TEACHING CONSTRUCTION SCHEDULING USING A SIMULATION GAME

Euysup Shim, Illinois State University; Wi Sung Yoo, Construction and Economy Research Institute of Korea;
Didier Ngoma, Illinois State University

Abstract

Repetitive construction projects are typically scheduled by the Linear Scheduling Method (LSM) due to repetitive construction processes in multiple units or locations. Workflow between subcontractors in repetitive construction projects affects project performance. Thus, selection of appropriate size workflow has been of interest to contractors. However, LSM is based on an assumption of single unit flow of work between subcontractors. Therefore, combining LSM scheduling with a consideration of impacts of workflow amount is important, and a simulation game was developed in this study for teaching the subject. The game simulates actual construction processes by using building blocks. The effectiveness of the game for teaching was evaluated through a hypothesis test which was conducted via a quiz on student learning. A questionnaire was also conducted to determine the effectiveness of the game. The evaluation results are presented here.

Introduction

In repetitive construction projects, such as multi-unit residential building construction projects, subcontractors need to repeat a construction process—or, at least, a similar one—in multiple units or locations by moving from one unit to the next. Then, the next subcontractor follows after which a series of subcontractors work on the job simultaneously. Since subcontractors require that the work be completed by a preceding contractor, the amount of work available to start with is an important issue to subcontractors. The amount of work available is affected by size of workflow between subcontractors, which affects the project's overall performance as well as each subcontractor's duration and cost [1], [2]

The Linear Scheduling Method (LSM) is a scheduling method used for repetitive construction projects, and its key features include the easy-to-understand relationship between quantity of units delivered and the rate of unit production [3]. However, LSM is based on a single-piece workflow and the impact of its size of workflow on project performance was not incorporated in LSM scheduling.

Therefore, a simulation game was developed to help Construction Management (CM) students learn LSM combined with consideration for the impact of workflow size. The game simulates actual construction processes of a repetitive construction project by building multiple houses with building blocks. Students are expected to learn LSM and the impact of the size of workflow on project performance. The effectiveness of the game for teaching was evaluated through a hypothesis test: the hypothesis is that teaching with the simulation game is more effective than typical lecturing methods. The hypothesis test was performed by comparing students' knowledge gained under two different teaching methods: one group was taught using traditional lecture and the other group was taught using the simulation game. Also, a questionnaire was conducted to gather students' perceptions about their learning and the helpfulness of the game.

Repetitive Construction Projects

Repetitive construction projects such as multi-unit apartment projects or highway projects need to execute (or install) similar construction processes in multiple units or locations, typically performed by subcontractors [4]. Each subcontractor is responsible for a construction activity to build or install one unit and then move to the next unit. Thus, multiple subcontractors are typically required to perform their jobs on different units or locations simultaneously.

Subcontractors in repetitive construction projects need work to be completed by preceding subcontractors before beginning their own work. If a subcontractor has to wait on other contractors to complete their work, then they will have to wait and possibly incur additional expenses. It is of interest to subcontractors to keep work continuity of each subcontractor's labor over the course of constructing the unit [5]. Therefore, workflow between subcontractors who work simultaneously affects the production rate of following subcontractors, and overall project performance in terms of duration and cost is affected accordingly. As Tommelein et al. [6] described the 'Parade' of subcontractors, it is important to balance or coordinate the pace of subcontractors in repetitive construction projects.

Scheduling Method for Repetitive Construction Projects

Due to repetitive construction processes required in multiple units or locations, repetitive construction projects are not scheduled by using the critical path method (CPM) [3]. Instead, LSM is used for repetitive construction projects. LSM is one method of construction project scheduling and is also called the Line of Balance (LOB) or Repetitive Scheduling method [3]. Since LSM can visually plot repetitive operations, it helps contractors schedule continuous workflow. The main benefits of LSM include simple graphical presentation and easy understanding of the progress of each activity and when, where and what activities are being performed at any given time [7]. Due to these features, LSM is reported to have advantages of maximized resource utilization and minimized interruptions [3].

The unit or location is a critical component of LSM and represents a numerical sequence of repetitive operations. For example, in the case of multi-unit residential building construction projects, each residential unit (or apartment) can be the base for scheduling and measuring progress. This means that contractors can schedule and monitor construction operations based on each residential unit. However, another size can be used for multi-unit residential building construction projects: each floor. If multiple units are to be constructed in a building, each floor can be the base for scheduling. Unit size can affect the amount of workflow between subcontractors, thus affecting production rates of subcontractors. Therefore, it is critical to select an appropriate workflow size in LSM [3].

Batching Production in Repetitive Construction Projects

Batching production means making products in lots, not by pieces [1]. Batching production related management is of interest in the manufacturing industry because the setup costs of work stations can be reduced by decreasing the number of setups and batching production. Some construction processes are considered as batching production. For example, a subcontractor (a work station in the manufacturing industry) repeats a construction operation in multiple units in a multi-unit residential building construction project. If there are four residential units on each floor in which subcontractors are to occupy a floor exclusively and release the space to the next subcontractor after completion of all the work on the floor, then the subcontractors construct four units in a batch. Thus, the size of workflow in this example is the batch size of four units.

Since batch size affects construction project performance, selection of an appropriate batch size in construction project scheduling has been of interest to researchers [1], [2], [8-10]. For example, Ward and McElwee [2] examined a hotel construction project in England and proposed using a small batch size of 4 rooms instead of a big batch size of 20 rooms, which was used in the real construction processes. Also, Sacks and Goldin [9] analyzed multiple apartment building construction projects and recommended using a small batch size to reduce overall project duration and to maximize the value to the project owner.

It has been reported by several researchers and practitioners that using a small batch size has advantages over bigger batch sizes: 1) faster project delivery, 2) cost reduction and 3) reduction in rework and defects [2]. While small batch size can lead to early completion of the project and reduced costs, as mentioned above, at the project level, a batch size preferred by one subcontractor may be different from a batch size preferred by another subcontractor, depending on their production rates and other job conditions.

In addition to batch size, buffer is another important factor to be considered in repetitive construction projects. Buffer is defined as "the additional absorbable allowance provided to absorb any disturbance between two activities or tasks as a component of the logical connection between two activities" [11]. Using a small batch size leads to small amounts of up-front work-in-process inventory; and, a small amount of work-in-process inventory may cause lost production or idle workers due to an insufficient amount of work-in-process inventory. Therefore, it is recommended to allocate a buffer along with a small batch size [2], [8].

Scheduling with the Consideration of Batching Production

While LSM is a practical and easy tool for scheduling repetitive construction projects, it is based on a selected unit of workflow (i.e., each unit in a multi-unit residential project) [3]. On the other hand, understanding the impact of batch size on project performance and incorporating it into scheduling can improve project performance. Therefore, it is recommended that repetitive construction projects are scheduled along with consideration of batch size.

Game and Simulation for Enhanced Teaching

Game and simulation is an instructional method that can enhance student learning through active participation [12].

While the benefits and disadvantages of game and simulation in the academic learning environment in general are discussed by Ncube [13], simulation games are excellent tools for practical decision-making and management experience [14]. Especially in the construction industry and construction education, simulation is a very useful tool due to the complex interaction among various participants or processes [15].

Due to the benefits of game and simulation and features in the construction industry, educators in construction have developed or used several games and simulations such as Super-Bid [16], Equipment Replacement game [14], *CONSTRUCTO* [17], Negotiation Game [18], Parade of Trade game [6] and LEAPCON game [19]. The LEAPCON game is to simulate interior finishing processes of a high-rise apartment building with customized design in each unit and is used to help students understand the benefits of LEAN construction management principles: 1) pull flow—to construct what the immediate downstream activity needs, not to build a product from what is available; 2) small batch size; and, 3) multi-skilled workforce.

However, there is no a simple game available which can be used for teaching LSM while also considering batch size. While the LEAPCON game can provide insight into the impacts of batch size on project performance, it is based on a specific case in which each apartment's design is customized and change orders are expected due to information available late. Therefore, a simulation game for teaching LSM combined with impacts of batch size was developed. This simulation game is based on a more typical and generalized repetitive construction project and, thus, students can understand the subject more easily.

The Simulation Game

The objective for the development of this simulation game is to help Construction Management (CM) students understand 1) features of construction processes in repetitive construction projects; 2) impacts of batch size (size of workflow) on project performance; and, 3) how to develop an LSM-based schedule with the consideration of different batch sizes.

The game is to build four houses by using building blocks, as shown in Figure 1. The four houses in the game are different from one another in terms of color and location. Four houses are to be built by six players each of whom plays the role of subcontractor. Table 1 shows the roles and jobs of six players required for this game. Each player is given a container with all blocks and information needed for four houses, as shown in Figure 2. The information included in the containers includes size, color, number of blocks needed and location of houses.

Figure 1. A House Built of Building Blocks in the Game

Table 1. The Roles and Jobs of Six Players in the Game

No.	Role	Assigned job
1	Building layout surveyor	To locate four corners of a building
2	Subcontractor for Foundation	To build the first layer
3	Subcontractor for wall	To build next five layers
4	Subcontractor for doors and windows	To install a door & frame, two windows & frames
5	Subcontractor for roof framing	To build next two layers
6	Subcontractor for roofing	To build the last layer

Four houses should be constructed in the order of the first player (surveyor) to the last player (roof subcontractor), sequentially. All subcontractors except a surveyor can start the building process only after a preceding subcontractor finishes his (or her) job: If a preceding subcontractor's job is not finished, a subcontractor has to wait. Only one subcontractor is allowed to perform building processes at each site. All players are given the information about preceding work as well as their own work. Therefore, game players are required to inspect the work completed by a preceding subcontractor. If erroneous work is detected, the defective work should be corrected by the preceding subcontractor. The game is finished when four houses are built.

Figure 2. The Game Being Played in a CM Course

The game players' performance is measured by time spent on the building process and wait time. Each player is given a sheet for recording time, and players are required to keep a record of start time and finish time for each house. At the end of the game, the amounts of time spent by the six players are totaled, and the total amount of time represents overall project duration. Also, the amount of wait time experienced by each player is calculated to present additional costs incurred due to waiting.

The game is designed to be played in two rounds with different batch sizes (or size of workflow between subcontractors). In the first round, it is assumed that the batch size for all subcontractors is one house. In other words, each subcontractor can occupy only one site and the work completed at one site should be released to the next subcontractor without a delay. After the first round, all finished houses should be disassembled for the next round. In the second round, players need to assume that the batch size for all subcontractors is four houses. Each player occupies four sites and the work completed on four houses should be released to the next subcontractor all at once. In the second round, some players may need to wait because preceding subcontractors' production rates may be slow. By comparing resulting time performances from two rounds of the game, students participating in the game can understand the impacts of different batch sizes on project performance along with LSM scheduling.

The game simulates actual construction processes and has the following features:

- Reflection of different production rates: subcontractors' production rates may vary depending on the amount of resources allocated, difficulty level of the jobs, etc., as in real construction projects. Also, production rates of subcontractors in a sequence may not be balanced or comparable to each other. The game is designed to reflect different production rates among subcontractors by different work amounts among subcontractors. For example, installation of one door and two windows can be done relatively quickly. However, building five layers of bricks for wall construction needs more time than installation of doors and windows. Therefore, students are expected to understand the importance of balancing production rates between subcontractors and recognize the need to buffer the time between subcontractors.
- Easy measurement of project performance: players need to keep records of times they start and finish each house. After each round of the game, all times for each player and the overall project are calculated. Thus, overall project performance and each subcontractor's performance are measured in terms of time and cost. Assuming that subcontractors do not do anything productive during their wait time, wait time would represent an additional cost caused by an insufficient amount of work.
- Reflection of uncertainty in quality: contractors (or their workers) may make mistakes. Erroneous work may be detected by an inspector or downstream subcontractor and should be corrected. The game reflects the uncertainty in quality of workmanship by defective work which may be produced by players.

Implementation of the Game

The game was played in a Construction Management course in December, 2011, as shown in Figure 2, after having been tested in a pilot study in April, 2011, at one educational institution. The students played the game over two rounds and discussed the results and what they learned. After playing the game, the time records were collected and simple plots of performance were prepared by one of the authors. The plots are shown in Figures 3 and 4. (The plots in Figures 3 and 4 are the results from one team's play). The plots in Figure 3 show the progress of six subcontractors: the plot on the left is from the first round with a batch size of one house; the plot on the right is with a batch size of four houses. These plots show overall project duration, production rates, wait time, the amount of buffer time and the differences between the two rounds.

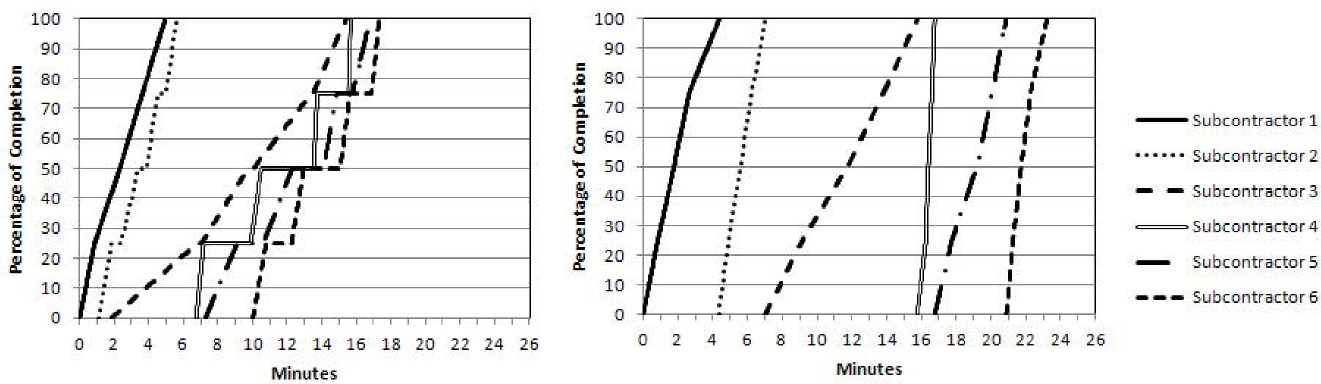

Figure 3. Examples of Progress Plots Resulting from the Game

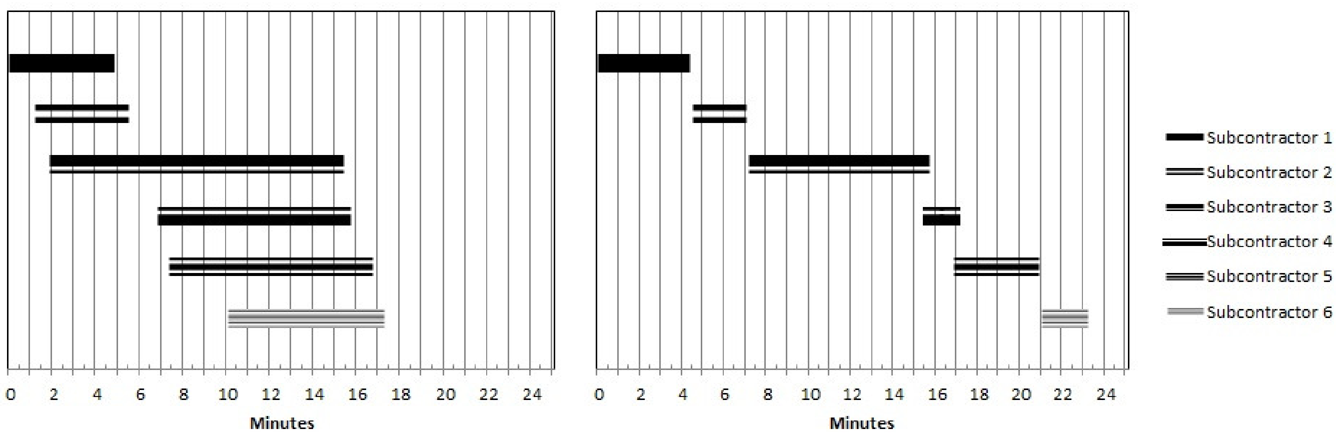

Figure 4. Examples of Duration Plots

The plots in Figure 4 show the amount of time spent by each player, which represents costs (or amount of resources) incurred by each subcontractor. The plot on the left is for a batch size of one house; the plot on the right is with a batch size of four houses. While the overall project duration is reduced when a smaller batch size (one house) is used, the small batch size caused more costs (wait time) for several subcontractors (subcontractors #2, #4, #5 and #6). In the discussion session after playing the game, it was discussed that subcontractors may have resistance to small batch size due to increased costs caused by no (or insufficient) buffers. Accordingly, it was also discussed that subcontractors may need buffer time in order to reduce wait time (or cost) under LSM.

Evaluation of the Effectiveness of the Game

Hypothesis Test

In order to evaluate the effectiveness of the game in teaching construction scheduling, a hypothesis test was conducted with the following hypothesis:

H_0: there is no difference between teaching using the simulation game and teaching using typical lecturing.
H_a: teaching using the simulation game is more effective than teaching using typical lecturing.

This hypothesis test was performed by comparing quiz results between two groups of students. The control group (16 students) received a lecture on the subject and then took a quiz. The experimental group (11 students) played the game and then took the same quiz.

The quiz included seven questions: the first five questions pertained to knowledge gained, while the other two questions pertained to perceived knowledge gained. The questions on the quiz were multiple-choice questions on the following topics:

- Question #1: definition of batching production
- Question #2: characteristics of repetitive construction
- Question #3: advantage of small batch size
- Question #4: disadvantage of small batch size
- Question #5: usage of both small batch size and buffer

Table 2 shows the mean and standard deviations of the percentage of correct answers to the questions pertaining to the knowledge gained (questions #1 through #5) by each group. While there was a slight difference between the two groups, it was concluded that the difference was not statistically significant from a student's t-test: the computed *t* value (0.358) is smaller than the critical value for the rejection of the null hypothesis at the 95% confidence level and the null hypothesis should not be rejected.

Table 2. Descriptive Statistics of the Quiz Results (Questions about the Knowledge Gained)

	% of correct answer	
	Experimental group	Control group
Question #1	54.5%	93.8%
Question #2	63.6%	56.3%
Question #3	100.0%	93.8%
Question #4	36.4%	56.3%
Question #5	72.7%	43.8%
Mean	65.5%	68.8%
Standard deviation	0.24	0.23

Questionnaire

In addition to the hypothesis test through a quiz, a supplementary evaluation of the efficacy of the game was conducted in two ways. The first approach to the supplementary evaluation was to ask questions (included on the quiz) of the two groups about their perception of knowledge gained, as follows.

- Question #6: confidence level in knowledge gained
- Question #7: degree of enhancement in knowledge by a teaching method

The students in both groups were asked to determine their confidence level on their knowledge gained on a scale of 1 to 5 (1 is for no confidence and 5 is for high confidence). The mean values and standard deviations of the students' confidence levels for both questions are summarized in Table 3. Based on a student's t-test, it was concluded that the students who played the game (the experimental group) had higher confidence in their knowledge than the students who received a lecture (the control group) for both questions.

Table 3. Descriptive Statistics of the Quiz Results (Questions about the Perceived Knowledge Gained)

Question		Experimental group	Control group
#6	Mean	4.09	3.50
	Standard deviation	0.70	0.82
#7	Mean	4.64	3.38
	Standard deviation	0.50	0.72

The second approach to the supplementary evaluation was a questionnaire on the helpfulness of the simulation game. The students in the control group were asked to play the game after taking the quiz. Also, the students in the experimental group received a lecture after taking the quiz. Then, the students in both groups were asked to take a questionnaire. Four questions were asked of the students, as shown in Figure 5.

The first question on the questionnaire was if the game was helpful in understanding batching production and impacts of batch size. All of the students (100%) answered that the game was helpful in their learning ('Strongly Agree' and 'Moderately Agree').

The second question was if the game was helpful in understanding the need for cooperation among subcontractors. The students compared the results of the two rounds: while overall project duration was reduced by using a small batch size in the first round, some of the subcontractors' durations were increased due to wait time. However, in the second round, each subcontractor's duration was minimized, while overall project duration was increased. Based on the results

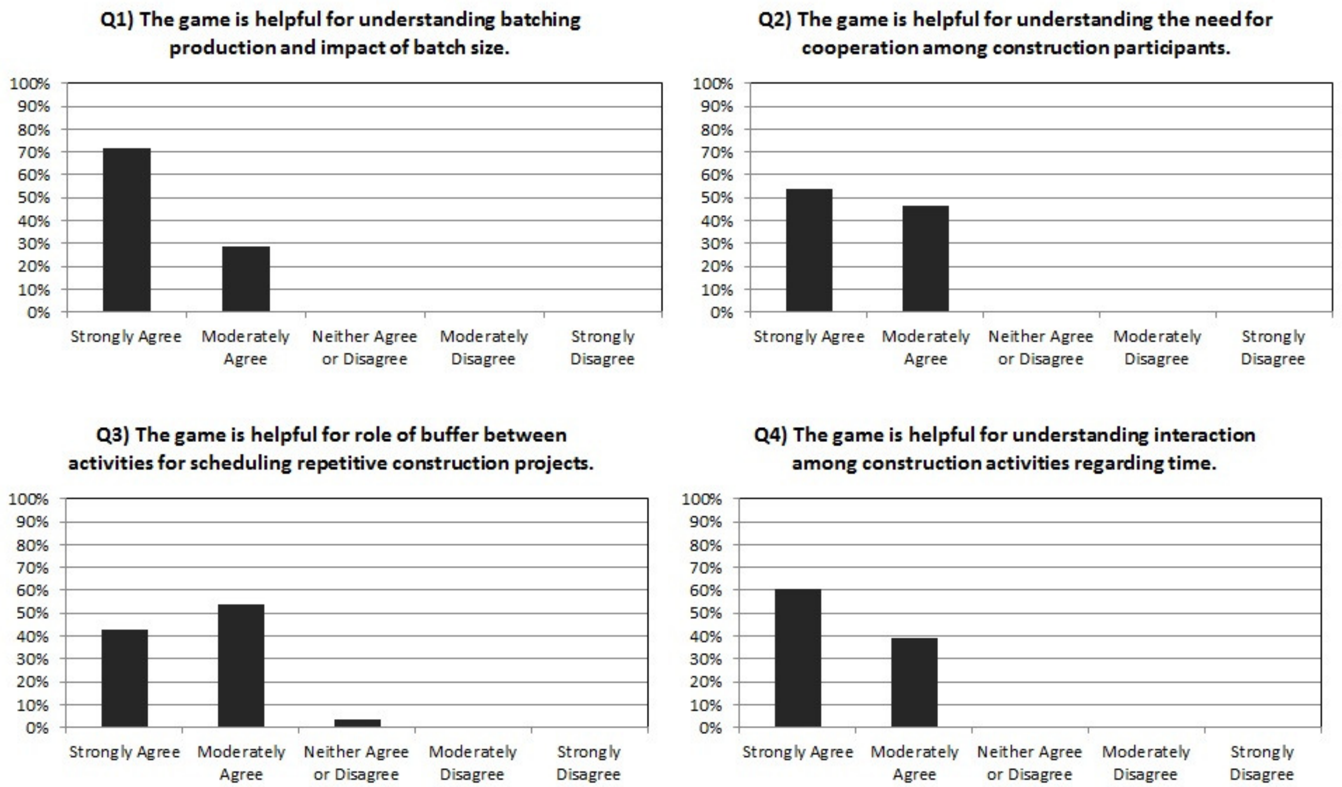

Figure 5. Results of the Questionnaire

shown in Figures 3 and 4, students recognized that construction project participants needed cooperation in regards to selection of batch size. The results of the questionnaire confirmed student learning. The third question was about the helpfulness of the game in understanding the role of buffers between activities. Almost all students (except one student) responded that the game was helpful.

The last question was about the helpfulness of the game in understanding the importance of interaction between construction activities. During the game, some students had to wait due to an insufficient amount of work available (or late progress in the preceding subcontractor's work). In the discussion session, some possible methods for improving the interaction were suggested and examined by the students. The overall results of the questionnaire show that the game was helpful for understanding the importance of interaction between activities.

Discussion and Conclusions

Repetitive construction projects are typically scheduled by LSM due to repetitive construction processes in multiple units (or locations). Also, the amount of workflow (or batch size) between subcontractors in a repetitive construction project is important and affects project performance. Therefore, teaching LSM along with the consideration of the impact of batch size can help construction management students prepare a better schedule for construction projects.

A simulation game was developed to help construction management students understand the impacts of batch size as well as LSM. The game simulates building processes by using building blocks. From comparisons between the results of two rounds of game play with different batch sizes, students can understand the impacts of batch size on project performance in addition to LSM.

The efficacy of the game in teaching was evaluated by a hypothesis test: teaching with the simulation game is more effective than typical lecturing. Student learning in both groups was measured by a quiz and the results of the quiz for the two groups were compared. The results of the student t-test showed that the hypothesis should be rejected. Therefore, it was concluded that teaching with the simulation game was not more effective than typical lecturing.

On the other hand, student perception about their knowledge gained in both groups was also analyzed. The results showed that the students who played the game had more confidence in their knowledge gained. Also, the helpfulness of the game based on the students' perception was determined by a questionnaire. The results showed that all of the students perceived the game as helpful in understanding the subject.

Combining the results from the hypothesis test and the questionnaire, it was concluded that the simulation game developed by the authors is not more effective than traditional lecture methods. However, considering the students' perceptions on their knowledge gained and helpfulness of the game, the game is still a good method of teaching.

The authors believe that students can learn more effectively through 'learning by doing' than 'learning by watching and listening'. Thus, the simulation game developed from this study can be utilized as a supplementary method for teaching construction scheduling with the consideration of the impacts of batch size.

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Biographies

EUYSUP SHIM is an Assistant Professor of Construction Management at Illinois State University. He earned his B.S. and M.S. degree (Architectural Engineering, 1996 and 1998) from Yonsei University, South Korea and Ph.D. (Civil Engineering 2008) from Texas A&M University. His research interest is construction project planning and LEAN construction. His email address is eshim@ilstu.edu

WI SUNG YOO is a Research Fellow of Construction Management Division at Construction & Economy Research Institute of Korea. He earned his B.S. degree from Dong-A University, Busan in South Korea, MS (Civil Engineering, 2003) from Texas A&M University, and Ph.D. (Civil Engineering, 2007) from the Ohio State University. Dr. Yoo is currently researching at Construction & Economy Research Institute of Korea. His interests are in (1) stochastic modeling, simulation, and quantitative effectiveness analysis for improving innovative project management and delivery strategies, (2) development of decision support models to control productivity and profit of construction projects, and (3) life-cycle cost analysis and risk management of international power plant construction projects. Dr. Yoo may be reached at wsyoo@cerik.re.kr

DIDIER NGOMA has been working as a building supervisor for the past six years. He earned his B.S degree from Illinois State University (Construction Management, 2012). His research interests are in project management, risk management, and quality. Ngoma pursues his master degree in project management in Illinois State University. Ngoma may be reached at dmngoma@ilstu.edu