to IV accordingly. The values for communication resistance among members of the project team could be calculated in the same manner and tabulated in a matrix form as shown in Table 6, which is a Communication Resistance Matrix for Fig. 2.

<insert TABLE 6. here>

Calculating Total Resistance of Each Organizational Structure

$$\begin{aligned} &\text{Total Resistance Matrix of the organizational structure } T_{mn} \\ &= \text{Activity Relationship Matrix} \bullet \text{Communication Resistance Matrix} \end{aligned} \quad (1)$$

where (\bullet) : product symbol; m,n: member of the project organizational structure

$$\text{Total Resistance Index (TRI)} = \sum T_{mn} \quad (2)$$

Multiplying all the values of the ARM shown in Table 1 by the corresponding values of the CRM shown in Table 6 produces the Total Resistance Matrix (T_{mn}) for that particular organization structure [see (1)]. The Total Resistance Index (TRI) is the sum of all the components of the T_{mn} [see (2)]. The calculated result of the total resistance for the example is shown in Table 7.

<insert TABLE 7. here>

$$TRI = \sum T_{mn} = 2(K5)+k5+(K5+ K2)+(K4+K5+K2)+K2+((K5+ K2)+K3$$

Determining the Optimal Organizational Structure

After the TRI for each possible organization structure is calculated, the one with the smallest value is determined to be the optimal organizational structure. This selection is further analyzed to check feasibility and the possible difficulties encountered during the project

execution. If there are no serious obstacles detected during this further evaluation process, then it is regarded as the optimal organization structure for the project.

CASE STUDY

The construction project adopted as the case study is a wharf construction project within the port. Generally, marine construction work is especially sensitive to changes in environmental conditions and includes many uncertain factors thus the coordination between the team members becomes more important than on other projects. The Trend Analysis developed by this paper will be utilized for the establishment of a well-coordinated organizational structure for smooth execution of all construction work.

Project Scope and Characteristics

(1) Work items: The construction procedures and work items are listed as follows:

a. Fabrication of 40 concrete caissons by slipform in the dry dock (in this example the number of caissons has been reduced to four for simplicity), b. Towing the caissons to their designated positions above the prepared stone beds by a tugboat, c. Leveling the stone beds for laying down the caissons, d. Placing the caissons on the prepared stone beds, e. Backfilling the caissons with sand, f. Casting and post-tensioning the bollard beams, g. Placing the capping concrete for the caissons, and h. Installing service facilities.

(2) Members of the Construction Team

a. Construction Manager: CM b. General Contractor: G c. Mech. & Elec. Contractor: M
d. Diver Subcontractor: D e. Tugboat Contractor: T f. Dredging Contractor: R
g. Prestressing Contractor: P

(3) Content and executor of each work item

a. Caisson production (executed by G): Caisson height is 7.6 m, so a vertical slipform system is adopted to accelerate construction work. They are fabricated within the dry dock specially built for this project and the buoyancy of the seawater is utilized for towing them.

- b. Curing the Caissons (executed by G): After a caisson is fabricated, curing the concrete is a necessity to ensure its quality of the concrete and prevent damage to the caisson in the towing and sinking process.
- c. Leveling the caisson stone beds (executed by D and R): The stone beds are also called rock fill foundations, and are composed of rocks dumped from the water surface. Dumping the rocks is directed and controlled by the divers.
- d. Towing Caissons out to the designated position (executed by T): A caisson is connected to the tugboat by ropes and towed to the designated location.
- e. Sinking the caisson onto the prepared stone beds (executed by T): After the caisson is in position, it will be sunk onto the designated position by using dynamite, pumping water in or opening the water gate to let the water flow into the caisson.
- f. Backfilling the caisson with sand (executed by R): After placing a caisson, sand should be filled into its compartment to increase its stability.
- g. Casting and post-tensioning of bollard beams (executed by G and P): The bollard beams are imbedded into the caisson during the backfilling operation and post-tensioned after completing backfilling of the caisson.
- h. Placing the capping concrete (executed by G and D): To prevent the washout of backfilled sand by the wave activity, the top of each compartment of a caisson is covered with cast-in-place concrete.
- i. Installation of the service facilities (executed by G and M): The parapet is constructed on the seaside of the caisson and other service facilities are installed if deemed necessary.

Project Network Development

Four caissons are fabricated in this project and there are 9 major activities in the construction of each caisson. Considering the repetitive work in the cycling operation of the construction work, the total working activities are reduced down to 36. Fig. 3 shows the project network. In the figure, the arrows represent the working activities and the end nodes of the

arrow imply the start, finish and logical relationship of each working activity, in other words, the preceding and sequential relationship of the working procedures. The frame and sequences of the construction procedure are established accordingly.

<insert FIG. 3. here>

Development of the Relationship Matrix

According to the network, the preceding and sequential relationship for the members of the project is filled in the relationship matrix as shown in Table 8. For example, the Prestressing contractor has to continue his job after the general contractor in a sequential way 4 times during this project, thus 4 is filled in at the intersection of row P and column G. The rest of the matrix is likewise completed in the same manner.

<insert TABLE 8. here>

Possible Organizational Structure

The development of the Work Breakdown Structure (WBS) is illustrated in this section. The sample project involves 42 working interfaces and the number of interfaces between different contractors is 27. It is a quite complicated operation. Prior to the establishment of the WBS, this study simplifies the working levels in consideration of the capability of each individual contractor and project needs to eliminate impossible contract relationships. Also, the basic restrictions for the establishment of the organizational structure are defined as follows:

- (1) Only three working layers are allowed under the C.M.
- (2) The restrictions on the working layer of the subcontractors under the C.M. are as follows: a. Considering the characteristics of the work, the G, M, and T could be considered as the first layer contractors, while G should always be the first layer contractor; b. Considering the working capability and expertise, the contractor is allowed to have two layers of subcontractors: G; c. Considering the working capability and expertise, the contractors are allowed to have one layer of subcontractors: T, R; and d. Considering the working capability and expertise, the contractors are not allowed to have any layers of subcontractors: P, M, D.

(3) Only those activities which have preceding and sequential relationships are considered to have a layer relationship in the organizational structure. According to the reliance degree identified in the Trend Model, the layer relationship could be classified into two categories:

a. Probable Layer Relationship: The working sequences of the members of the project teams are listed in Table 9. According to the working sequence, the layer relationship of the operation could be defined and the preceding and succeeding contractors of that particular activity are listed in Table 10.

<insert TABLE 9. here>

<insert TABLE 10. here>

b. Definite Layer Relationship: From Table 9 and 10, it is found that G is both the preceding and succeeding working unit of T and this relationship happens several times during the execution of the project. So G and T have a definite layer relationship and so as with G and P. In this basic assumption, it is clearly defined that G must be on the first layer, so G could not be the subcontractor of P or T. In the Trend Model, T and P should be the subcontractors of G.

In consideration of all the above conditions, 7 different alternatives are identified during the establishment of the organizational structure (as shown in Fig. 4). In Fig. 4, Alternative 1 was the organizational structure used for executing this project.

<insert FIG. 4. here>

Developing the Project's Communication Resistance Matrix

In this section, alternative 1 in Fig. 4 is taken as the example to illustrate the procedures for the development of the communication resistance matrix. In alternative 1, should the dredging subcontractor(R) want to communicate with the tugboat contractor (T), he should pass the message to the general contractor first and let the general contractor inform the tugboat contractor of the request for smooth coordination. Following this logic, the impedance value K of this coordination work is $K_5 + K_2$. Within the same manner, the impedance values of all the activities can be added and filled in the matrix as shown in Table 11 for alternative 1. Likewise, the matrix for other alternatives could be completed in the similar way.

<insert TABLE 11. here>

Calculating the Total Resistance Index of Each Organizational Structure

Multiplying each value of the ARM with its corresponding value of the CRM, the values of the Resistance Matrix of each alternative are obtained. The Total Resistance Index (TRI) for each alternative is the summation of all the values in the corresponding Resistance Matrix, and higher values indicate poorer communication. Table 12 shows the calculation result of the TRI of alternative 1. The TRIs of all the alternatives are shown in Table 13.

<insert TABLE 12. here>

<insert TABLE 13. here>

Determining the Project's Optimal Organizational Structure

As the organizational structure with the lowest TRI is the best choice, alternative 6 in Table 13 is the optimal organizational structure for this particular project. Comparing alternative 6 with the project's real organizational structure (alternative 1), it can be seen that the proposed organizational structure is better as it has fewer number of conflicts in communication and more efficient for coordination. As shown in Fig. 4 and Table 12, the major communication obstacles occur in two places: (1) relationship between the General contractor and Mech.&Elec. contractor and (2) relationship between the tugboat contractor and dredging subcontractor. After rearranging the organizational structure and contractual relationships, the efficiency of communication and coordination among the team members improves as indicated by alternative 6. In other words, implementing alternative 6 should result in the minimum number of communication obstacles and maximum coordination efficiency during work execution.

According to the evaluation results, the organizational structure with fewer layers or hierarchical levels is very close to the optimal organizational structure and the coordination efficiency among the team members can be enhanced. This finding is similar in context to the results of studies on Business Process Reengineering. However, the most optimal structure is not necessarily the flattest one, and the most suitable layer relationship should be derived from

the mutual reliance relationship on the project network. Moreover, other alternatives with only minor differences in TRI from alternative 6 could be provided as good references for the manager in elaborating the organizational structure.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The following conclusions can be drawn based on the research work.

- (1) Due to the numerous working interfaces, complicated networks and diversified team members of a large construction project, coordination efficiency among members of the construction team is vital to the project's success. For a simple network or small organization, the organizational structure could be decided based on experience or simple analysis and the impact of poor organization on the execution of such a small project is limited. In the case study of this research, the sample project entails 42 working interfaces and the number of interfaces between different contractors is 27. Smooth coordination is a key issue for the success of this project. Trend Model analysis method provides a useful tool for the quantitative evaluation of the optimal organizational structure, leading to successful execution of the project.
- (2) This study pioneers quantitative evaluation to determine the optimal organizational structure. Before usage of the Trend Model, selection of an organizational structure could be based on rough guessing or a manager's intuition and estimation. However, incorporation of the Trend Model clarifies the evaluation process and uses clear measures and variables to determine the optimal organizational structure.
- (3) Based on the findings of this study, adequate simplification and leveling of organizational structure is not too far away from optimal organizational structure and could promote coordination efficiency among team members. However, the flattest structure is not necessarily the most optimal one, and the most suitable layer relationship should be derived from the mutual reliance relationship on the project network.

Recommendations

(1) In order to simplify the complicated calculation procedure, several assumptions are made in proposing the possible organizational structures. In its real application, it is suggested that the planner should make the necessary modifications based on their demands and project characteristics to decide the possible organizational structures for further evaluation. These modified alternatives will then be evaluated by the Trend Model to determine the optimal organizational structure.

(2) This study proposes a quantitative evaluation method for determining the optimal organizational structure. In future application of this method for evaluating the optimal organizational structure, the resistance index is the key factor for realizing the organizational structure. Thus, it is suggested that some modifications be made on the resistance index based on the characteristics and working conditions of the construction project.

(3) Due to time restrictions and basic assumptions, this study focuses on the quantitative evaluation of the organizational structure under static conditions. Operations with high uncertainty will have greater variability in determining project progress. In these cases, project execution could be severely behind or ahead of schedule due to uncertain factors. After the sequential relationship of the interfaces are clearly defined, the increase of the uncertainty of some particular operation will be very important to the layer relationship between the project members. It would be a worthwhile study to integrate this subject with organization design in order to assist project manager in the decision-making process.

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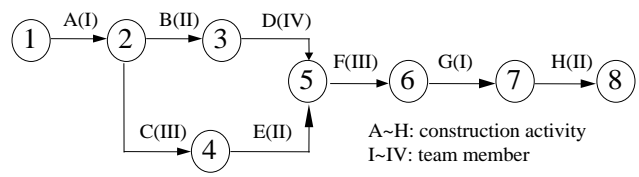


FIG. 1. Project Network

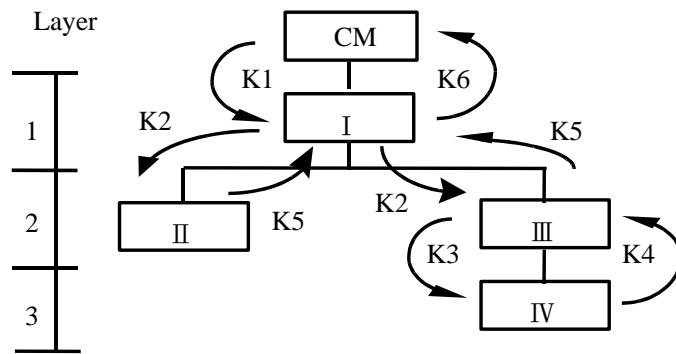


FIG. 2. Project Organizational Structure

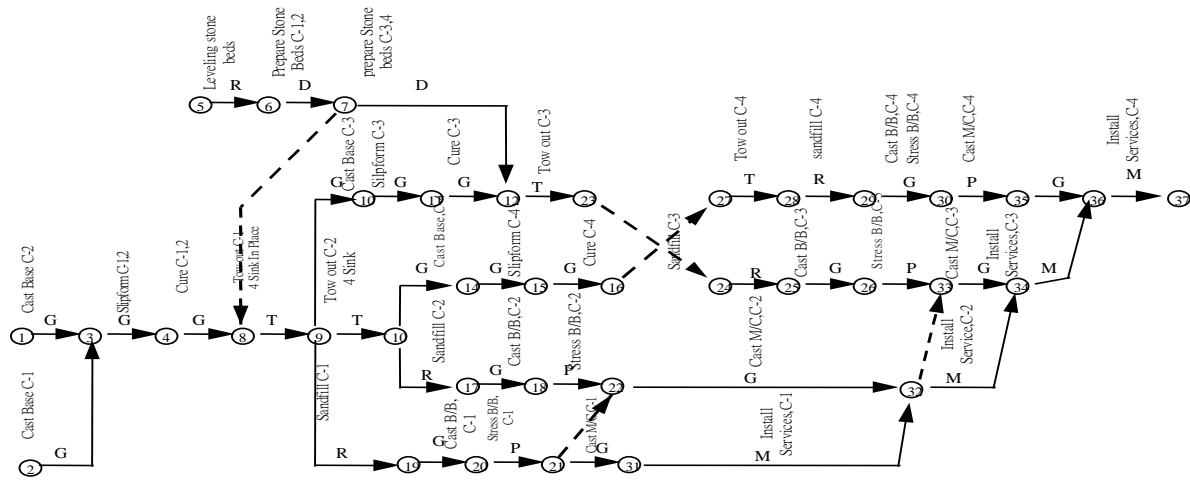
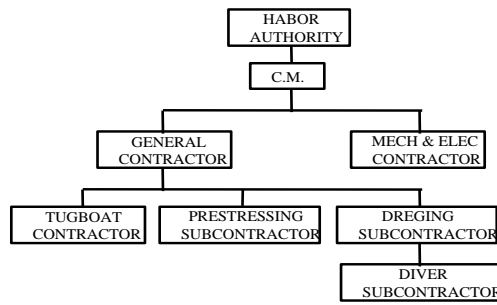
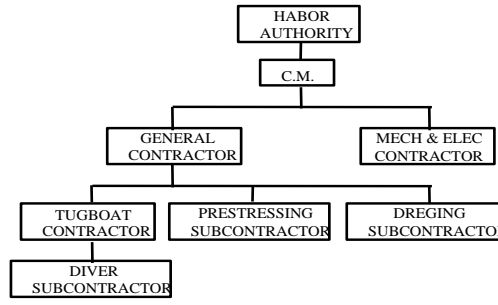


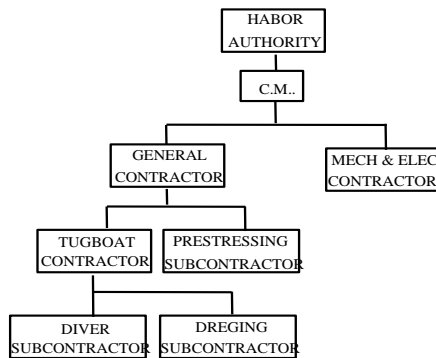
FIG. 3. Sample Project Network



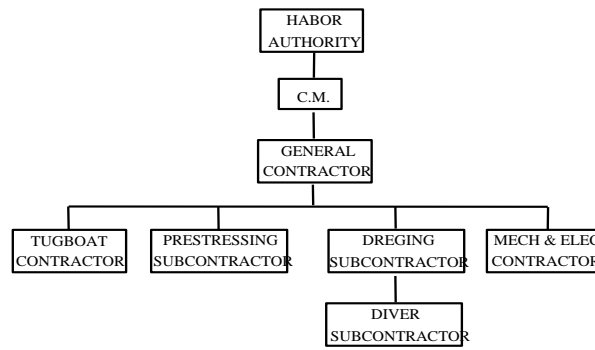
(Alternative 1)



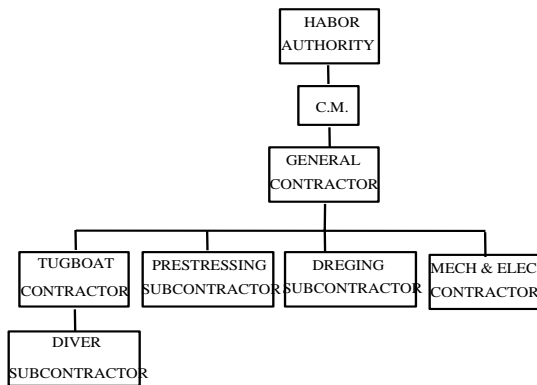
(Alternative 2)



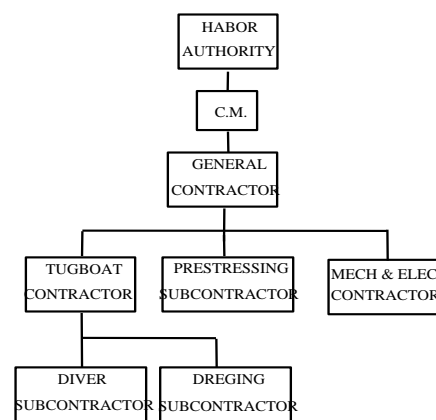
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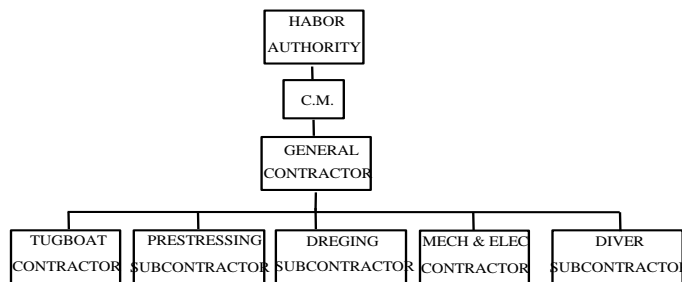
(Alternative 4)



(Alternative 5)



(Alternative 6)



(Alternative 7)

FIG. 4. Sample Project Organizational Structures

TABLE 1. Activity Relationship Matrix

		Succeed Activity Unit			
		I	II	III	IV
Precedent Activity Unit	I	0	2	1	0
	II	0	0	1	1
	III	1	1	0	0
	IV	0	0	1	0

TABLE 2. Preceding/Succeeding Activity
Relationship

Name of member	Continuous activity unit	
	Preceding activity unit	Succeeding activity unit
I	III	II,III
II	I,III	III,IV
III	I,II,IV	I,II
IV	II	III

TABLE 3. Probable Layer Relationship

Name of member	Potential superior or subcontractor
I	III,II
II	I,III,IV
III	II,IV,I
IV	II,III

TABLE 4. Pair-Wise Comparison

Ki \ Resist	very easy		easy		equal		difficult		very difficult	
	5	4	3	2	1	1/2	1/3	1/4	1/5	
K1							v			K2
K1							v			K3
K1									v	K4
K1								v		K5
K1							v			K6
K2						v				K3
K2								v		K4
K2								v		K5
K2							v			K6
K3								v		K4
K3								v		K5
K3							v			K6
K4				v						K5
K4			v							K6
K5				v						K6

TABLE 5. Resistance Coefficient

	Average	Variance
K1=	0.106	0.0835
K2=	0.117	0.0607
K3=	0.134	0.0737
K4=	0.195	0.0928
K5=	0.218	0.0756
K6=	0.230	0.1100

TABLE 6. Communication Resistance Matrix

	I	II	III	IV
I	0	K5	K5	K4+K5
II	K2	0	K5+K2	K4+K5+K2
III	K2	K5+K2	0	K4
IV	K2+K3	K5+K2+K3	K3	0

TABLE 7. Total Resistance Calculation of the Organizational Structure

	I	II	III	IV
I	0	2	1	0
II	0	0	1	1
III	1	1	0	0
IV	0	0	1	0

•

	I	II	III	IV
I	0	K5	K5	K4+K5
II	K2	0	K5+K2	K4+K5+K2
III	K2	K5+K2	0	K4
IV	K2+K3	K5+K2+K3	K3	0

=

	I	II	III	IV
I	0	2(K5)	K5	0
II	0	0	K5+K2	K4+K5+K2
III	K2	K5+K2	0	0
IV	0	0	K3	0

TABLE 8. Activity Relationship Matrix of the Project

		Success activity					
		G	D	P	R	M	T
Precedent activity	G	10	0	4	0	4	3
	D	0	1	0	0	0	1
	P	4	0	0	0	0	0
	R	4	1	0	0	0	0
	M	0	0	0	0	3	0
	T	2	0	0	4	0	1

TABLE 9. Preceding/Succeeding Activity
Relationship Table of the Project

Name of member	Continuous activity unit	
	Preceding activity unit	Succeeding activity unit
G	P, R, T	P, M, T
D	R	T
P	G	G
R	T	G, D
M	G	-
T	G	G

TABLE 10. Probable Layer Relationship of the Project

Name of member	Potential superior or subcontractor
G	P, R, T, M
D	R, T
P	G
R	T, G, D
M	G
T	G

TABLE 11. Communication Resistance Matrix for Alternative 1

Alternative 1	Communication Resistance Matrix					
	G	D	P	R	M	T
G	0	k_4+k_5	k_5	k_5	k_1+k_6	k_5
D	k_2+k_3	0	$k_5+k_2+k_3$	k_3	$k_1+k_2+k_3+k_6$	$k_5+k_2+k_3$
P	k_2	$k_4+k_5+k_2$	0	k_5+k_2	$k_6+k_1+k_2$	k_5+k_2
R	k_2	k_4	k_5+k_2	0	$k_6+k_1+k_2$	k_5+k_2
M	k_6+k_1	$k_4+k_5+k_6+k_1$	$k_5+k_6+k_1$	$k_5+k_6+k_1$	$k_5+k_6+k_1$	0
T	k_2	$k_4+k_5+k_2$	k_5+k_2	k_5+k_2	$k_6+k_1+k_2$	0

TABLE 12. Total Resistance Index for Alternative 1

Activity Relationship Matrix							Communication Resistance Matrix						
	G	D	P	R	M	T		G	D	P	R	M	T
G	10	0	4	0	4	3	G	0	0.41	0.2	0.22	0.3	0.22
D	0	1	0	0	0	1	D	0.25	0	0.5	0.13	0.6	0.47
P	4	0	0	0	0	0	P	0.12	0.53	0	0.34	0.5	0.34
R	4	1	0	0	0	0	R	0.12	0.2	0.3	0	0.5	0.34
M	0	0	0	0	3	0	M	0.34	0.75	0.6	0.55	0	0.55
T	2	0	0	4	0	1	T	0.12	0.53	0.3	0.34	0.5	0

	G	D	P	R	M	T
G	0	0	0.9	0	1.4	0.66
D	0	0	0	0	0	0.47
P	0.48	0	0	0	0	0
R	0.48	0.2	0	0	0	0
M	0	0	0	0	0	0
T	0.24	0	0	1.36	0	0

Σ Tmn=6.13

TABLE 13. Total Resistance Index Table

Alternatives	1	2	3	4	5	6	7
TRI	6.13	6.12	5.98	5.65	5.56	5.4	5.52
Normalized	1.14	1.13	1.09	1.05	1.03	1.00	1.02

numerous different WBSs can be defined for each construction plan. For example, upper-level activities might be related to facility components such as foundation elements, and then lower-level activity divisions into the required construction operations might be made. Alternatively, upper-level divisions might represent general types of activities such as electrical work, while lower work divisions represent the application of these operations to specific facility components. As a third alternative, initial divisions might represent different spatial locations in the planned facility. The choice of a hierarchy depends upon the desired scheme for summarizing work information and on the convenience of the planner.

To clearly understand the construction sequences, the components of the project should be disassembled into independent activities, and the project network drawn according to their construction sequences. Prior to development of the project network, it is generally advantageous to introduce an explicit hierarchy of work activities for the purpose of simplifying the presentation and development of a schedule. For example, the initial plan might define a single activity associated with “site clearance.” Later, this single activity might be subdivided into “relocating utilities,” “removing vegetation,” “grading”, etc. These activities could continue to be identified as sub-activities under the general activity of “site clearance.” This hierarchical structure also facilitates the establishment of organization charts and contracting principles in which detailed operations with the same working characteristics, required resources or technology are grouped into the same subcontract. Thus, the number of working interfaces is not only reduced, but communication and coordination efficiency between the detailed operations is also increased.

A number of different activity hierarchies can be defined for each construction plan. The choice of a hierarchy depends on the desired scheme for summarizing work information and on the convenience of the planner. In addition, the number and detail of activities in a construction plan can either be a matter of judgement or based on requirements. Construction plans can easily range from less than a hundred to thousands of defined tasks, depending on the planner’s

decisions and scope of the project. If the subdivided activities are too refined, it is not beneficial as reasonably accurate estimates of activity durations and required resources cannot be made at the detailed work breakdown level. On the other hand, if the specific activities are too coarse, it is impossible to develop realistic schedules and details for resource requirements during the project.