Applying Process Simulation Technique to Value Engineering Model: A Case Study of Hospital Building Project

Boo Young Chung, Syadaruddin Syachrani, Hyung Seok (David) Jeong, and Young Hoon Kwak

***Abstract*—Applying value engineering (VE) in a construction project has proven to be an effective way to save the cost of a project. Different VE models have been developed and used in construction projects in the past. One common attribute of construction projects is the dependence of a highly qualitative decision making process: capturing, interpreting, and quantifying expert's subjective judgment. This study proposes an advanced five-phase VE model, each phase of which consists of a series of steps to better quantify subjective opinions of VE team members. Construction simulation technique, the Cyclic Operation Network, is used as a means to minimize subjectivity in estimating the value of different alternatives in terms of time and cost savings. A case study shows that the advanced five-phase VE model improves analysis, assessment, and decision on VE. This new approach has a great potential to minimize subjectivity during VE process and improves VE decision-making process by using quantitatively derived data from the simulation analysis.**

***Index Terms*—Case study, construction, decision making, project management, simulation, value engineering.**

I. Introduction

VALUE engineering (VE) is an organized approach to obtain the optimum value of unit cost, while assuring the quality, safety, reliability, and maintainability of a construction project [5], [10], [13]. VE can be utilized at any of the three main stages of a construction project: planning and design stage; construction; and maintenance and operations stage. The greatest potential for the application of VE exists during the planning and design stage because its usage in the later stage will greatly increase the level of effort/investment to implement any meaningful changes [25] that will result in large cost savings.

However, the solutions generated through the VE application model are often biased or poor. The following two sources are the main causes of these poor recommendations. One source is the lack of robust steps to quantitatively measure, evaluate, and aggregate the expert's opinion for VE application. A simple numeric rating system or averaging values may not accurately capture the alternatives that are under consideration. Recently, Sanchez *et al.* [15] attempted to overcome this shortcoming by using the fuzzy set theory. In their work, an expert's qualitative opinions were synthesized quantitatively by converting the opinions into a range of numerical values. The aggregation function using weighted sum was used to generate the final score for each alternative. The other source is attributed to subjective estimation and assessment of key parameters from experts such as productivity, cost, and schedule. Every construction project is unique and nonrepeatable. As a result, it is extremely difficult to obtain historical data to accurately estimate those factors.

This study proposes an advanced five-phase VE model that contains numerical algorithms for each stage. A construction simulation technique, namely, the CYCLic Operation NEtwork (CYCLONE), is used as a tool to minimize the subjectivity of evaluating different alternatives in the development phase. Among many different simulation programs such as PETRY net, Semantic, Neyron network for simulation, the construction industry has been using CYCLONE [7], STROBOSCOPE [11], EZStrobe [12], and recently a 3-D construction simulation program called VITASCOPE [8] to properly and efficiently represent unique construction activities. Among the currently available construction simulation programs, CYCLONE is a well-established and widely used system to effectively model complex construction operations. CYCLONE has also provided theoretical foundations for other construction simulation programs.

II. VE in Construction Industry

Although VE has its origin in the manufacturing industry, its methodology has been well developed and discussed in the construction industry [4], [14], [20]–[24], [26]. Different experts have defined different procedures for application of VE to construction projects, but typically, they fall into five phases:

1) the information phase;
2) the speculative/creative phase;
3) the evaluation/analytical phase;
4) the development/recommendation phase;
5) the report and implementation phase.

The information phase focuses on collecting as much information as needed and conducting a function analysis. The speculative/creative phase identifies every possible proposal that potentially can improve the value of the function. In the evaluation/analytical phase, the proposals are screened to develop

Manuscript received December 4, 2007; revised June 26, 2008 and September 16, 2008. First published April 10, 2009; current version published July 17, 2009. Review of this manuscript was arranged by Department Editor J. K. Pinto.

B. Y. Chung is with the U-City Center of Excellence, Samsung SDS Company, Ltd., Seongnam-si, Korea (e-mail: constopia@gmail.com).

S. Syachrani and H. S. (D.) Jeong are with the School of Civil and Environmental Engineering, Oklahoma State University, Stillwater, OK 74078 USA (e-mail: syadaru@okstate.edu; david.jeong@okstate.edu).

Y. H. Kwak is with the Department of Decision Sciences, School of Business, The George Washington University, Washington, DC 20052 USA (e-mail: kwak@gwu.edu).

Color versions of one or more of the figures in this paper are available online at http://ieeexplore.ieee.org.

Digital Object Identifier 10.1109/TEM.2009.2013831

TABLE I
VALUE ENGINEERING APPLICATION PROCEDURES

Prior Studies	Generic VE Job Plan (Zimmerman and Hart 1982, Dell' Isola 1997)	Snodgrass and Kasi (1986)	Acharya et al. (1995)	Lane Davis (2004)
Phases	1) Information	1) Information	1) Team selection	1) Goal definition
				2) Information
		2) Functional analysis	2) Information gathering	3) Function Analysis
	2) Speculation/Creative	3) Speculation	3) Brainstorming	4) Creativity
	3) Evaluation /Analytical	4) Evaluation	4) Evaluating alternatives	5) Evaluation
	4) Development/ proposal/Recommendation	5) Planning	5) Developing alternatives	6) Development
	5) Report/Implementation	6) Implementation /follow-up	6) Recommendations	7) Presentation
			7) Implementing	8) Implementation

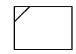
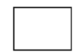
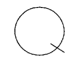
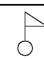
a short list of potential alternatives. The proposals in the short list are further developed in the development/recommendation phase and are evaluated to select the best alternative. In the last phase, the best alternative is presented to the owner for final acceptance before it is implemented to the project.

Table I summarizes the VE procedures developed in prior studies. These studies are mainly based on the generic five-phase VE procedure, but in some cases, they slightly modified and expanded the generic VE procedure to emphasize the importance of phases added in a particular study. Snodgrass and Kasi [17] separated the functional analysis from the information phase. Acharya *et al.* [1] added team selection as the first of their seven-phase procedure, while Lane Davis [9] puts goal definition as the first of their eight-phase VE procedure.

Whatever procedure is employed to implement VE for a construction project, alternatives that are expected to maximize the whole-life value are selected based on the best judgment of the study team. Wixson and Heydt [18] explored the importance of people for the success of VE implementation and discussed leadership skills, verbal and nonverbal communication, team member recognition and participation, and the role of each part in the job. Shen and Liu [16] emphasized a workshop as a mechanism to accommodate the process of decision making and the critical success factors (CSFs) in value management studies of a construction project. The authors found that the success of value management activities was strongly influenced by the requirements of the value management team, the support and active participation of clients, the competence of facilitator, and support from internal departments regarding the information access.

The qualitative assessment process using weighted evaluation is the most common way to evaluate VE alternatives [2], [5], [19]. These studies also stated that a matrix analysis is the simplest way to compare one alternative against another. The matrix approach enables its user to put all competing alternatives and their scores for each evaluation criterion in a structured manner. It provides all information on one page for easier evaluation. Assaf *et al.* [3] developed a computer program in creating a more user-friendly method to conduct a VE job plan based on qualitative decision making. This program is backed up with three main databases: a project information database, a database for proposal detail information, and a database for the weighted evaluation of proposals. The user must provide all the input data

TABLE II
BASIC MODELING ELEMENTS OF CYCLONE [7]

Name	Symbol	Function
Combination (COMBI) Activity		This element is always preceded by Queue Nodes. Before it can commence, units must be available at each of the preceding Queue Nodes. If units are available, they are combined and processed through the activity. If units are available at some but not all of the preceding Queue Nodes, these units are delayed until the condition for combination is met.
Normal Activity		This is an activity similar to the COMBI. However, units arriving at this element begin processing immediately and are not delayed.
Queue Node		This element precedes all COMBI activities and provides a location at which units are delayed pending combination. Delay statistics are measured at this element.
Function Node		It is inserted into the model to perform special functions such as counting, consolidation, marking, and statistical collection
Accumulator		It is used to define the number of times the system cycles.
Arc		Indicates the logical structure of the model and direction of entity flow.

for each input screen, and the result of each phase is used as the base for the next phase evaluation.

III. PROCESS SIMULATION MODEL: CYCLONE

CYCLONE is a modeling technique that allows the graphical representation and simulation of discrete systems that deal with deterministic or stochastic variables [7]. CYCLONE modeling consists of a set of nodes representing work tasks and delay positions with connecting arrows as the directional flow. Each work task has user-defined resources and time information. The program will simulate the construction process and generate quantitative outputs such as the cycle time and production rate. Interaction between resources can be analyzed since information about productivity and delay at each work task is available. Thus, the sources of a low productivity problem can be traced. This simulation program also has a sensitivity analysis feature that allows its users to evaluate different models and changing resources with different job conditions. In this study, CYCLONE is used for modeling the case study process. Its basic modeling elements are shown in Table II. The simulation for the analysis of process design is executed by using MicroCYCLONE.[1]

IV. SIMULATION APPLIED TO VE MODEL

The VE process is prepared after the scope of the project is properly defined. VE is concerned more with the time and cost of a project since the quality aspect is not negotiable. The focus on the quantitative aspects, such as cost and time, means that current qualitative decision making in a traditional VE job plan needs to be improved. A five-phase VE process using a simulation program is proposed to overcome this problem, and its job plan is described as follows.

[1] A microcomputer-based simulation program designed specially for modeling and analyzing site-level processes that are cyclic in nature. CYCLONE is a modeling technique, while MicroCYCLONE is a computer simulation program for CYCLONE.

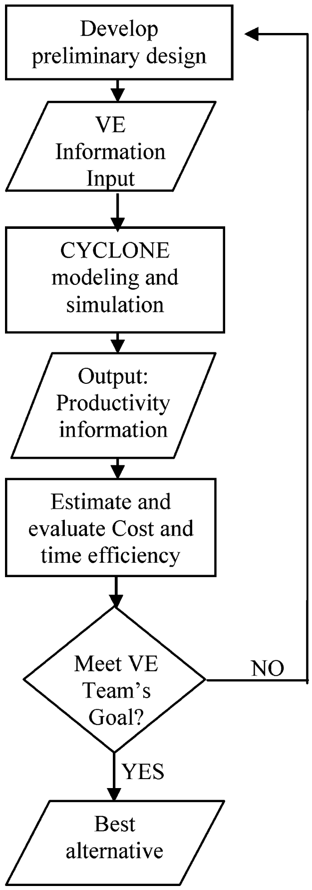


Fig. 1. Time and cost estimation procedure.

Phase 1 (information phase) starts with data collection regarding the scope of the project, the budget, and the preferred completion date. Most of the information is available from the owner. Based on this information provided, function[2] analysis is performed to find the importance levels of functions associated with the VE objects. In phase 2 (speculation/creative phase), the VE team generates any ideas that potentially could improve the values of the VE objects.[3] In phase 3 (evaluation/analytical), the proposals are ranked by the VE team using weighted evaluation and personal (expert) judgment. The weighted evaluation is performed to grade every proposal by considering the quantifiable aspects (cost and completion time) while using expert judgment to evaluate the nonquantifiable aspects, such as quality, safety, constructability, aesthetics, user comfort and performance, environmental impact, historic preservation, etc. As the process continues, the alternatives are screened for further assessment. When the process reaches phase 4 (development/recommendation), more information, such as the sequence of work tasks for each alternative and their estimated duration and the involved resources, is required for CYCLONE simulation modeling and analysis. Fig. 1 shows the complete procedure using the simulation technique in the development/recommendation phase.

[2]The intended role of a component of the facility, which is under design and construction phase.

[3]Components or specific operations of a construction project that are considered for the application of VE to reduce its construction cost and time by VE team.

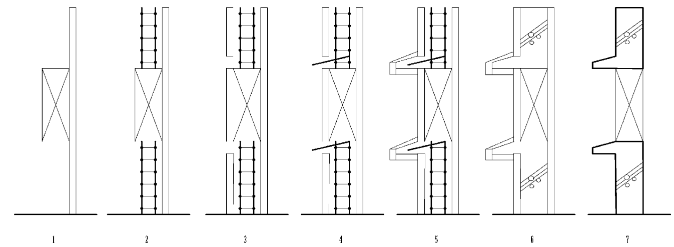


Fig. 2. Original design for awning and external wall. Notes: 1) Internal form erection: Forms for the inner part of wall are erected. Window boxes are embedded in this step to shape the window opening. 2) Installing reinforcing bars for the wall construction: After internal forms are erected, rebar work for wall starts. 3) External form erection: Forms for the outer part of wall are erected. The window side should be cut for forming awnings at the next step. 4) Installing reinforcing bars for awnings: Reinforcing bars for awnings are set and anchored. 5) Awning form setting: After completion of this stage, wall is ready for concrete pouring. 6) Pouring and curing concrete: Concrete is poured into wall and awnings simultaneously and cured until it reaches the required strength. 7) Removing forms: Forms are removed and cleaned for the use of the next cycle once concrete reaches the required strength.

In the case of the VE alternative related to the improvement of engineering processes and construction methods, accurate or realistic productivity information with regard to work tasks in each proposal is crucial because eventually this information is a decision factor in estimating the cost and time of the proposed alternative. The utilization of CYCLONE simulation in this phase is an efficient approach because fewer proposals remain in this stage after screening in the previous stage. By comparing the results of different alternatives from CYCLONE analysis in terms of cost and time, the VE team, therefore, has quantitative and realistic information about how the proposed alternatives will affect the project. The last phase of the proposed VE model is to summarize the findings and present the VE team's recommendations to the owner and its representatives. The owner's input determines which proposals will be implemented in the project. The VE process is then documented in the final VE report.

V. Case Study: Hospital Building Project

A construction project in South Korea is used to demonstrate the entire process, the level of information required, and benefits and strengths of the proposed VE model. This case study shows that the proposed advanced five-phase VE model can be successfully applied to a real construction project and can assist project stakeholders in making better VE decisions by using quantitative simulation analysis. The project is a hospital building construction project located in Kyungki-Do, South Korea. It has a capacity of 1000 beds, with 46 000 m^2 floor area. The project cost is approximately \$60 million. The facility is mainly a reinforced concrete (RC) structure.

This case study focuses on the specific construction activity for the awning of external windows among the many activities in this project. In the original design, the external concrete wall and the awnings were planned to be built by using conventional wooden forms and concrete would be poured simultaneously into these two parts (see Fig. 2). Then, the exterior insulation

TABLE III
FUNCTION ANALYSIS

No.	Work tasks	Estimated Cost	Function (Verb-Noun)
1	Steel reinforcements	$39,800	Strengthen tension
2	Formwork	$73,200	Fabricate shapes
3	Concrete pouring	$7,680	Fabricate shapes
4	Cement finish	$16,000	Acquire a good surface
5	EIFS finish	$16,100	Decorate the external wall
	Total	$152,780	

TABLE IV
FUNCTION EVALUATION

Function	Team member							Importance Index (%)
	1	2	3	4	5	6	7	
F1 Fabricate shapes	40	35	35	50	35	45	45	40.71
F2 Strengthen tension	30	30	25	30	30	25	25	27.86
F3 Decorate the external wall	20	25	30	15	25	25	25	23.57
F4 Acquire a good surface	10	10	10	5	10	5	5	7.86
Total	100	100	100	100	100	100	100	100.00

and finish system (EIFS) was planned to be installed on the external concrete wall as a final finishing work. EIFS consists of insulation boards made of polystyrene or polyisocyanurate foam, which provide superior energy efficiency compared to other cladding products [6]. The following sections describe the phase-by-phase application of the simulation-based VE process with numerical examples.

A. Information Phase

The information phase starts with the selection of the VE team members. Seven members were selected for this VE study. The team began by identifying work tasks[4] involved in building the awning and analyzing the main function and cost of each work task. Function and cost must be clearly defined because the main purpose of VE is to achieve at least the same level of function and quality using the most cost-effective method. In order to keep this process easy, however, the function of each task must be defined as simply as possible, such as using two verb-noun words.

1) Function Analysis: The activities for building an external awning can be broken down into five work tasks, based on the occurrence order of the tasks, as follows: preparing steel reinforcements, erecting forms, placing concrete, applying the cement finish, and applying the EIFS finish (see Table III). The estimated cost for each work task was taken directly from the estimation data of the project. Relating to the identified functions, it is possible for work tasks to have the same function, e.g., the functions of "Formwork" and "Concrete pouring" are to "Fabricate shapes."

Based on the function analysis performed, the team evaluated each function to obtain the level of importance among the functions. In this process, the VE team assessed a relative importance among the four identified functions with total points being 100. The point sum assigned to different functions by each member should be 100, i.e.

$$\sum^{n} \mathrm{RI}_i = 100 \qquad (1)$$

where, RI_i = relative importance of function i and n = number of identified functions.

The importance index (I) for a function, which is the mean value of each team member's assessment on each function, represents the importance of the particular function on a scale of 0–100 (percentage). The importance index is calculated by

$$I_i = \sum_{j=1}^{m} \frac{\mathrm{RI}_i^j}{m} \qquad (2)$$

where, I_i = importance index of function i, RI_i^j = relative importance of function i by VE member j, and m = total number of VE team members.

The result is shown in Table IV and indicates that "fabricate shapes" was the most important function of the awning with 40.71% importance. The second most important function was "strengthen tension" with 27.86%. "Decorate the external wall" and "acquire a good surface" followed with 23.57% and 7.86%, respectively.

2) Value Analysis: A value analysis is the next step in order to determine which function should be given higher priority in identifying and generating alternatives. Work tasks and their associated estimated cost information (Table III) were reclassified by their functions. The cost of each function, based on its importance (CI_i), is the fraction of the currently estimated total cost proportional to the importance index derived from Table IV, while the function value (FV_i) is the minimum value between the current estimated cost of each function and the cost of each function based on its importance. CI_i and FV_i are calculated by (3) and (4), respectively.

$$\mathrm{CI}_i = I_i * \sum C_i \qquad (3)$$

$$\mathrm{FV}_i = \mathrm{Min}\{C_i, \mathrm{CI}_i\} \qquad (4)$$

where, CI_i = cost of function i based on its importance, C_i = estimated cost of function i, FV_i = function value of function i.

The function–cost ratio (FCR) indicates the level of effectiveness of the actual cost to achieve the particular function. A value of 1 indicates the most effective use of funds. If the ratio is lower than 1, the cost for the function is higher than the worth or value of the function. Thus, a small FCR value implies a

[4]Independent construction activities that are no longer dividable into subwork activities.

TABLE V
RESULTS OF VALUE ANALYSIS

No.	Function (Verb-Noun)	C	I	CI	FV	FCR	DC	Priority
F1	Fabricate shapes	$80,880	40.71%	$62,749	$62,749	0.78	$18,131	1
F2	Strengthen tension	$39,800	27.86%	$43,106	$39,800	1.00	0	-
F3	Decorate the external wall	$16,100	23.57%	$33,830	$16,100	1.00	0	-
F4	Acquire a good surface	$16,000	7.86%	$13,095	$13,095	0.82	$2,905	2
Total		$152,780	100 %	$152,780				

greater potential for improvement in terms of VE. The FCR of a function is calculated by

$$\mathrm{FCR}_i = \frac{\mathrm{FV}_i}{C_i} \tag{5}$$

where, $\mathrm{FCR}_i = \mathrm{FCR}$ of function i.

The priority of functions is determined by ranking the differences between the estimated cost (C) and the function value (FV) of each function. The cost difference (DC) of function i is calculated by (6).

$$\mathrm{DC}_i = C_i - \mathrm{FV}_i \tag{6}$$

where, $\mathrm{DC}_i =$ cost difference of function i.

The DC indicates the amount of money wasted to obtain the specific function. Thus, the function with the greatest difference should be given the highest priority when identifying and generating alternatives. Table V shows the output of this process. It indicates that “fabricate shape” was the top priority function when creating alternatives to the original design.

B. Speculative/Creative Phase

In this stage, the VE team generated alternative construction methods for the awning based on the results of the previous phase. Since “fabricate shape” was the top priority followed by “acquire a good surface,” alternatives were theorized to satisfy these two functions in a cost-effective way compared to the original design. Based on their experience and conducting brainstorming sessions, three alternatives for constructing the awning were identified for further evaluation, as follows.

Alternative 1: Fabricate using precast concrete.
Alternative 2: Fabricate using EIFS.
Alternative 3: Fabricate using concrete (separate from external wall concreting).

C. Evaluation/Analytical Phase

The VE team judged and ranked the alternatives generated from the previous stage. The objective of this phase is to remove alternatives that are impractical or noteworthy of additional study. Alternatives with great potential for cost and time savings would be selected for detailed analysis in the next stage. Once the final assessment in the next phase proved to be unsatisfactory by the VE team, the remaining group of alternatives would be revisited and repeated for the detailed analysis process until the best alternative was chosen.

TABLE VI
EVALUATION OF ALTERNATIVES

No	Alternatives	Evaluation			Results
		Quality	Constructability	Cost	
1	Precast-Concrete (PC)	●	▲	▲	
2	EIFS	●	●	●	Select
3	Concrete (Separate from External Wall)	●	▲	▲	

(●: Good, ▲: Moderate, X: Poor).

Three criteria were used to screen the alternatives: quality, constructability, and cost. The VE team performed a group assessment for each alternative using three indicators, namely good, moderate, and poor. The main reason of using only these three indicators was to treat alternatives equally (apply the same weight) and to pass them to the next stage for final detailed quantitative analysis if they did not possess clearly distinctive advantages over the others. Table VI shows the results of this assessment. In terms of quality, all three alternatives were assessed to be acceptable. However, EIFS (alternative 2) was determined to be the least expensive, while precast concrete method (alternative 1) and concrete method (alternative 3) were determined to be moderately expensive based on the real cost data provided by the specialty contractors for the alternatives. In the criterion of constructability, precast concrete and concrete were determined to be significantly inefficient compared to EIFS mainly because of the difficulty in handling concrete on site. In this case study, only EIFS was chosen for next-stage analysis.

D. Development/Recommendation Phase

During this phase, a quantitative assessment using the simulation approach was performed to compare the selected alternatives with the original design in terms of time and cost. Figs. 3 and 4 describe the sequence and details of the proposed design for awnings and external wall construction.

In the proposed design, the external concrete wall is constructed using ganged forms and, thereafter, the awnings made of EIFS would be installed. Ganged forms can be defined as prefabricated panels joined to make a much larger unit (up to 9×15 m) for convenience in erecting, stripping, and reusing; usually braced with wales, strongbacks, or special lifting hardware. The proposed design eliminated the need for special formwork for the awning portion, which was required in the original design. This modification allowed the utilization of the ganged form system for constructing the external wall. It also made the work task for installing EIFS awning completely independent from the main external wall construction operations because the separate EIFS element could be installed any time later at the subcontractor’s convenience. In addition, the EIFS awning can provide a better external finish since it is a prefabricated factory product.

The procedure of conducting a simulation analysis starts with identification of the flow units relevant to the process to be

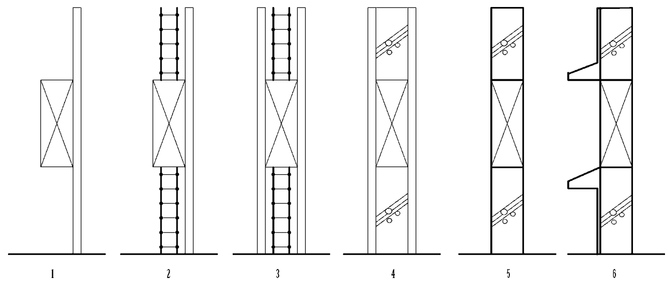


Fig. 3. Proposed design. Notes: 1) Internal form erection: Forms for the inner part of wall are erected. Window boxes are embedded in this step to shape the window opening. 2) Installing reinforcing bars for the wall construction: After internal forms are erected, rebar work for wall starts. 3) External form erection: Ganged forms for the outer part of wall are erected. Productivity will increase significantly because the window side does not need to be cut. The ganged form system also has higher productivity than the conventional wooden formwork system. 4) Pouring and curing concrete: Concrete is poured into wall and cured until it reaches the required strength. 5) Removing forms: Forms are removed and cleaned for the use of the next cycle once concrete reaches the required strength. 6) Awning setting: Awnings are formed by using EIFS. Since this activity is not included in the critical path of the project, the total duration of one cycle can be reduced significantly. Also, the productivity of setting EIFS is much higher than that of setting form and pouring concrete for awnings.

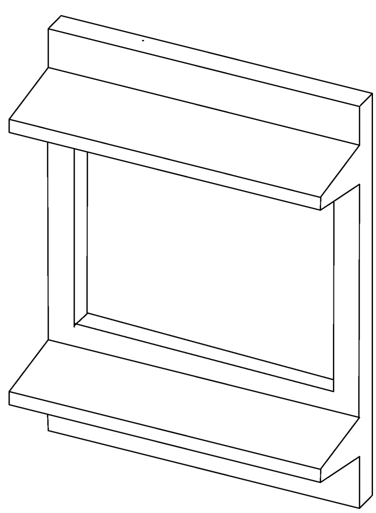


Fig. 4. Prefabricated EIFS awning in detail.

modeled. Typically, the flow units are physical items such as crews, pieces of equipment, and materials. The next step is to identify every possible state of the flow unit and develop the cycles and repetitive paths transited by the flow unit. The flow unit cycle shows the active (working state) and passive (idle state) of the flow unit. Each flow unit has time information, and the estimated time for each task of the flow unit is used. However, by using appropriate probabilistic durations for each task and simulating the entire procedure multiple times, the final output can be more reliable and realistic.

1) Simulation Modeling for the Proposed Design: The revised plan for constructing the awning significantly affects the external wall construction activities since the awning is no longer a part of the RC external wall construction. Thus, in order to measure the impact of the revised plan on the project cost and time, the whole process of the RC wall construction in the repetitive section of each floor must be included in this simulation analysis.

The number of simulation cycles of the RC external wall construction operation is determined by the number of repetitions of the operation, with the defined set of crews and resources related to this operation. In this project, the contractor divided each floor into two sections for the construction planning purpose as described in Fig. 5. The simulation modeling is based on this basic floor plan. It is assumed that all the sections have exactly the same floor plan. This hospital building has seven floors. Therefore, there are 14 sections representing 14 cycles in the simulation analysis.

The sequence of RC construction for each section is described in Table VII. After RC construction is finished, EIFS for external finish would be applied to the external wall at any time, without affecting the total duration of the project. Since installing EIFS on the external wall is not on the critical path of the project, this work task can be eliminated from the sequence of construction for the unit section. Based on the sequence described in Table VII, the CYCLONE models for the original design and proposed design are created as shown in Figs. 6 and 7. The duration for each work task described in Table VII was determined in a range using the subcontractor's experienced estimation. By analyzing the collected data from the subcontractor, a set of distributions, such as deterministic and triangular, is used to model the duration of each work task. Eight working hours per day and 25 working days per month were assumed for the modeling purpose. Note that concrete pouring time for a section is always estimated as one full day even though it may take over 8 hours but less than 24 hours. It is because the concrete pouring job should be completed continuously without interruption. So, its distribution is considered deterministic. The main differences between the original and proposed design are as follows.

1) Construction for awnings is eliminated from the proposed design.
2) The duration of work tasks related to formwork for the external wall is significantly reduced because of the higher productivity of the ganged form system.

2) Analysis of Simulation Results: Table VIII shows the output of the simulation analysis for the original and proposed design. It indicates that the average cycle time of the proposed design is 152 working hours (19 working days), while the original design required 185 hours (23 working days) for each cycle. The required time to finish each section has decreased by 17.8% compared with the original design.

The reduction of cycle time is four working days per cycle or 56 working days for 14 cycles. In order to calculate the time savings in calendar days, the nonworking days should be considered. In this project, the average nonworking days per month were estimated to be five days because the workers involved in this project are usually off every alternate Sunday (thus, two days per month) and three rainy days are usually expected. So, the reduction of the project duration of the revised plan in terms of calendar days is 65 days [56 days $\times$ (1 + 5/30)]. This time saving has a potential to directly reduce the total duration of

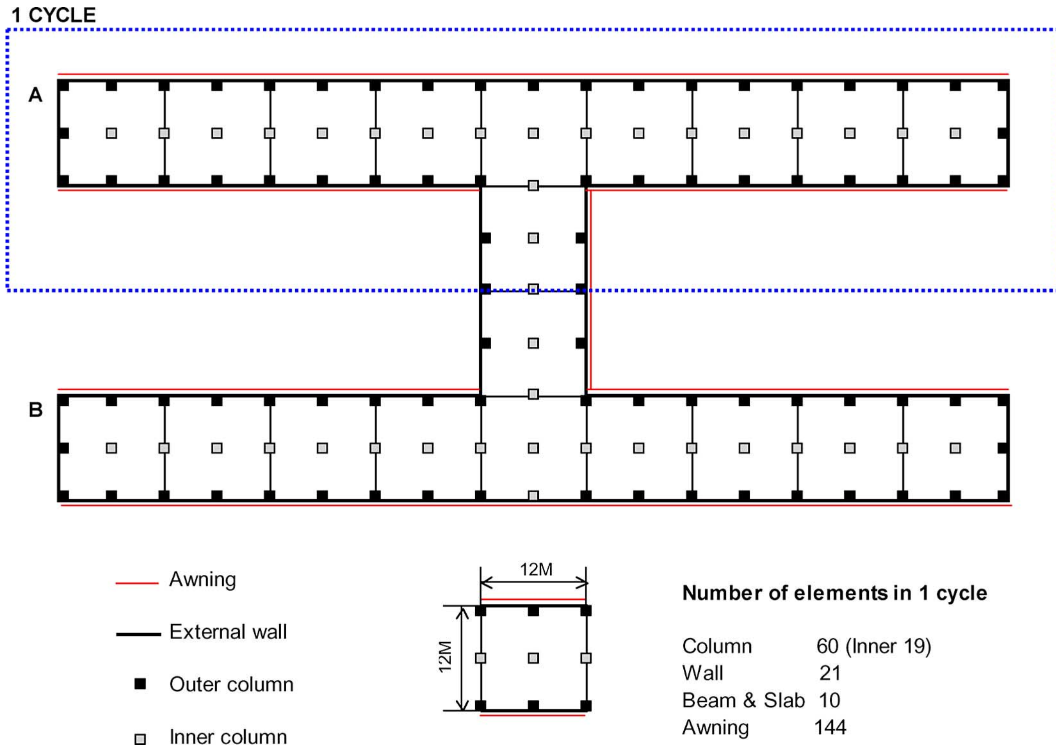


Fig. 5. Basic floor plan of the project.

TABLE VII
SEQUENCE OF CONSTRUCTION AND DURATION OF EACH WORK FOR THE UNIT SECTION

Sequence of Construction	Type of Distribution (minutes)			
	Original Design		Proposed Design	
1. Column rebar set	Triangular	[40,50,60]	Triangular	[40,50,60]
2. Column form set	Triangular	[20,30,40]	Triangular	[20,30,40]
3. Internal wall form set	Triangular	[180,240,300]	Triangular	[180,240,300]
4. Wall rebar set	Triangular	[150,200,250]	Triangular	[150,200,250]
5. External wall form set	Triangular	[180,240,300]	Triangular	[15,20,30]
6. Awning rebar set	Triangular	[15,20,30]		
7. Awning form set	Triangular	[20,25,40]		
8. Beam & slab form set	Triangular	[1200,1440,1680]	Triangular	[1200,1440,1680]
9. Beam & slab rebar set	Triangular	[960,1200,1440]	Triangular	[960,1200,1440]
10. Concrete pouring	Deterministic	480	Deterministic	480
11. Curing1	Deterministic	960	Deterministic	960
12. Curing2	Deterministic	9600	Deterministic	9600
13. Pull & move1	Triangular	[15,20,30]	Triangular	[15,20,30]
Pull & move2	Triangular	[80,90,120]	Triangular	[80,90,120]
Pull & move3	Triangular	[80,90,120]	Triangular	[25,30,40]
Pull & move4	Triangular	[4,5,6]		
Pull & move5	Triangular	[300,360,480]	Triangular	[300,360,480]

Note: Pull and move forms—1 for column forms, 2 for internal wall forms, 3 for external wall forms, 4 for awning forms, and 5 for beam and slab forms.

the project by the same amount because the RC external wall construction process was on the critical path of this project schedule.

The direct costs are analyzed for the external wall and the awning. The cost savings in labor cost of the wall and awning portions are about 69% and 99%, respectively, which are mainly due to productivity improvements from using ganged forms for the external wall and EIFS for the awning. Collectively, the proposed plan resulted in 40% savings on the total direct cost (see Table IX). Note that the actual cost saving of the awning

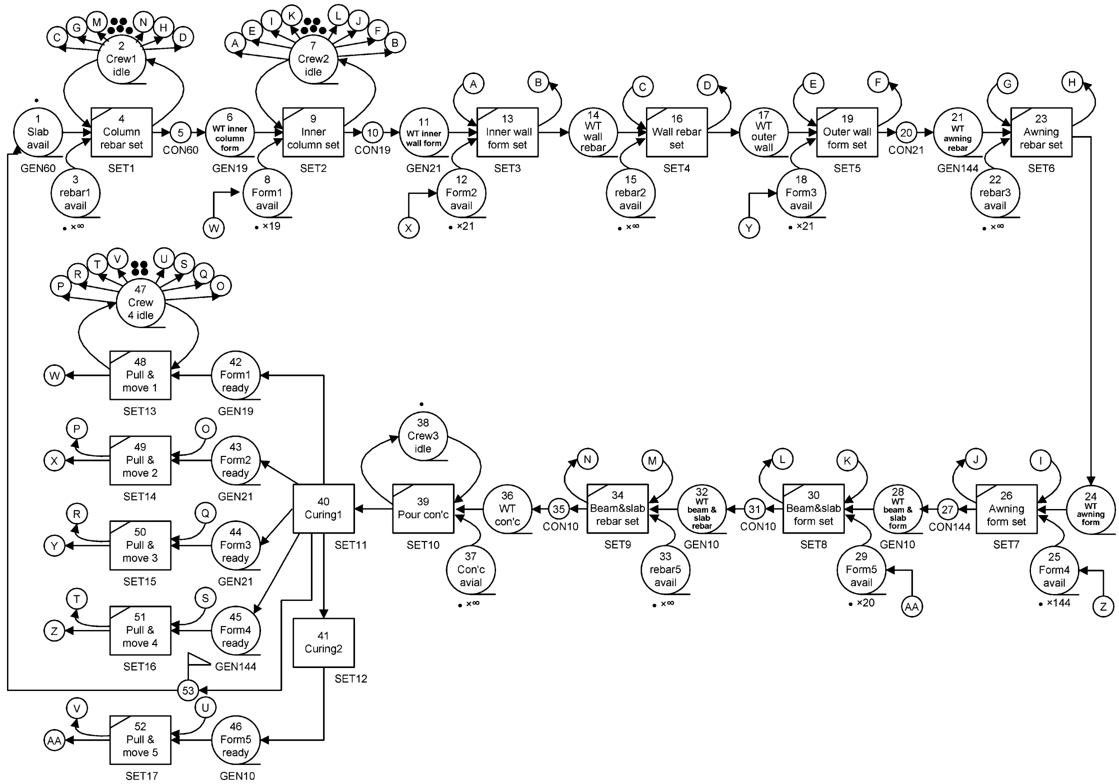


Fig. 6. CYCLONE model of the original design.

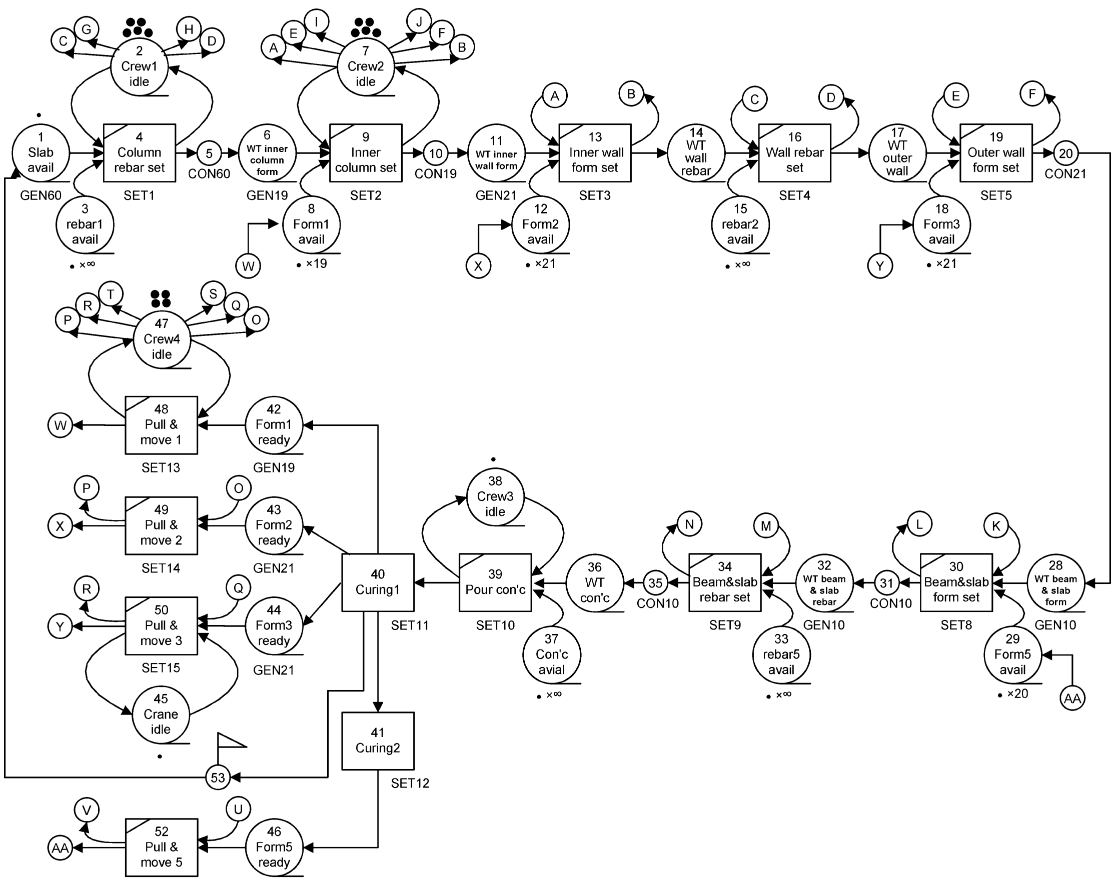


Fig. 7. CYCLONE model of the proposed design.

TABLE VIII
CYCLE TIME COMPARISON BETWEEN ORIGINAL AND PROPOSED DESIGN

Description	Original design	Proposed design	Duration Difference	Time savings
Cycle time (hour)	185	152	-33	17.8%
Days per section	23	19	-4	

TABLE IX
COST COMPARISON BETWEEN ORIGINAL AND PROPOSED DESIGN

Item	Estimated cost ($)		Cost Savings ($)	
	Original Design	Proposed Design	Cost	%
Direct Cost				
Material Cost				
(Awning)				
formwork(awning)	4,800	-	(4,800)	
rebar	5,000	-	(5,000)	
concrete	4,800	-	(4,800)	
EIFS finish	12,000	-	(12,000)	
EIFS(Fabricated)		108,000	108,000	
Total Material Cost	26,600	108,000	81,400	306%
Labor Cost				
(Awning)				
formwork (awning)	68,400	-	(68,400)	
rebar	34,800	-	(34,800)	
concrete	2,880	-	(2,880)	
cement finisher	16,000	-	(16,000)	
EIFS finish	4,100	-	(4,100)	
EIFS (Fabricated)		1,200	1,200	
	126,180	1,200	(124,980)	-99%
(Wall)				
formwork (inner wall)	84,840	84,840	-	
formwork (outer wall)	84,840	-	(84,840)	
formwork (ganged)	-	7,680	7,680	
Pull & move	25,000	6,200		
	194,680	98,720		
Total Labor Cost	320,860	99,920	(220,940)	-69%
Total Direct Cost	347,460	207,920	(139,540)	-40%
Indirect Cost				
			(207,133)	
Direct/Indirect Cost Savings				
			(346,673)	

part was much higher than that listed in Table IX, which was because the contractor promised the EIFS subcontractor that a portion of the cost savings for the RC subcontractor would be awarded to the EIFS contract amount as an incentive. Sharing the benefits of the total savings was an incentive to encourage the quality construction of the EIFS awning.

The reduction of the project duration also directly impacts the indirect costs such as the management staff's salary, site-office maintenance, insurance, site utilities, etc. In the case study project, a total of 20 field and office engineers were employed and a relatively large temporary site office was used. The average monthly indirect costs of this project were estimated at approximately $95 600 per month. Thus, the indirect cost savings were estimated to be $207 133 ($95 600 per month $\times$ 65 days).

The costs of implementing this advanced five-phase VE model at each stage were estimated in Table X to determine

TABLE X
ESTIMATED COSTS FOR IMPLEMENTING THE PROPOSED VE MODEL

VE Activities	Number of engineers	Duration in days (min-max)	Average Daily Wages ($)	Costs (min-max)
Project Team Members				
Reviewing the designs	7	4-7	200	$5,600-$9,800
Developing ideas	7	2-4	200	$2,800-$5,600
Reviewing alternatives	7	1-3	200	$1,400-$4,200
Data Collection	3	1-2	200	$600-$1,200
Data Analysis	3	2-4	200	$1,200-$2,400
Final Report	1	3-4	200	$600-$800
Experts from Home Office				
Simulation modeling	1	8-12	300	$2,400 – $3,600
VE Process consultation	1	4-5	300	$1,200-$1,500
Total VE application Cost				$15,800-$29,100

the actual total cost savings achieved in this case study. Any VE process in construction projects is usually initiated and executed during periodic meetings where the project manager and team members discuss cost, schedule, and progress of the construction project. Therefore, it is very difficult to accurately measure and quantify the actual resources used for specific VE applications. It is important to note that the values in Table X are, at best, order-of-magnitude estimates that are used to determine the total cost savings from applying the new VE model to this specific case study.

The total savings by implementing VE are determined from Tables IX and X. Direct and indirect cost savings using the alternative method identified from the VE procedure were $346 673, and the cost required to implement the new VE model was estimated to range between $15 800 and $29 100. Thus, the actual total cost saving was about $317 573–$330 873. From this case study, the implementation cost of this new VE model accounted for 5%–8% of the expected direct and indirect cost savings. The return on investment of applying the VE model is estimated to range from 1200% to 2200%.

E. Report and Implementation Phase

The findings using this VE model were presented to the owner. The owner subsequently accepted the recommendation to construct the awning entirely made of EIFS, and the project was successfully implemented.

VI. DISCUSSIONS

One of the most successful stories of VE application is the experience of City of New York Office of Management and Budget, which has achieved $100 in savings for each $1 invested in VE [5]. The amount of fund expected to be allocated for VE study varies depending on the type and size of the project. The results of over 500 studies on the application of VE in various sectors showed a saving range between 5% and 35% for initial costs and between 5% and 20% for annual operation and maintenance costs [5].

The case study indicates that the proposed VE model using a simulation approach can be successfully applied to a real construction project. Through a series of tools to quantify data in assessing alternatives, the proposed model greatly assists the decision making process by the owner, designer, and the contractors. However, the proposed model was applied only to a specific construction project. The application and validation of this model must continue with different sizes, types, and locations of projects to see whether the same benefits can be achieved in different project settings. For instance, one of the main limitations of this model is the early involvement of potential subcontractors because the model is data driven in assessing alternatives that focus more on quantitative data rather than qualitative data. It would be difficult and sometimes time-consuming to find qualified subcontractors that can provide those required data at an early stage. Another technical difficulty in applying the proposed model lies in the stage of using the simulation tool. The VE team must have in the team or in the home office an expert who is familiar with construction simulation programs. This may pose a challenge for the VE team as construction simulation programs have only been introduced actively to the industry since the 1990s, and, as a result, many contractors do not have project engineers who can handle and operate those programs. In addition, as the project size increases, it may require significant amount of time to develop full simulation models for each alternative under consideration, which may negatively affect the efficiency of the proposed model unless the simulation modeler has a very good understanding of technical and operational details of the entire project scope and activities.

VII. Conclusion

VE has been actively used in different industries, including the construction industry, as a means to improve the value of the final product. Various procedures have been developed and introduced to construction industry to produce a better outcome of the VE process. The success of VE applications depends on the quality of the information and the utilized decision making process. Accurate estimation regarding productivity is an important factor on VE proposals related to construction methods. In the case of a complicated construction process and the randomness of work task durations, an intuitive estimation (expert judgment) on productivity could lead to inaccurate estimate of cost and time savings.

This study introduced an advanced VE model using a five-phase quantitative approach. Each stage involves a structured framework for quantitative assessment in dealing with the subjective opinions of experts. Capturing the monetary value of each function and comparing it with the estimated actual cost can greatly assist the VE team in identifying effective alternatives to the original plan. In addition, a construction simulation technique (CYCLONE) is used as a tool to minimize subjectivity in estimating the value of different alternatives in terms of time and cost in the development phase. The proposed model has been successfully applied and evaluated using an actual hospital building construction project. This new approach has a great potential to minimize subjectivity during VE process and improves confidence in VE decision-making process by using quantitative data from the simulation analysis. Future research will attempt to apply the proposed VE model on different types, sizes, and locations of construction projects to test its efficiency and applicability.

References

[1] P. Acharya, C. Pfrommer, and C. Zirbel, “Think value engineering,” *J. Manage. Eng.*, vol. 11, no. 6, pp. 13–17, 1995.

[2] A. Al-Hammad and M. A. Hassanain, “Value engineering in the assessment of exterior building wall systems,” *J. Archit. Eng.*, vol. 2, no. 3, pp. 115–119, 1996.

[3] S. Assaf, O. A. Jannadi, and A. Al-Tamimi, “Computerized system for application of value engineering methodology,” *J. Comput. Civil Eng.*, vol. 14, no. 3, pp. 206–214, 2000.

[4] A. J. Dell’Isola, *Value Engineering in the Construction Industry*. Washington, DC: Smith Hinchman & Grylls, 1998.

[5] A. J. Dell’Isola, *Value Engineering: Practical Applications for Design, Construction, Maintenance and Operations*. Kingston, MA: R.S. Means, 1997.

[6] EIMA (EIFS Industry Members Association). (2006). What are EIFS? [Online]. Available: http://www.eima.com/eima/eifs.htm

[7] D. W. Halpin and L. S. Riggs, *Planning and Analysis of Construction Operations*. New York: Wiley, 1992.

[8] V. R. Kamat and J. C. Martinez, “General-purpose 3D animation with VITASCOPE,” in *Proc. 2004 Winter Simul. Conf.*, vol. 2, pp. 1691–1697.

[9] K. E. Lane Davis, “Finding value in the value engineering process,” *Cost Eng.*, vol. 46, no. 12, pp. 24–27, Dec. 2004. ABI/INFORM Global.

[10] F. F. Mansour, “Value engineering in engineering/construction,” in *Proc. 35th Annu. Meeting, Trans. Amer. Assoc. Cost Eng.*, 1991, pp. b.4.1–b.4.5.

[11] J. C. Martinez and P. G. Ioannou, “General purpose simulation with stroboscope,” in *Proc. 1994 Winter Simul. Conf.*, pp. 1159–1166.

[12] J. C. Martinez, “General-purpose simulation system based on activity cycle diagrams,” in *Proc. 2001 Winter Simul. Conf.*, pp. 1556–1564.

[13] J. J. O’Brien, *Value Analysis in Design and Construction*. New York: McGraw-Hill, 1976.

[14] A. Omigbodun, “Value engineering and optimal building projects,” *J. Archit. Eng.*, vol. 7, no. 2, pp. 40–43, 2001.

[15] M. Sanchez, F. Prats, N. Agell, and G. Ormazabal, “Multiple-criteria evaluation for value management in civil engineering,” *J. Manage. Eng.*, vol. 21, no. 3, pp. 131–137, 2005.

[16] Q. Shen and G. Liu, “Critical success factors for value management studies in construction,” *J. Constr. Eng. Manage.*, vol. 129, no. 5, pp. 485–491, 2003.

[17] T. J. Snodgrass and M. K. Kasi, *Function Analysis: The Stepping Stones to Good Value*. Madison, WI: Univ. Wisconsin Press, 1986.

[18] J. Wixson and H. J. Heydt, “The human side of value engineering,” in *Proc. 1991 SAVE Int. Conf.*, Kansas City, MO, pp. 30–38.

[19] L. W. Zimmerman and G. D. Hart, *Value Engineering: A Practical Approach for Owners, Designers, and Contractors*. New York: Van Nostrand Reinhold, 1982.

[20] Federal Facilities Council, “Sustainable Federal Facilities: A Guide to Integrating Value Engineering. Life-Cycle Costing, and Sustainable Development,” Nat. Res. Council, Washington, DC, Federal Council Tech. Rep. No. 142, 2001.

[21] M. H. Pulaski and M. J. Horman, “Continuous value enhancement process,” *J. Constr. Eng. Manage.*, vol. 131, no. 12, pp. 1274–1282, 2005.

[22] S. Green and P. Popper, *Value Engineering: The Search for Unnecessary Cost*. Ascot, U.K.: Chartered Inst., 1990.

[23] P. D. Rwelamila and P. W. Savile, “Hybrid value engineering: The challenge of construction project management in the 1990s,” *Int. J. Project Manage.*, vol. 12, no. 3, pp. 157–164, 1994.

[24] A. Palmer, J. Kelly, and S. Male, “Holistic appraisal of value engineering in construction in United States,” *J. Constr. Eng. Manage.*, vol. 122, no. 4, pp. 324–328, 1996.

[25] D. L. Younker, *Value Engineering: Analysis and Methodology*. New York: Marcel Dekker, 2003.

[26] C. Y. J. Cheah and S. K. Ting, “Appraisal of value engineering in construction in Southeast Asia,” *Int. J. Project Manage.*, vol. 23, no. 2, pp. 151–158, 2005.

Boo Young Chung received the B.S. degree from Seoul National University, Seoul, Korea, and the M.S. degree in construction engineering and management form Purdue University, West Lafayette, IN, and the Ph.D. degree in project management from the University of Maryland, College Park.

He is a Principal Researcher at the U-City Center of Excellence, Samsung SDS, Seongnam-si, Korea. He had been with the construction industry for over ten years. He was a Principal Researcher at Jeonin, Inc., which is one of the top construction management companies in Korea, before joining Samsung SDS. Currently, he is an Elected Member of the construction research council of the American Society of Civil Engineers. His current research interests include the area of information systems management, mainly focusing on the convergence of construction, and information technology. He has several scholarly publications in the area of strategic issues in project management, construction engineering and management, and information systems management. His publications appear at *Journal of Construction Engineering and Management*, *Journal of Computing in Civil Engineering*, and others.

Syadaruddin Syachrani received the B.S. degree in civil engineering and the M.S. degrees in industrial engineering from Institut Teknologi Bandung, Bandung, Indonesia.

He is a Graduate Research Assistant and Doctoral Student in the School of Civil and Environmental Engineering at Oklahoma State University, Stillwater, OK. His current research interests include the areas of advanced infrastructure asset management system including the application of knowledge discovery in database (KDD) and data mining, life cycle modeling, and optimal decision-making process.

Mr. Syachrani received the Best Research Paper presentation awards at the OSU Research Symposium in 2007 and 2008 along with Advisor D. Jeong.

Hyung Seok (David) Jeong received the B.S. degree from Seoul National University, Seoul, Korea, and the M.S. and Ph.D. degrees in civil engineering from Purdue University, West Lafayette, IN.

He is an assistant professor in the School of Civil and Environmental Engineering, Oklahoma State University, Stillwater and is part of the school's Construction Engineering and Project Management group. His current research interests include management issues during construction stages and post-construction stages. He is the author or coauthor of more than 20 technical papers in several research areas. His current research interests include the following.

1) *Construction project management:* Construction project scheduling and estimating, productivity, project organization, and emergency construction project management;

2) *Civil infrastructure asset management:* Condition assessment techniques, life cycle modeling, prediction of future performance, data filtering and dissemination, optimal resource allocation, and decision support systems;

3) *Civil infrastructure preparedness against extreme natural hazards and man-made disasters:* Disaster mitigation strategies, engineering response strategies, rapid recovery, appropriate redundancy management, simulation approaches for analyzing infrastructure network behavior after a disaster, etc.

He was the recipient of several academic awards throughout his academic career including the Best Paper award by IIE (2008), Best Research Paper Presentation Awards at the OSU Research Symposium (2007 and 2008), and Outstanding Teacher of the Year award by Chi Epsilon (2007). He is an active member of the following professional organizations: the American Society of Civil Engineers (ASCE), the Construction Research Council of ASCE, the Utility Pipeline Asset Management Committee of ASCE, the North American Society of Trenchless Technology, and the American Society of Engineering Education.

Young Hoon Kwak received the B.S. degree from Yonsei University, Seoul, Korea, and the M.S. and the Ph.D. degrees in engineering and project management, respectively, from the University of California, Berkeley.

He is a Faculty Member of the Project Management Program at The George Washington University's School of Business (GWSB), Washington, DC. He was a Visiting Engineer at the Massachusetts Institute of Technology, Cambridge, and taught at the Florida International University, Miami, FL, before joining GWSB. He is the author or coauthor of more than 70 scholarly publications in the area of strategic issues in project management, project risk management, project control, performance improvement, and engineering, construction, and infrastructure management. His publications appear in *California Management Review,* the IEEE TRANSACTIONS ON ENGINEERING MANAGEMENT, *Technovation: The International Journal of Technological Innovation, Entrepreneurship and Technology Management, the International Journal of Project Management, Project Management Journal, the International Journal of Managing Projects in Business, Risk Management: An International Journal, the Journal of Construction Engineering and Management, the Journal of Management in Engineering, the Journal of Computing in Civil Engineering, Korean Management Review, ICAFAI Journal of Operations Management, Projects and Profits, PM Network*, and others. Currently, he is a specialty editor (associate editor) for case studies section of the *Journal of Construction Engineering and Management* (*ASCE*) and serves on the editorial board for *International Journal of Project Management* (*Elsevier*), *Project Management Journal* (*Wiley*), *and Journal of Management in Engineering* (*ASCE*).

Dr. Kwak is an elected member of the Construction Research Council of American Society of Civil Engineers and a three-time recipient of the Project Management Institute's research grant. In 2008, he received an International Project Management Association's Outstanding Research Contribution Award.