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Construction management process reengineering: Organizational human resource planning for multiple projects

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Abstract

Applying the business process reengineering and organization planning philosophy, this study focuses on human resource planning in construction management process reengineering (CMPR) to develop a team-based human resource planning (THRP) method for deploying laborpower. The THRP method has two purposes; the first is to determine the maximum loading of projects the original laborpower can carry, and the second is to identify the range of laborpower required for expected project loadings in the future. The THRP method includes four phases, namely, process reengineering, data preparing, human resource allocation, and simulation. Using the THRP method, a construction company cannot only design a team-based organizational structure, but also allocate human resources based on cross-functional processes. Moreover, human resource utilizations before and after CMPR can be compared to evaluate savings attributable to the CMPR. As a consequence, optimum laborpower can be assessed, and human resources allocated to fit the changing processes and circumstances of a construction company's growing business.

Keywords: Human resource planning; Construction management process reengineering; Team-based organization; Simulation

1. Introduction

The phrase "business process reengineering" (BPR) first appeared in 1990, raised by Michael Hammer in a Harvard Business Review paper called "Reengineering work: Don't automate, obliterate" [1]. Hammer believed that, although in the fiercely competitive environment of the 1990s most businesses were adopting measures such as rationalization and automation to improve their organizations, none of these measures was truly improving business operations. Many businesses were also spending millions of dollars to improve or implement new information technology; however, these efforts served only to strengthen the existing false working processes, thus causing organization costs to increase, with negligible gains in improved performance. To solve these problems, the idea of "engineering" was advanced as a theory and tool for business reorganization. In Hammer's fundamental definition, BPR starts from very basic issues and asserts that the reengineering process can dramatically improve an organization in terms of its costs, quality, services, and speed. For this purpose, three BPR "cores" are insisted on in Hammer's article: process reorganization, the use of information technology, and organizational redesign [2]; that is, a successful implementation of BPR depends not only on process innovation, but also on organizational changes [19].

To implement the BPR, existing activities spread among different departments are integrated into a single complete process designed to fulfill a specific business goal. However, when business functions are integrated, new processes with multiple functions are easily impeded by departmental barriers within function-based organization structures. Conversely, process execution is smoother in a team-based organization [2,20]. A work team is a cross-functional unit consisting of workers from relevant departments. In a team-based organization, department barriers do not exist and business resources can collaborate to achieve the process targets. Due to the fundamental differences between team-based and function-based organization structures, both the organization and the human resource need to be reorganized to match the redesigned processes. In addition, as companies grow, the growth of

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organization is continuous; therefore human resource planning for future project loading is equally essential for construction companies.

As is apparent from the above, the prudence and efficiency of a human resource planning directly influences the success of the BPR. Thus, a reliable methodology to create a team-based organization depending on operation processes, and to determine credible laborpower capability for allocating human resources is essential and significant for construction companies.

However, for human resource planning, most approaches allocate laborpower in construction projects based on the assumption of a steady organization structure for executing processes [3,4], or some forecast human resource requirement depending on mass sampling survey with statistical analysis [5]. In most cases, these would be valid methods in an organization-steady company. However, considering the changes of processes and of organization structure after process reengineering, this study applied the simulation method for laborpower allocation and prediction.

Simulation method has been applied widely in construction processes and resource management issues [6–13,21]. Construction simulation was introduced by Halpin [7] with the development of the CYCLONE modeling methodology [7,11]. Due to its using small abstract set of basic modeling elements, CYLCONE framework is probably the most commonly known of construction-specific process simulation techniques [14]. However, fewer simulation researches and applications were aimed at construction management processes and organization behaviors. To analyze behaviors of a concurrent design team, Jin and Levitt [15,16] developed the virtual design team (VDT) simulation environment and described three different approaches to the simulation of organizational behavior and discusses the issues related to how to create a computational organization model for simulation [15,16]. According to Levitt's researches, characteristics of activities, human resource, information flow and organization structure are all crucial for analyzing organizations.

Consequently, this study combines the BPR philosophy, team approach and simulation method to demonstrate a team-based human resource planning (THRP) model. Applying the THRP model, a team-based organization can be designed based on the reengineered processes; therefore, the corresponding maximal project loading of laborpower can be determined, and vice versa, the laborpower required for expected project loadings can also be evaluated. Typically, a real construction company's BPR case is illustrated in this paper to confirm the feasibility of the THRP model.

2. Team-based human resource planning for multiple projects

The THRP model is endued with two purposes of this study: (1) create a team-based organization structure based on the reengineered processes, and (2) predict laborpower requirements for a team-based organization. The THRP model achieves the study purposes by mapping a company's processes to a simulation system in four phases as shown in Fig. 1. First, a new processes model and a team-based organization structure are designed in the process reengineering phase. Then, data preprocessing methods and the simulation algorithms are, respectively, analyzed and developed. Finally, all results from the previous three phases are integrated in the simulation system. Through simulation, the maximal laborpower capability in a work team can be predicted and served as references for human resource planners to make up their lack of experience and information in team-based organization.

2.1. Process reengineering

In the THRP, to ensure that human resources can be allocated from rational business processes, the bases of THRP are the rational processes. Hence, in the first phase of the THRP model,

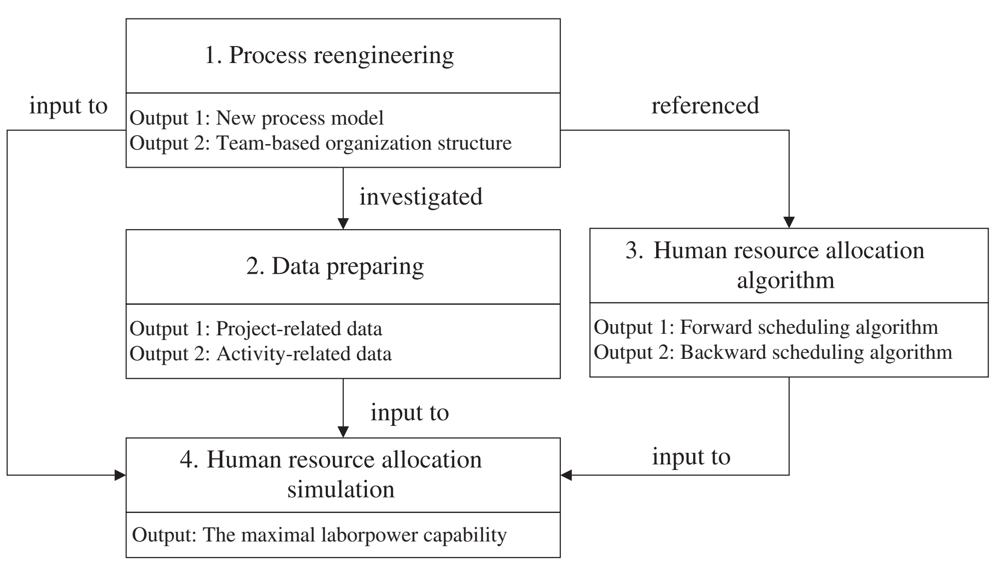


Fig. 1. The THPR Model.

BPR philosophy is applied to integrate organizational functions smashed in different departments into independent and complete new processes, and team approach is used to design a team-based organization to facilitate the newly-designed process. Accordingly, two primary purposes are served in this phase:

1. *Redesign the process model*: Problems hidden in the process are identified and the findings used as the basis for an analysis of the existing management problems of construction companies. A new process model is then drafted in accordance with the analysis and the applications of management information technology systems.
2. *Create the team-based organization*: Based on the new process model, the team approach is used to integrate the cross-organizational functions into specific process teams. The team-based organization is a constitution of several process teams.

For both purposes, this study applies the business process reengineering model addressed by Cheng and Tsai [17] as shown in Fig. 2. As team-based organization designed, the laborpower allocation can be derived and simulated based on the next three phases.

2.2. Data preparation

Applying simulation system to predict the laborpower capability of the new processes, information such as activity duration, laborpower requirements, project loadings, etc., need to be examined preliminarily and analyzed. In this study, the required laborpower allocation simulation data was divided into project parameter and process parameter classifications. The project parameters include (1) project start time, (2) bidding success ratios, and (3) number of subcontracts, as defined below:

1. Project Start Time: describes the point at which a project is considered to have occurred; i.e., when managers accept an invitation to bid, this is the start time of the project.
2. Bidding Success Ratio: a default value in the simulation system to generate a trigger event to enable the budget process. By counting the number of bidding successes in historical bidding data, the probability of success in bidding can be calculated.
3. Number of Subcontracts: For a given project, the procurement process will iterated several times depending on the number of subcontracts included in the project, while both the bidding/contract and the budget processes will only be performed once in every project. Therefore, statistical information about the number of subcontracts in a project is needed for the simulation program. Based on construction company historical data, the average, coefficient of variation, and standard deviation of number of subcontracts are calculated.

Obviously, the values returned for process parameters differ between the original processes and the new processes due to changes in task contents or operational methods. Hence, data preparation procedures may differ too in the new process model. Data preparation of process parameters is addressed as follows:

1. Data preprocessing of original process parameters.

Activity duration with maximal laborpower is an important parameter in process simulation. Activity duration is defined as the shortest operation time with maximal laborpower for an activity. To examine the actual duration of all activities, this study queried senior engineers with questionnaires. The results showed that the duration of an activity could be simplified as a linear function of the number of workers in an activity; i.e., activity duration will decrease as more laborpower is assigned, but only to the point of maximal laborpower because after that point is reached, more workers cannot further reduce the duration. Based on the investigated historical data, activity durations can be analyzed as follows:

(1) Expectation and variance. The data is summarized, and the expectation and variance of durations of all activities in the process are calculated.

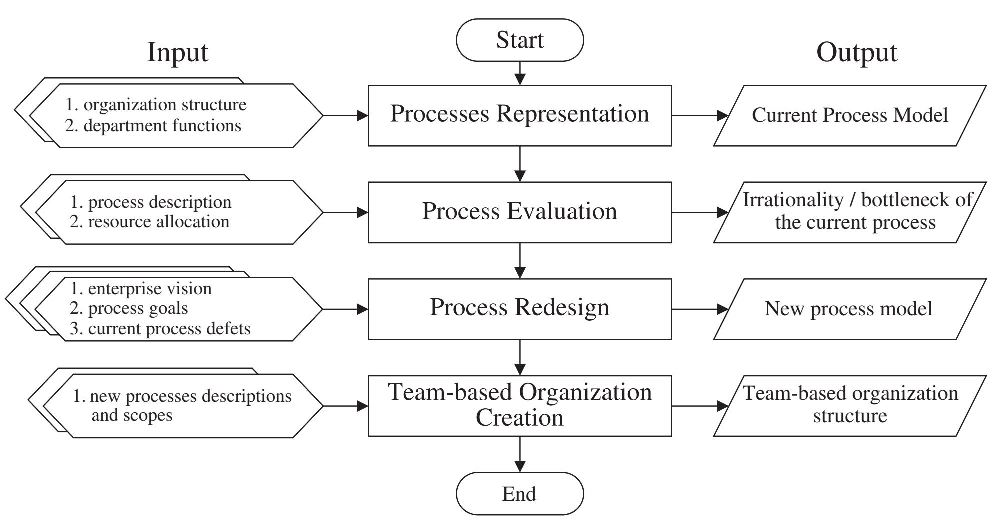


Fig. 2. The stages of process reengineering.

(2) Goodness-of-fit analysis. The purpose of goodness-of-fit is to verify the fittest probability distribution of the duration of an activity. Since AbouRizk and Halpin [6] encourage the use of all fitting methods available within a fitting computer software program and the selection of the parameters that produce the best fit to the collected data, this study used the "Datafit" module in the eM-Plant to verify the fittest distribution of all activity durations.

(3) Schedulable ranges of processes. The schedulable range of a process depicts the process duration from the early-start point of the first activity to the last-finish point of the last activity in the process. Except in the bidding/contract process, the early-start points of processes are the same as the finish point of their predecessors. The last-finish points of the processes would be the early-start point plus the summarized durations of all orderly activities within a 95% confidence interval.

2. Process parameters of the new process model

Due to the lack of historical data for new process performance, investigation rules for new process parameters are necessary. Per investigating features of activities in new processes, three data collection rules are demonstrated as follows:

Rule 1: The duration of an activity in a new process can refer to the same activity in the former process only if there is no change between the new and former process.

Rule 2: The total operation time of information systems must be investigated to realize the duration of activities that are fulfilled with the assistance of information systems, such as the cost estimation system applied by the study case.

Rule 3: Time spent on group decision making and on cost estimation system operation tasks in the new processes is estimated according to the experience of executives.

As with data analysis in the original process model, new process data is calculated for the following parameters:

1. Expectation and variance: The activity duration is summarized, and the minimum, maximum, average, expectation and variance of each activity duration are calculated.
2. Activity duration: Due to the forming of work teams after BPR, the activities in the process are accomplished by work team members. Each work team consists of one senior engineer and at least one junior engineer. The junior engineers are considered generalists well trained to perform process tasks. They can achieve activity targets in the process, and also can aid mutually and dynamically according to work loadings. For this reason, process duration depends on the laborpower deployed in the work team, and the required laborpower of a team can be related to the maximal laborpower required for the activities showing the most complexity or demanding the most effort. Based on these assumptions, we can firstly analyze the laborpower requirement for each activity of the process, and then evaluate the required laborpower range of work teams.
3. Goodness-of-fit analysis: As in the analysis of the original process, the fittest distribution of activity operation time is analyzed by the "Datafit" model.
4. Process schedulable range: The time range of the new process scheduling is determined by the same method used in the original process model.

2.3. Human resource allocation algorithm

To auto-generate laborpower allocation alternatives, an algorithm is needed reflecting the complexity of construction company operations and providing procedures for activity selection and laborpower assignments. Project scheduling techniques under human resource constraints are referenced with the objective of minimizing project duration, and a proper human resource allocation algorithm standing on multi-project scheduling, with a heuristic procedure for searching out approximate optimal allocation, is adopted.

A forward/backward scheduling technique is the primary allocation algorithm; it evaluates maximal and minimal laborpower allocations for activities.

1. Forward Scheduling:

Activities are scheduled at their earliest start times until either available resources or schedulable activities are exhausted; i.e., each activity with predecessors completed and resource requirements met by the currently available resource levels will be taken into the schedulable activity set. Maximal resources are thus possibly assigned to upstream activities to fulfill them as early as possible, and consequently, downstream activities may be accomplished with fewer resources if the project duration does not expire.

2. Backward Scheduling:

Activities are scheduled to be accomplished just at the latest finished times; that is, an activity is schedulable at a current decision time if all of its successors have been completed and its resource requirements can be met by the currently available resource levels. Thus, minimal resources may be assigned to upstream activities while total remaining time is sufficient for the project.

Based on the definitions of forward/backward scheduling, this study addressed the corresponding algorithms as follows.

Forward/backward scheduling algorithm:

Input:

P_i /processes set where $i=1,2,3,\ldots,n|n$ is the no. of processes/

Proj_k /projects set where $k=1,2,3,\ldots,l|l$ is the no. of projects/

lft_k /the last-finish time of Proj_k/

A_{ijk} /activities set where $j=1,2,3,\ldots,m|m$ is the no. of activities of P_i for Proj_k/

$m^i_{\max}$ /the maximal laborpower required for j-th activity of the j-th process/

$m^i_{\min}$ /the minimal laborpower required for j-th activity of the j-th process/

Output:

mf_{ijk} /the laborpower assigned for j-th activity of P_i for $Proj_k$ by forward scheduling/

mb_{ijk} /the laborpower assigned for j-th activity of P_i for $Proj_k$ by backward scheduling/

Forward algorithm: /Determine the required laborpower of one activity/

From $X=1$
Loop until (X *.equal* to. $m^{ij}{}_{max}$)
If (A_{ijk} is fulfilled by the laborpower of X) and (all the downstream activities are fulfilled by their minimum laborpower) and (the P_i can be accomplished before lft_k)
Then $mf_{ijk}=X$
Else $X=X+1$
End If
End Loop

Backward algorithm: /Determine the required laborpower of one activity/

From $X=1$
Loop until (X *.equal* to. $m^{ij}{}_{max}$)
If (A_{ijk} is fulfilled by the laborpower of X) and (all the downstream activities are fulfilled by their maximum laborpower) and (the P_i can be accomplished before lft_k)
Then $mb_{ijk}=X$
Else $X=X+1$
End If
End Loop

The allocation results of forward/backward scheduling are two extreme scenarios. However, due to constraints in laborpower, the human resource allocation can encounter conflicts between activities, processes, and projects, so enforced idleness owing to such conflicts has to be considered in the THRP model. To identify the human resource conflicts, an algorithm for checking available laborpower for the scheduling activities is also addressed.

Available laborpower checking algorithm:

Input:

$m^t{}_{avl}$ /the available laborpower of the t-th work team /

mf_{ijk} /the laborpower assigned for j-th activity of P_i for $Proj_k$ by forward scheduling/

Output:

S_{ijk} /the status of j-th activity of P_i of $Proj_k$/

Available laborpower checking algorithm:
For each scheduling activity
Loop until (S_{ijk} is Firing)
If ($m^t{}_{avl}$ *.greater than.* mf_{ijk}) or ($m^t{}_{avl}$ *.equal* to. mf_{ijk})
Then S_{ijk}=firing
Else S_{ijk}=queuing
End If
End Loop

2.4. Human resource allocation simulation

For predict laborpower performance in the new processes and new organization structure, this study transfers the process context to a mathematical model which is computable to simulate functions of the processes.

2.4.1. Targets and assumptions of simulation

Based on the results of BPR, two outputs should be predicted from the simulation, namely, (1) the maximal project loading of the existing laborpower, and (2) the laborpower requirement for future project loadings. Consequently, the simulation system should be able to deal with project scheduling considering both constraints on the amount of human resources and time limitations, and laborpower allocation decisions can automatically be made by the system. Moreover, the simulation system rests on six assumptions:

1. The property values of projects can be derived from the probability distribution functions.
2. Only human resources need be considered. Other resources, such as capital, facilities, etc., need not be addressed in this model.
3. The sequences of all activities in projects are identified, and a successor activity cannot be started until the predecessor has been finished completely.
4. A single worker can only be assigned to one activity at one time.
5. Personnel abilities can be set to equivalent.
6. The productivity of an activity is a linear function of laborpower.

2.4.2. Simulation system development

Once system inputs and criteria are defined, a machine simulation system can be developed. By referring to information system development phases, this study schematized a preliminary simulation system development procedure which includes five major steps, namely, (1) determination of fitness assessing indexes, (2) simulation runtime procedure design, (3) simulation system creation, (4) system validation, and (5) system application.

2.4.2.1. Step 1. Determination of fitness assessing indexes. In keeping with the problems definition, this study uses a "laborpower idleness" index expressing the efficiency of the human resource to evaluate the fitness of each allocation alternative. Only if all activities in a process are finished, the simulation with least laborpower idleness will be the result of a simulation.

2.4.2.2. Step 2. Simulation runtime procedure design. Here we summarize the results of another three phases and create the system scenario that guides simulation of every new company process. Process description and system runtime procedure are two parts of the system scenario.

The process description provides the scenario of process simulation in the system. Each process has its corresponding description including activities involving laborpower. That is, the description includes process scope, activities, number of team members, and probability distribution function of occurrence of process enabling events. In addition, a set of laborpower allocation alternatives is derived taking into consideration the availability of human resources.

The system runtime procedure describes the mechanism for choosing the fittest human resource allocation from the set of laborpower allocation alternatives and for determining the maximal project loading of laborpower. Fig. 3 shows the system runtime procedure. As the test simulation is started, the number of personnel available and the amount of projects will both be

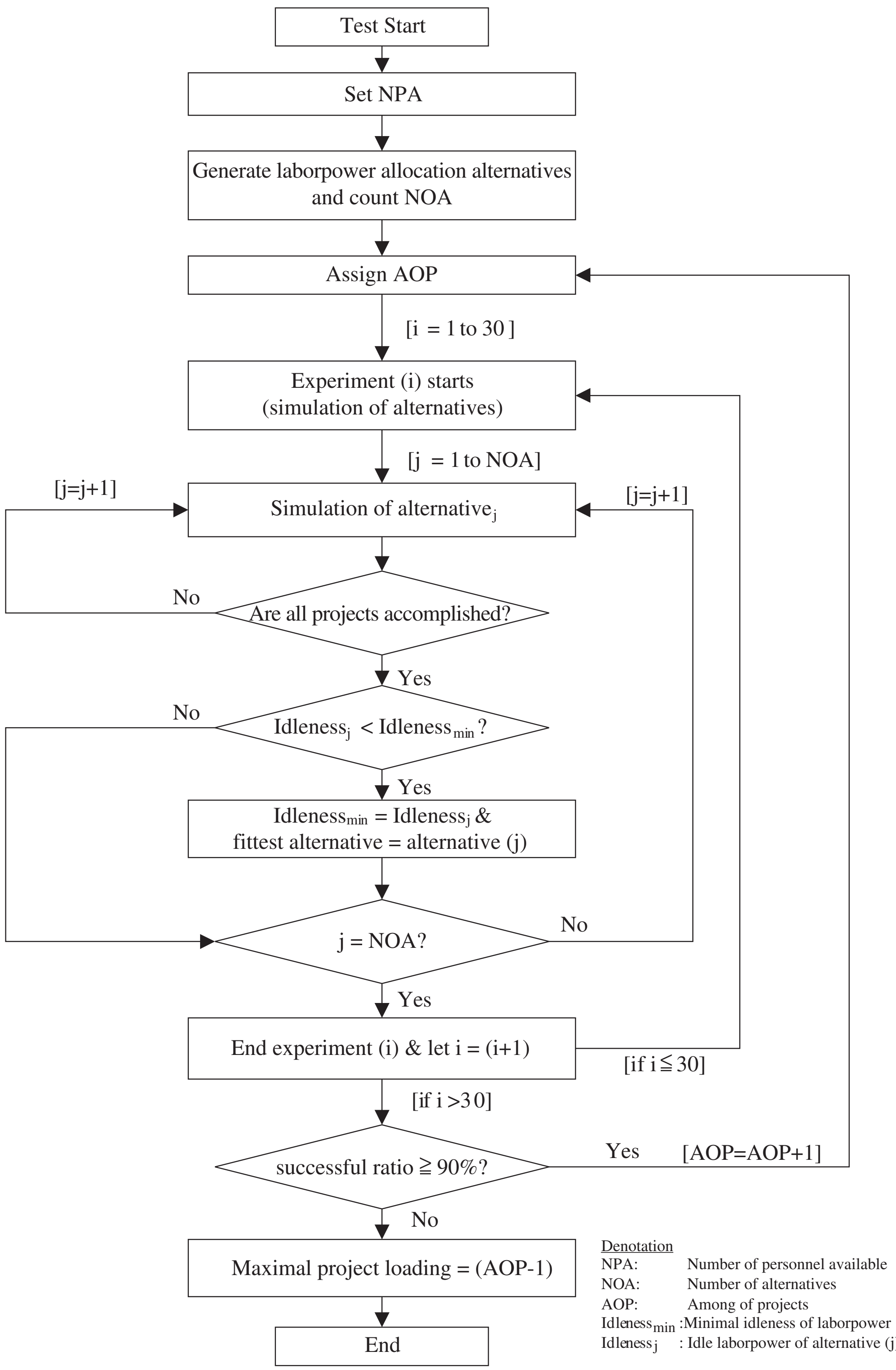
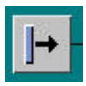
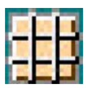
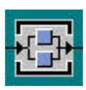
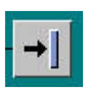


Fig. 3. Simulation runtime procedure.

Table 1
Object relations between eM-plant and the real world

System components	Function/ feature	Legend	Object name	Corresponding object in real world
MainFrame	Develop the simulation model		Frame	Process
Project arrival	Project occurrence		Source	Project be started
Proceeding of project	Project is in progress		Entity	Project
Activity item	Activity of the process		Parallel-Proc	Activity
Project finished	End of a project		Drain	Project finished
Parameter	Constant, default value, data	NewData	Variable	1. The initial value of the activities 2. The values needing to be calculated
Table	Input and output data recorder		Table file	Information concerning alternative simulations, experiments and the test simulation.
Control method	Procedure control, data collection		Method	Allocation methods, procedure controller, and data collection handler

set preliminarily, and all possible laborpower allocation alternatives will be generated too. Then, every alternative can be simulated in one experiment. When one alternative is found able to accomplish all project tasks, its operation time and resulting effect on idle laborpower will be recorded in the system. After all alternatives have been simulated, the one causing least idleness is chosen as the fittest alternative in this experiment. If no alternative could accomplish all project tasks in one experiment, the result of this experiment fails; vice versa it succeeds. In total, thirty experiments for every test simulation are finished subsequently, and the simulation program then examines whether the project loadings (described by amount of projects) to the laborpower limit (described by number of personnel available) can be carried out within an experiment threshold ratio of 90% successes (27 experiments succeeded). If laborpower capability is found to be greater then the current project loading, the number of projects to be run in the next test simulation is increased progressively until overloading occurs and the laborpower limit is exceeded. In this way, maximum project laborpower capability for one set of available laborpower can be determined by the test simulation progress.

2.4.2.3. Step 3. Simulation system creation. This study uses the object-oriented simulation software named "eM-Plant" to develop and simulate the possible allocation alternatives. As Table 1 shows, a set of default graphical modeling objects were provided to make the process of building a simulation model easier since the user does not have to access lower-level programming language details. Using these objects, the tasks in this step include: (1) system objects model creation, (2) objects allocation, (3) object attributes defining and values setting, (4) control method programming, and (5) output defining.

Finally, the outputs of system include six categories as shown in Table 2.

2.4.2.4. Step 4. System validation. The purpose of the system validation is to verify the robustness of the simulation system by testing the simulation results for closeness to the real system. Deviations being found acceptable, the simulation system computes sound results depending on the input process model and parameters. Thus, system can then be fed new process model with parameters to predict its laborpower performance and requirement. Consequently, to validate the simulation system, the before-reengineered process model should be constructed and simulated additionally to compare the results with the project loading and laborpower allocation in the real existing process.

2.4.2.5. Step 5. System application. The simulation model having been verified, the next step was to aim at new processes. In this step, the simulation system is applied to evaluate the maximal project loading of the existing laborpower, and to create combinations of laborpower and project loading which may serve as references for human resource planning as the company and its business change in the future.

3. A THRP case study

A real case involving construction Company "A" is summarized in this section with the intention of illustrating a

Table 2
Output definitions of simulation system

Output category	Output item
Activity information	Start time, finish time, required laborpower, and the duration of activities.
Process information	Early-start time, start time, finish time, last-finish time, laborpower requirement, duration, and laborpower idleness of the processes.
Project information	Early start time, occurrence time, finish time, last-finishing time, laborpower requirement, duration, and total laborpower idleness of each project.
Alternative simulation information	Simulated results of one laborpower allocation alternative.
Experiment information	Simulation result of one experiment (the allocation alternative with the least laborpower idle time).
Test information	Summarized results of 30 experiments.

business process reengineering project. The THRP model was applied to assist “Company A” with reengineering of the construction planning process and evaluating the rationality of human resource use in the newly designed process.

3.1. Process reengineering phase

Fig. 4 shows the functional organization structure of “Company A”. In the figure, the construction planning process was executed by the construction planning department. To fulfill different specific functional goals, the department was divided into three functional task groups. As top managers decided to accept the invitation for bidding of a construction project, the planning process was enabled and split into (1) bidding/contracting, (2) estimation/budget and (3) purchasing sub-processes, which were performed by the corresponding task groups sequentially. However, due to the task groups were responsible only for partial goals of the construction planning process, the three task groups hardly supported each other and some of them experienced overload, a vital cause of inefficient human resource deployment in functional organizations. Considering the ineffectiveness of previous construction planning, the manager had chosen the construction planning process to reengineer.

3.1.1. Process representation

In process reengineering, one of the most difficult and important tasks is to identify a company’s processes. Therefore, the primary purpose of process representation is to develop a systematic definition of process to assist companies in clarifying and establishing their management process [17]. For the purpose, two tasks need to be accomplished: (1) activity data collection, which investigates an activity’s functions and compiles information on the original organization, and (2) process modeling, which uses the Architecture of Integrated Information System (ARIS) modeling tool to create the original process model based on the collected data.

3.1.1.1. Task 1. Activity data collection. To map a business process model from function-based to process-based organization, detailed information on the activities of functional departments is required. Since processes are performed behind the functional organization structure, the functional gaps may be obscured and evaluated only with difficulty. For this reason, a modeling language which presents key aspects and detailed information of a process is necessary for the diagnosis and design of a construction management process. For this reason, this study uses the e-EPC diagram of the ARIS process modeling tool to delineate both existing and the new-designed management processes of a construction company.

To create from the functional organization an e-EPC diagram of the existing construction planning process, three sections of collected process data are needed. The first section investigates tasks fulfilled in each department by using the “Departmental Tasks/Documents Investigation Table”. The second section then arranges the collected data and presents the results of the investigation to division managers for probing into the more advanced details of the original management processes. Finally, the last section searches formal documents such as ISO descriptions and specifications or internal-auditing documents to fully establish the relationships between and regulations affecting process activities.

3.1.1.2. Task 2. Process modeling. Based on the collected data, An example of the bidding/contract process model of

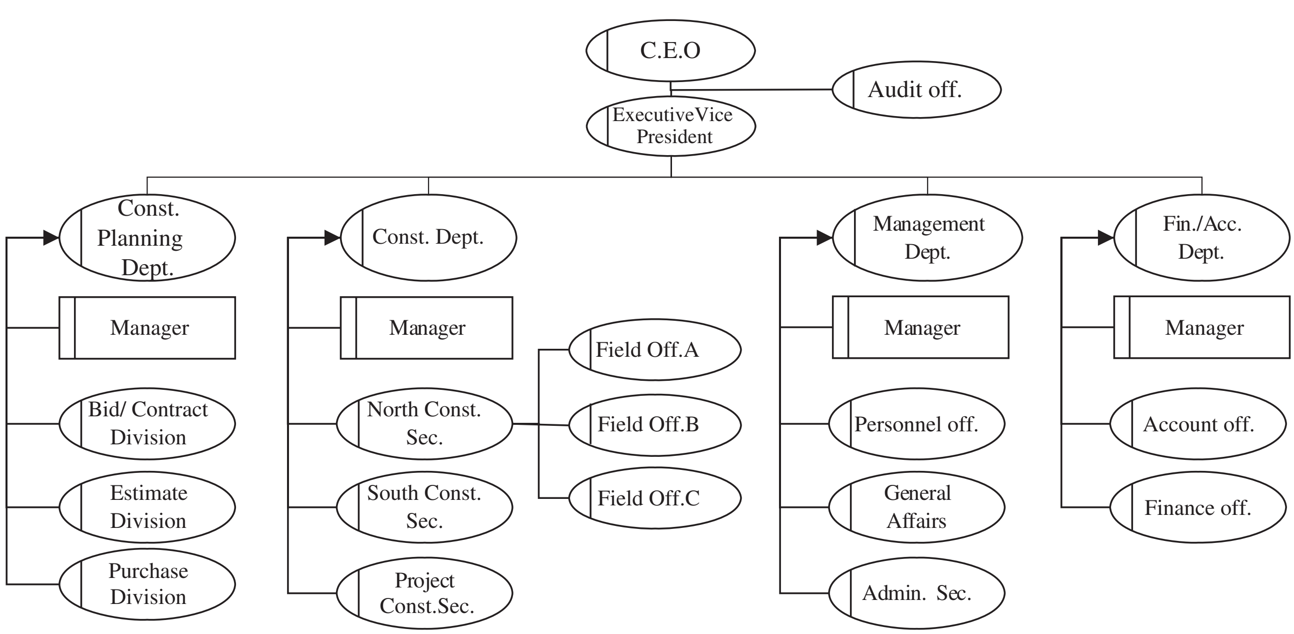


Fig. 4. The organizational structure of “Company A” before BPR.

”Company A” was represented by using the ARIS modeling tool after the data collection task, and Fig. 5 shows the modeling results.

3.1.2. Process evaluation

This is the kernel of the process reengineering phase, of which the purpose is to assay the rationality and effectiveness of

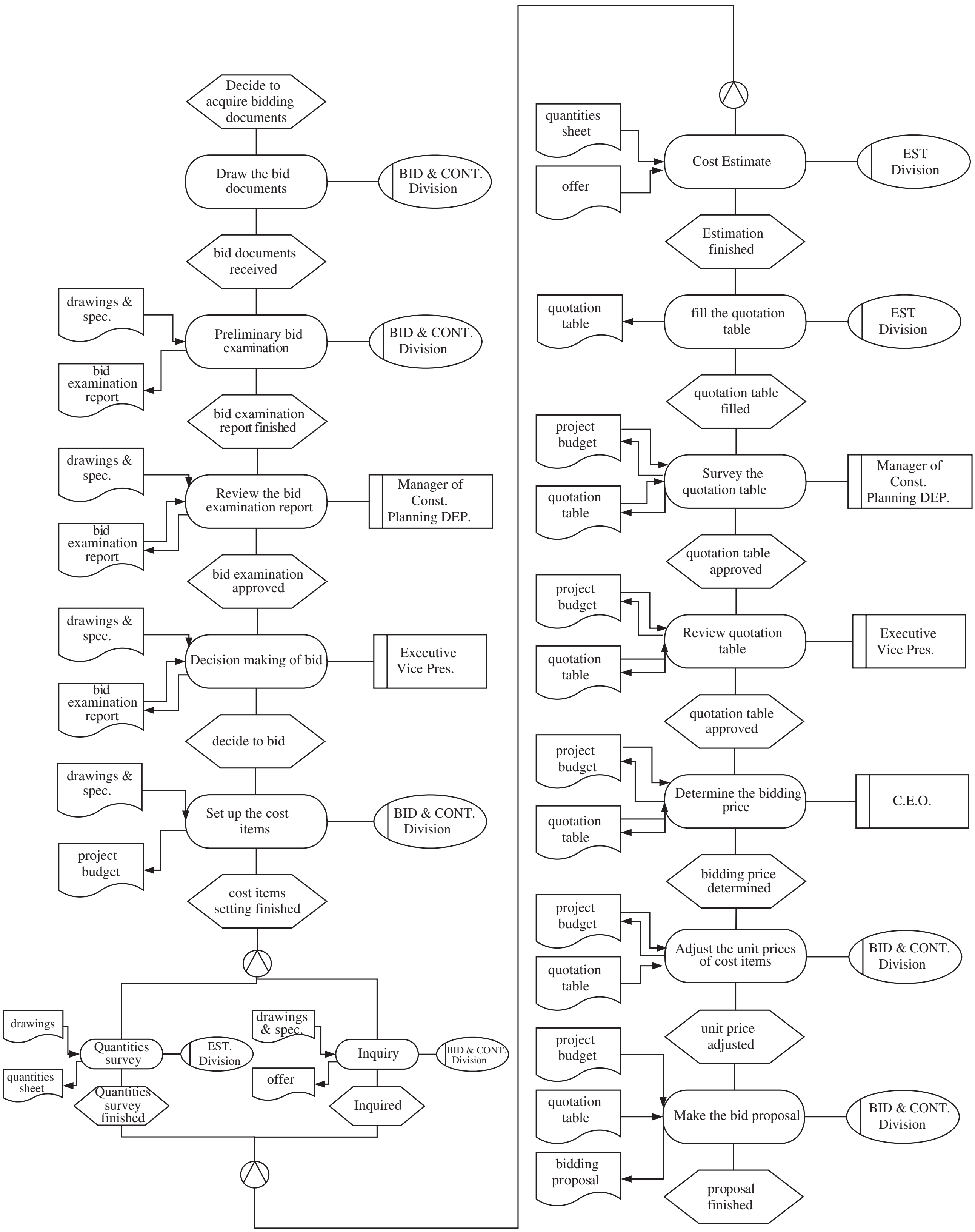


Fig. 5. The original bidding/contract process in “Company A”.

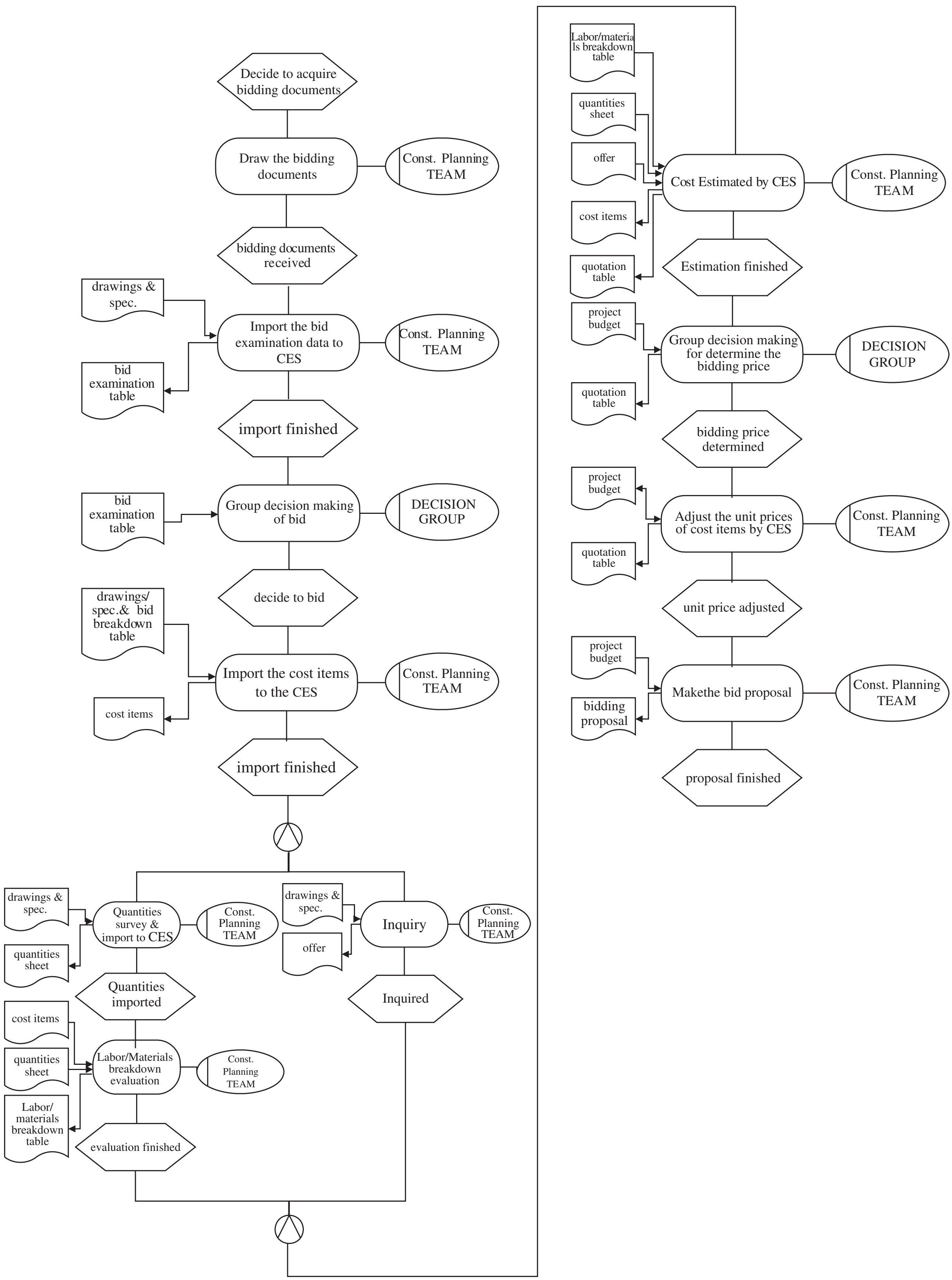


Fig. 6. The new bidding/contract process of “Company A” after BPR. Note. CES: Cost Estimation System.

process based on the eEPC process diagrams created in the process representation step. Through discussion and brainstorming with the senior managers, this study located the hidden problems within the original bidding/contract process (shown in the Fig. 5) as follows:

1. Only quantity surveys were implemented with computer-aided software while all other activities were completed manually; accordingly, the efficiency of the activities and the utilization of the laborpower were limited due to lack of full support from information technologies.
2. Job loading was not proportional to task divisions due to the magnitude of various construction projects. In fact, it is difficult to assign appropriate laborpower dynamically to proper groups in a functional organization structure.
3. No valid history reference data on material and labor was on hand to assist the estimator so that cost estimations failed to correspond with prevailing prices.
4. The time consumed by document circulation increased unexpectedly because all documents were required to be submitted to the managers.

3.1.3. Process redesign

In this step, to fix the process defects, the process model was redesigned on process design principles [17] and a new process model created. Because information can be the "glue" that holds an organizational structure together [18], a cross-functional information system of cost estimation system was particularly applied. Some activities could be integrated and executed by cost estimation system. Moreover, certain approval activities, such as "review bidding examination reports" and "survey quotation tables" which were irrelevant to the objective of the process, were superseded and decision making activities delegated to the decision group. Consequently, the existing bidding/contract process was integrated into a shortened and efficient new process. One of the alternative process models is shown in Fig. 6.

3.1.4. Team-based organization creation

After new processes have been created, structural changes of organization are necessary to facilitate the new processes. In addition, BPR stresses that departmental barriers must be smashed so that managers can pay much more attention to improving process performance. Thus, this study applied a team approach to combine multiple division functions into one unit which could facilitate functional interfaces and parallel process activities.

Fig. 7 shows the team-based organization structure of Company A corresponding to the new construction planning processes. The primary difference between the former structure and the team-based structure is the forming of the decision group and the two construction planning teams. The construction planning teams, which combine cross-functional skills, are responsible for the entire construction planning process.

In the adjusted organization structure, the construction planning teams were composed of generalists, who, familiar with bidding, contracting, estimating, budget planning and purchasing affairs, could be self-directed in accomplishing all project planning affairs. Basically, each construction planning team consists of one senior engineer as team leader and several project engineers, adjustable in number depending on work loadings. However, when a team lacks experience in teamwork, its rationality of laborpower can be difficult to estimate. For this reason, as a reference for human resource allocation decision making, the study addressed an evaluation method with simulation tools to reveal the relation between work loading and the laborpower of work teams so that the managers could assess the capability of laborpower allocated in a team.

3.2. Preprocessed data

In the data preparation phase, the values of project parameters and process parameters were estimated according to the historical data of projects and activities of Company

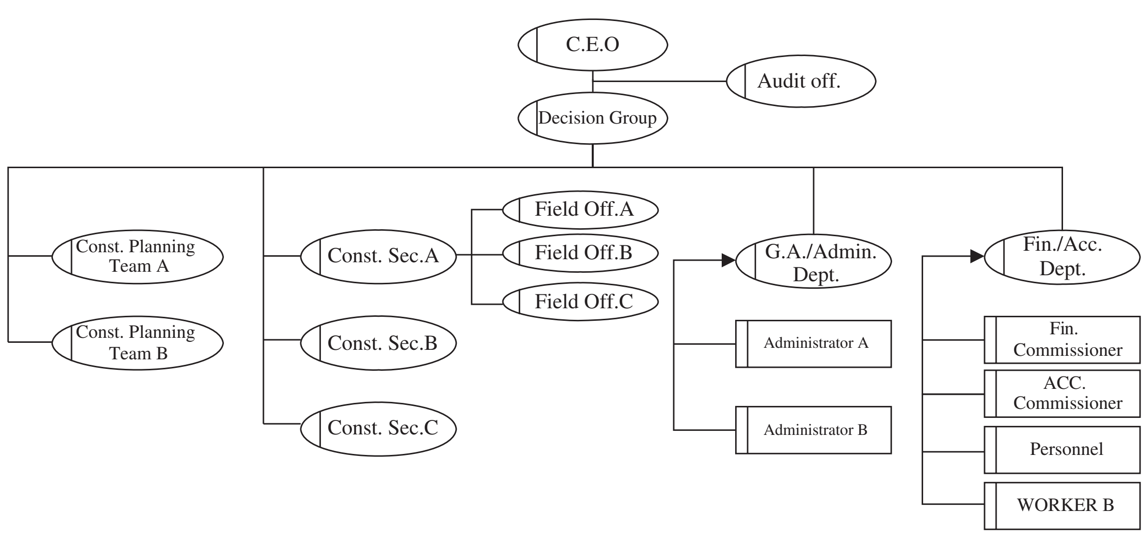


Fig. 7. The organizational structure of "Company A" after BPR.

Table 3
Project parameters of Company "A"

Project parameter	Function/value
Start time of project	Uniform distribution
Success ratio of bidding	20%
Number of subcontracts	25
Required laborpower	7 employees

"A". Table 3 shows the project parameters of the Company "A".

Meanwhile, the process parameters for both the original and the new-designed processes were estimated and then evaluated for laborpower in activities, for probability distribution functions, and for durations with 95% confidence level. Tables 4 and 5 illustrate the results of the bidding/contract process, a sub-process of the construction planning process.

3.3. Human resource simulation

In this section, to validate the feasibility of the simulation system, the "construction planning process" of Company "A" was taken as an example. The current process model within the original organization structure was developed and simulated. Comparing the simulation results with the performance of the current process model, the simulation system was validated.

The results of the model validation were very close to the real situations. 16 projects, the maximal project loading of seven workers was estimated by the simulation system with the test model. Table 6 shows the simulation results. This result matched the real capability in the range of 15 to 18 projects estimated by the mangers of Company "A". Moreover, the average of idled laborpower also was close to the real situation as evaluated by the managers with experience.

After the model test, the new-designed construction planning process was modeled in the eM-Plant system and evaluated with two situations: (1) the number of members of the construction planning team remained constant at seven, which was the total laborpower of the construction planning department; (2) the project loading was taken as a function of the number of team members, and the combinations of laborpower and project loading were estimated.

The main purpose of the first simulation is to estimate the potential project loading that current laborpower can take. Therefore, the value of current number of personnel available was set in seven workers. Moreover, each team consists of one senior engineer and at least one junior engineer, so there were eight possible laborpower allocation alternatives for seven workers. Fig. 8 shows the allocation alternatives and the amount of projects which were simulated. Following the test simulation process shown in Fig. 3, all alternatives were simulated in one experiment, and thirty experiments progressed in one test. That is, there were in total 240 simulations for one specific project loading.

As applying the forward scheduling method, the success ratio was always higher than 90% when the project loading was less than 25 projects. It decreased to 83% (less than the threshold of 90%) as the loading increased to 26 projects. Therefore, the maximum project loading for seven members was evaluated at 25 projects. Likewise, as the backward scheduling method was applied, the success ratio was always higher than 90% when the project loading was less 40 projects, but decreased to 80% as the loading increased to 41 projects. Therefore, the maximum project loading for seven members proved to be 40 projects when the backward scheduling method was applied.

Because forward scheduling deploys the maximum resource at the beginning of a project to accomplish the process as soon as possible, laborpower capability might be limited by more resource conflicts than in the backward scheduling method. Therefore, this research speculates that optimum project loading falls between the two above referenced extreme cases. Based on this corollary, Company A's laborpower margin was adapted to a minimum of 25 projects and a maximum of 40 projects.

Table 4
Process parameter table of the original bidding/contract process of Company "A"

Activity	Samples	Personnel in activity	Possibility distribution function	Duration (h, 95% confidence interval)
Preliminary bidding examination	21	1	Gamma(5.34, 1.57)	10.00
Review the bidding examination report (by the manager)	21	1	Student-t(8.62, 2.85)	9.92
Decision making of bid (by the E.V.P.)	21	1	Gamma(6.17, 0.89)	6.00
Set up the cost items	21	1	Gamma(7.22, 2.14)	19.00
Take off quantities	21	2	Gamma(5.70, 9.34)	68.00
Inquiry	21	1	Student-t(87.38, 16.32)	94.81
Costs estimate	21	1	Gamma(7.84, 2.22)	21.00
Fill the quotation table	21	1	Student-t(2.81, 1.21)	3.36
Survey the quotation table (by manager)	21	1	Gamma(4.70, 1.35)	7.00
Review the quotation table (by E.V.P.)	21	1	Student-t(12.29, 2.70)	13.52
Determine the bidding price(by C.E.O)	21	1	Student-t(12.10, 2.07)	13.04
Adjust the unit prices of cost items	21	1	Student-t(2.19, 1.08)	2.68
Make bid proposal	21	1	Student-t(1.67, 0.66)	1.97
			Summary	270.29

Table 5
Process parameter table of the new bidding/contract process of “Company A”

Activity	Samples	Laborpower required for activity	Possibility distribution function	Duration (h, 95% confidence interval)
Import the bid examination data to CES	8	1	Gamma(4.30, 2.10)	14.00
Group decision making of bid	8	1	Student-t(1.38, 0.35)	1.50
Import the cost items to the CES	8	1	Student-t(1.13, 0.58)	1.50
Quantities survey and import to CES	8	dependent	Student-t(64.19, 28.26)	96.00
Labor/materials breakdown evaluation by CES	8	1	Student-t(9.19, 1.60)	10.00
Inquiry	8	dependent	Student-t(124.13, 13.11)	135.00
Cost estimated by CES	8	1	**	0.01
Group decision making for determine the bidding price	8	1	Student-t(1.38, 0.35)	1.50
Adjust the unit prices of cost items by CES	8	1	**	0.20
Make the bid proposal	8	1	Student-t(1.88, 0.64)	2.00
			Summary	261.71

CES denotes cost estimation system.

In addition, the outputs of the simulation exhibit positive evidences of the advantages of process reengineering. That is, by comparing simulation results between the original process and the new, integrated construction planning process, we can see the laborpower capability increasing from 16 projects to 40 projects, and idled laborpower decreasing obviously due to the integration of functions.

For the second situation, this study extended the number of personnel available from 2 to 15 workers to realize the relation between laborpower and project loading. By repeating the simulation procedure run for the first situation, the project loadings of each NPA were estimated with forward/backward scheduling methods, and the results are shown in the Fig. 9. In Fig. 9, one NPA value corresponds to two project loadings; one is backward scheduling result and the other is forward scheduling

Table 6
Simulation results of the original construction planning process (forward scheduling, NPA = 7, Project loading = 16)

Experiment	Start time	Finish time	Bid/contract division		Estimate division		Purchase division		Summary	
			Working time	Idle time	Working time	Idle time	Working time	Idle time	Working time	Idle time
1	232	5440.6	4935.2	7357.8	659.1	9625.4	892	12,991	6486.3	29,974
2	200	4587.8	5083.1	6729.8	3283	5601.1	4710	5308.5	13,076.1	17,639
3	648	5305.3	5085	6487.8	2038.2	7862.1	2783.2	8345.5	9906.4	22,695
4	144	4986.5	5208.9	7516.8	2414.4	7595.8	3703.5	7459.6	11,326.8	22,572
5	0	5596.4	4845.6	8791.8	2507.5	8462.7	3685.9	10,882.4	11,039	28,137
6	552	5254.7	4957	14,051	1202.9	3954.3	1762.9	6992.6	7922.8	24,998
7	48	5089.6	5105.2	16,303	1166.6	3976.3	1840.6	6900.4	8112.4	27,180
8	240	6067.6	5258.5	7442.8	1872.1	8576.1	2813.5	14,831.2	9944.1	30,850
9	64	5436.5	4754.4	13,236	599.4	4723.8	934.4	13,359.6	6288.2	31,320
10	48	4695.6	5276.7	10,730	2611.5	6407.6	3802.5	3706.2	11,690.7	20,844
11	160	5527.8	4865.1	3874.2	2614.5	7942.6	3689.4	14,590	11,169	26,407
12	384	6297.5	5058.3	7522.8	2543.7	8265.6	3743.2	14,261.1	11,345.2	30,050
13	152	6142.6	4987	8337.8	1243.8	9463.6	1808.1	16,094.5	8038.9	33,896
14	24	4587.3	5056.2	11,334	1302.8	3584.3	1873	8793.1	8232	23,712
15	576	5035.5	5177.9	14,191	1820.9	2589.8	2778.6	4660.2	9777.4	21,441
16	280	6075.5	5272.5	5748.8	0	11,591	0	11,591	5272.5	28,931
17	104	5360.7	5281.3	12,133	640.3	4623.8	881.5	13,237.8	6803.1	29,995
18	168	5133.2	5336.1	16,752	2014.6	2853.8	2791.1	5008.9	10,141.8	24,615
19	80	4809.5	4859.6	14,989	1203	3627.3	1794	6634.1	7856.6	25,250
20	96	5236	4905.2	7987.8	2608.5	7716.6	3641.6	9121.4	11,155.3	24,826
21	136	5557.2	5160.8	7852.8	1205.2	9463.5	1868.4	12,399	8234.4	29,715
22	152	5525.3	5124.4	6304.8	1894.7	7600.1	2826.9	13,864.5	9846	27,769
23	280	5311.7	4870.3	11,424	1839.4	3309.8	2797.6	10,982.2	9507.3	25,716
24	472	5563.1	5020.5	6600.8	1189.8	9020.4	1879.5	11,928.9	8089.8	27,550
25	16	5493.9	5089.5	8283.8	1245.6	9442.2	1850.5	12,435.6	8185.6	30,162
26	80	5980.3	5266.9	7482.8	1231	9821.6	1927.4	15,573.2	8425.3	32,878
27	440	5348.2	5149.3	15,139	1289.9	3946.3	1841.5	6992	8280.7	26,077
28	40	5571.4	5104.5	8316.8	1818.1	9032.2	2761.5	11,687.5	9684.1	29,037
29	64	5305.2	5136.5	17,232	1942.5	3418.8	2746.1	6213.9	9825.1	26,865
30	104	5231.4	4864.2	12,038	585.2	4546.8	959.9	12,898.4	6409.3	29,484

Unit of time: hour.
NAP denotes Number of Personnel Available.

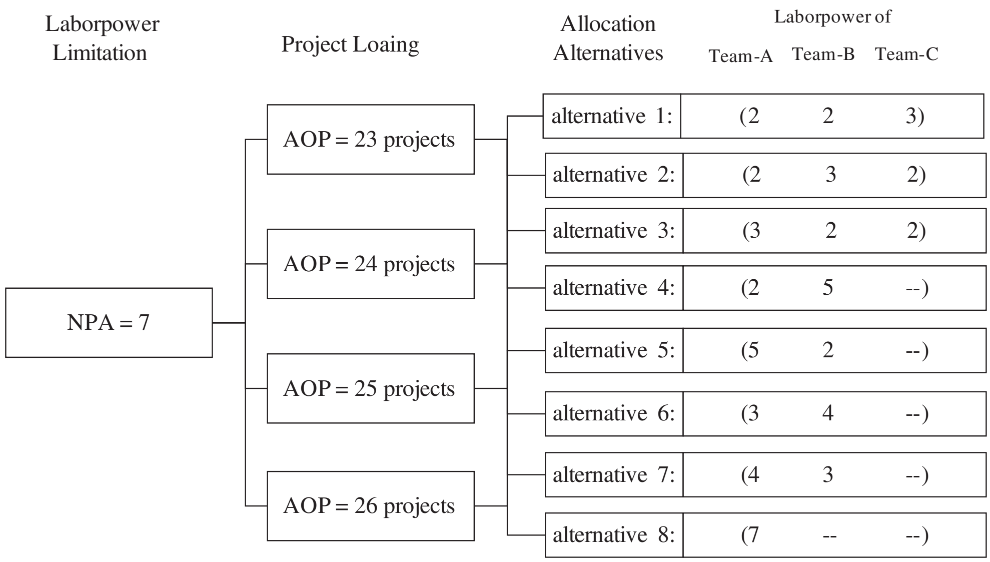


Fig. 8. The possible laborpower deployment alternatives tree for the construction planning team with project loading (NAP = 7). Note. NPA: Number of Personnel Availabe; AOP: Amount of Projects.

result. As each NPA has been simulated, two curves could be finally sketched which present the relation of laborpower and project loadings. Based on Fig. 9, not only the capability range of specific laborpower, but also the range of laborpower requirement for specific project loading can be identified. Therefore, managers can estimate the efficiency of laborpower or the amount of it needed based on the number of projects.

4. Conclusion

With integration of team approach and simulation method, this research addressed a team-based human resource planning model, where team approach was applied in reorganizing the structure of a company to facilitate newly designed process, and simulation was used to predict laborpower capability for the new organization after BPR. To validate the soundness and feasibility of the THRP model, a case study was to demonstrate the viability of the presented concepts. According to the case study, the results of human resource allocation algorithms with the eM-Plant simulation are close to the actual laborpower capability. Therefore, the maximum project loading of laborpower corresponding to a newly designed process could be evaluated by simulation: Moreover, the relation between project loading and laborpower could consequently be delineated which illustrates the efficiency of laborpower utilization in the new processes. This result can potentially

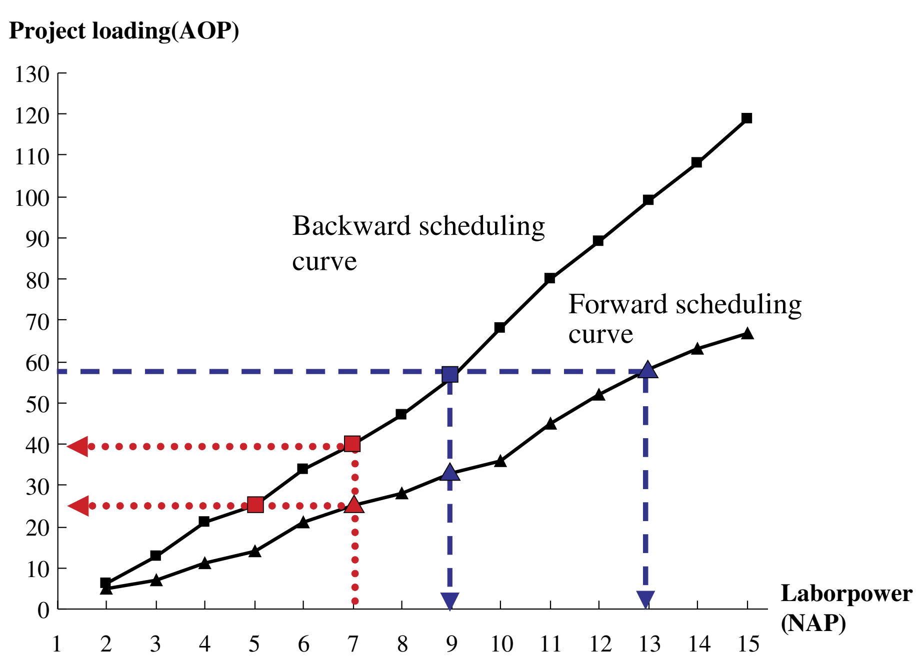


Fig. 9. Simulated output curves of the new construction planning process.

provide decision-makers valuable information for human resource planning.

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