

## **AC 2009-2143: A SIMULATION APPROACH TO CONSTRUCTION MANAGEMENT EDUCATION**

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# **A simulation approach to Construction management education**

## **Abstract**

Construction management requires decision-making skills. Main approaches to teach decision-making skills to construction management major students are: (1) analyzing sample situations involving decision-making; and (2) teaching logical decision-making procedures. The absence of ‘pressure’ factors in these approaches has significant negative impacts on the success of the education. The approaches also lack ‘dynamic’ effects that help create a spontaneous plan for construction projects where unforeseen changes and interruptions may occur. To minimize the adverse effects of the existing approaches, this paper proposes a framework for developing a web-based training system. The application is delivered as a game involving decision-making on the student’s part in response to developments at the job-site, and where one student competes against another in an attempt to simulate a real-world scenario.

## **Key words**

Construction education, decision-making, process simulation, web-based system.

## **Introduction**

In the real world, one of the most natural ways of acquiring knowledge and experience is to be immersed in relevant situations and to practice. However, construction students often have few opportunities for direct exposure to practical issues involved with real-world construction management scenarios. Case studies in a class-room setting and construction site tours are less interactive and efficient than the mode of learning-by-doing. Simulation gaming has been successfully introduced to construction education by many researchers since the late 1960s. These games have been shown to provide practical decision-making and management experiences to students<sup>8</sup>. They immerse students in a simulated environment where student can collaborate, compete, and create synthetic solutions for various situations utilizing techniques they learned in the classroom.

A number of simulation games have been developed to address various aspects of construction management that a project manager will face with, such as bidding and cost analysis, contract negotiation, trade coordination, and operation design and analysis. In the area of bidding and cost analysis, there are Construction Management Game<sup>3</sup>, CONSTRUCTO<sup>5</sup>, Superbid<sup>1</sup>, and VIRCON<sup>6</sup>. For contract negotiation, Dubziak and Hendrickson<sup>4</sup> developed a game that involves role-playing by the participants in negotiating various contract issues. Tommelein et al.<sup>12</sup> presents a game, Parade of Trades, for the learning of crew coordination and effect of variability. Nassar<sup>8</sup> and Sawhney et al.<sup>11</sup> developed games for construction equipment and material processes. Virtual Coach<sup>10</sup> was developed to enable “what if” analyses by the participants.

This paper proposes a framework for developing a web-based training system for integrated project planning and control, which includes scheduling, resource selection, pricing, and control. This paper discusses the development and implementation of the computer simulation based game. The game focuses on the resource management aspect of scheduling and controlling a construction project. Students form a number of teams and play the role of construction managers in the same residential construction project to be completed within a specified time-frame. Each team would compete against the other teams in the game to complete their project on time and within the specified budget. This game was applied as a supplementary tool for the project scheduling and control course in a construction management program.

## **Research methodology**

This research can be divided into two parts. The first part involves the development of the game. The scope of the game is followed by the game implementation framework. Then the developments of the various components of the game are followed. The second part details the implementation of the game. The various responsibilities of students and the game moderator are also outlined. Finally, the result of the first-run of the game is presented and inferences are drawn.

## **Development of the game**

### ***Purpose of the game***

The purpose of the game is to allow students to do the followings:

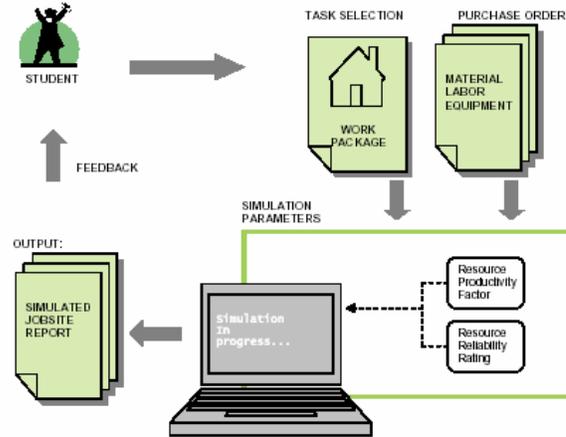
- develop a base schedule for a project;
- identify the resources required for the tasks scheduled;
- analyze the options available in the market with respect to hiring the services of labor force and renting the equipment required;
- schedule resources to enable its execution by issuing purchase orders;
- track progress of the project;
- analyze the daily jobsite report;
- re-schedule the project when schedule-variance occurred; and
- complete the project within the specified budget.

The purpose of the game is also to introduce students to the element of pressure that arises due to competition, by allowing them to compete against each other and to complete the project within the budget and ahead of other students in the class.

### ***Game implementation framework***

From the development perspective, the game has to provide the students with an environment close to reality, where they could employ the concepts learnt in the lecture and lab sessions of the scheduling course with respect to scheduling the resources and tracking the progress of the project. At the same time, the number of variables involved in the game, particularly those

controlled by the students, have to be manageable to allow the students to focus on each one of them while making decisions. Based on these parameters the game's conceptual implementation framework was developed as illustrated in Figure 1.



**Figure 1.** Game Implementation Framework

The students are assigned to a construction project with well-defined work breakdown structure (WBS) identifying the independent work packages. The resources required for each work package namely labor, equipment and material along with the quantity of work and the sequential order of execution of the various work packages are listed in the WBS.

The students would be required to determine the work packages available execution. The condition for a particular work package to be available for construction would be the completion of its preceding work packages. After the determination of the available work package, its resources required would have to be identified and scheduled. Market price-list would have to be referred to understand the options available in hiring the services of labor force, renting equipment and purchasing material. A decision would have to be made with regard to grade and supplier of every resource to be scheduled. Depending on the productivity and reliability rating of the resources scheduled, the construction process involved with the work package would be simulated and a jobsite report would be produced.

The jobsite report would serve as a feedback for the students. The students can analyze the effectiveness of their decisions from the jobsite report and check if their project is progressing according to their pre-planned schedule. The jobsite report would also help the students in making future decisions in the game.

## *Development of the components of the game*

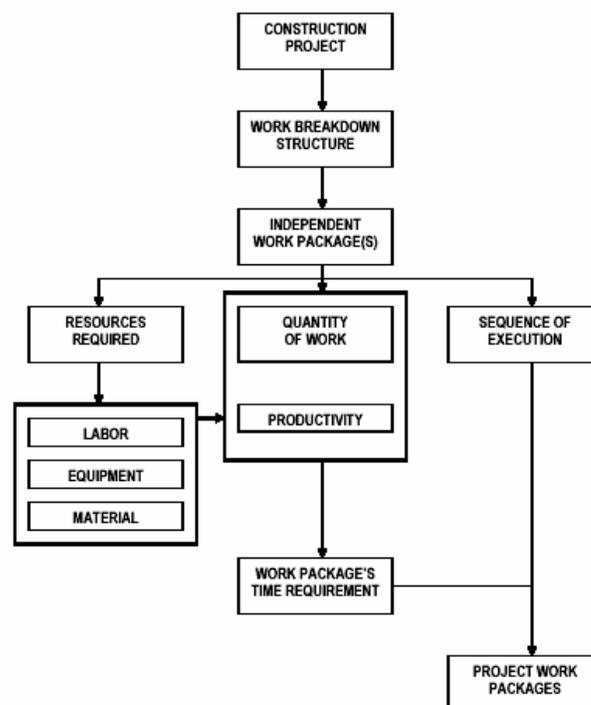
Based on the conceptual framework of the game discussed above, the following components of the game have to be developed:

- work packages;
- simulation code to model the construction processes involved in the work packages; and
- market price-list of the various resources involved.

The development of the various components listed above for the game is explained in the following sections.

### Development of work packages

The various steps involved in the development of work packages for a residential construction project are illustrated in Figure 2. A WBS will be developed for the construction project to identify the various independent work packages. These independent work packages will be further detailed in terms of the resources required namely labor, equipment and material. Next, the quantity of work involved with each work package and the logical sequence of execution will be determined. The productivity factor of the labor and equipment will then be determined. With the productivity of the resources and the quantity of work involved with each work package, the time required to complete each work package will be calculated. The data gathered would be compiled to form the project work packages.



**Figure 2.** Steps Involved in Developing Project Work Packages

Based on the outline, a residential construction project was identified for the game<sup>2</sup>. Using the tasks listed in the previous research, a work breakdown structure was developed for the project. The sequence of execution of the various tasks and their respective durations (measured in days) were also identified. The labor and equipment resource required for each identified work package was identified from the Means Building Construction Cost Data book by R.S. Means Company<sup>9</sup>. The average productivity factor for all the identified resources was also obtained.

The quantity of work to be done for the completion of each task was calculated by multiplying the duration of the task by 24. This was due to an assumption in the simulation code that a unit of work of any work package will be done in 20 minutes and hence 24 units of work could be done in a day (or 8 hours). The data gathered were compiled together as the project work packages.

### Development of the simulation network

A simulation network was developed to model the various construction processes involved in the construction of the residential project using STROBOSCOPE simulation language that was developed by Julio Martinez<sup>7</sup>. The variables incorporated in the simulation source code of the simulation network for the game and the assumptions were as follows.

### Variables

The number of variables incorporated in the game, was reduced to a manageable number to help the students focus on each one of them as they make their decisions during the game. The variables involved in the game were as follows:

- Number of crew members of each type
  - Their collective productivity factor (the average of the individual productivity factor of each crew member)
  - Variability factor of the collective productivity
- Number of equipments of a particular type
  - Their collective productivity factor
  - Variability factor of the collective productivity
- Amount of work
- Quantity of material

### Assumptions

The following is a list of assumptions that were used in the source code of the simulation file:

- Simulation time would be comprehended in minutes.
- There would be eight hours available for construction in a day.
- Each unit of work would take 20 minutes with a variability of 5 minutes distributed normally about the mean value.
- Simulation would stop either due to lack of time, lack of required resources, or when the

work package was completed.

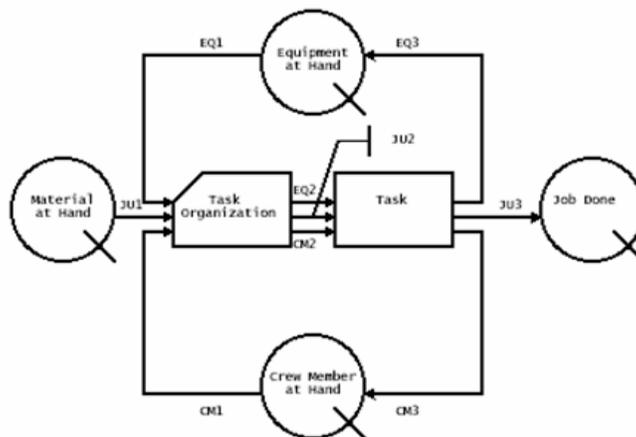
- Time taken by the equipment and labor resources to travel through the simulation network and return to their respective initial-positions would be comprehended as their respective rates of productivity.
- The productivity of resources was normally distributed about the collective productivity.
- Material required for various task would be the same and would be considered as a bulk resource.

### Simulation network

The simulation network to model the construction processes involved in the residential-construction project that was identified for the game, is developed. First, a conceptual simulation network is developed. Next, the need for revision of the conceptual simulation network is discussed. Finally, a revised simulation network is presented.

### Conceptual simulation network

The conceptual simulation network consists of Queues, Combi, Normal and Links as illustrated in Figure 3. Four Queues are created namely *MaterialAtHand*, *EquipmentAtHand*, *CrewMemberAtHand* and *JobDone*. Three of these Queues namely *MaterialAtHand*, *EquipmentAtHand* and *CrewMemberAtHand* hold the resources *Material*, *Equipment* and *CrewMember* before the start of simulation.



**Figure 3.** Basic Project Simulation Network

Simulation will start when the above mentioned Queues are non-empty or when they hold resources. The Combi activity *TaskOrganization* will draw resources from its preceding Queues namely *MaterialAtHand*, *EquipmentAtHand* and *CrewMemberAtHand* through the links *JU1*, *EQ1* and *CM1*. The number of resources drawn through each of the links is determined by the requirement of the work package being executed. When all the resources in the required quantities are acquired by the Combi activity, the resources will move to the Normal activity

*Task*. This Normal activity will hold the resources for 20 minutes of simulation time on an average, with a variability of 5 minutes to indicate that work is in progress.

At the end of Normal activity, the resources *Equipment* and *CrewMember* will return to their respective Queues through the link *EQ3* and *CM3*. On the other hand, the resource *Material* will move to the Queue *JobDone*.

At the end of each simulation run, the content-count of the Queues *EquipmentAtHand* and *CrewMemberAtHand* will remain the same. The content-count of the Queues *EquipmentAtHand* and *CrewMemberAtHand* will decrease at the start of each simulation run as resources will be drawn by the Combi activity *TaskOrganization* and the content-count will increase at the end of the simulation run as the resources will return to their respective Queues from the Normal activity *Task*. However, the content-count of the Queue *MaterialAtHand* will decrease while the content-count of the Queue *JobDone* will increase after each simulation run as the *Material* resources will be drawn from the Queue *MaterialAtHand*, by the Combi activity *TaskOrganization* at the start of the simulation run, and will be released to the Queue *JobDone* at the end of the simulation run.

Need for revision of the conceptual simulation network

According to the conceptual simulation network, the time taken by the resources *CrewMember* and *Equipment* to reach their respective Queues *EquipmentAtHand* and *CrewMemberAtHand* after they are drawn by the Combi activity *TaskOrganization* and released by the Normal activity *Task* will be the same, as they follow the same path during the simulation run. This time-taken will also correspond to the time taken by the *Material* resources to move from the Queue *MaterialAtHand* to the Queue *JobDone*.

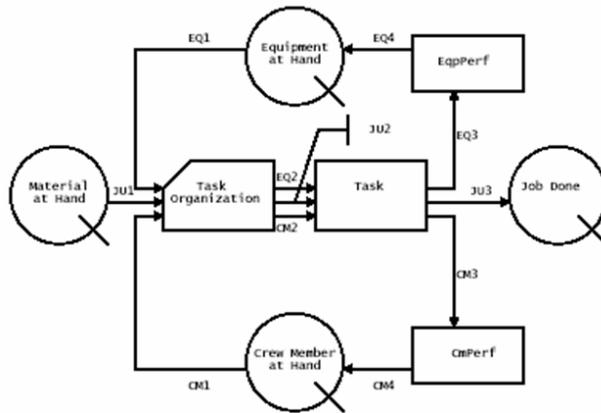
By the assumptions of the game, the time taken by the equipment and labor resources to travel through the simulation network and return to their respective initial positions (or Queues) is to be comprehended as their rates of productivity. Hence there arises a need to revise the conceptual simulation model to vary the time taken by the resources to return to their respective Queues according to their individual rates of productivity.

Revised simulation network

To vary the time taken by the *Equipment* and *CrewMember* resources to return to their respective Queues *EquipmentAtHand* and *CrewMemberAtHand*, the links *CM3* and *EQ3* are broken and Normals are inserted in the simulation network named *CmPerf* and *EqpPerf*, which are short for 'Crew Member Performance' and 'Equipment Performance' respectively as shown in Figure 4.

In the revised simulation network, the resources *Equipment*, *CrewMember* and *Material* will be drawn by the Combi activity *TaskOrganization* and released to the Normal activity *Task*. When the resources are released by the Normal activity *Task*, *Material* resources will enter the Queue *JobDone* while the resources *Equipment* and *CrewMember* will enter the Normal activities

*EqPerf* and *CmPerf* respectively. The Normal activities *EqPerf* and *CmPerf* will hold the resources for a duration corresponding to the rates of productivity of the resources before releasing them to their respective Queues. The simulation would continue in this manner until one of the end conditions becomes true. When the end condition becomes true, the simulation will stop and the report will become available.



**Figure 4.** Revised Project Simulation Network

### Development of market price-list

The following section details the development of the price-list for the material resource, labor, and equipment resources.

### Material price-list

The material units are not work-package-specific based on the assumptions for the development of the simulation network. During the implementation of the game, the students may use a purchased material unit for the execution of any work package. Hence there is a possibility of purchasing the total amount of material resources required for the entire project at the start of the game. If such a situation occurred, the students would have to manage fewer variables during the implementation of the game because they would not have to consider the scheduling of material resource.

To prevent the occurrence of such a situation, the purchase of material units by the students during the implementation of the game is regulated. A price-list is developed for the purchase of material units which discourages the students from purchasing all the material units at the start of the game. According to this pricing-methodology, the price per unit of the material increases with

the increase in the purchase quantity. This will discourage the students from purchasing more material units than was necessary. The reasoning that is provided for the increase in unit cost with increase in the quantity of purchase is the storage cost associated with the stocking of the unused material units purchased. Based on the above methodology, the material price-list that was developed is indicated in Table 1.

**Table 1.** Material price-list

Material Purchase Quantity (In unit)	Price (In \$ / unit)
< 16	200.00
16 – 30	300.00
31 – 45	325.00
46 – 60	350.00
61 – 100	400.00
100 <	500.00

#### Labor and equipment price-list

The purpose for the development of the labor and equipment price-list is to provide students with options while selecting labor and equipment resources for their project. The students are provided with the option of choosing from five suppliers: Blue Diamond Suppliers; Ruby Red Providers; Yellow Stone Providers; White Pearl Suppliers; and Green Day Providers. These suppliers have fixed productivity factors associated with them as indicated in Table 2.

**Table 2.** Productivity factors of suppliers

Supplier	Productivity Factor
Blue Diamond Suppliers	20
Ruby Red Providers	22
Yellow Stone Providers	24
White Pearl Suppliers	26
Green Day Providers	28

The productivity factors associated with suppliers indicate the time that will be taken by a labor

or equipment resource, hired from the respective supplier, to complete one job unit of work. Hence from Table 2, a labor or equipment resource hired from Blue Diamond Suppliers would take 20 minutes to complete one job unit of work while a resource hired from Green Day Providers would take 28 minutes to complete the same unit of work.

In addition to suppliers, grades are also introduced from A through E. These grades reflect the reliability rating or variability of the productivity factor of the resource hired. Table 3 shows the reliability rating for Blue Diamond Suppliers and the resulting variability in minutes. Since a resource must be hired by specifying the supplier and grade in the game, reliability rating associated with the grade reflects the variability of the productivity factor associated with the supplier. For example, if an equipment is hired from Blue Diamond Supplier of grade 'A', then the resource would be able to complete one job unit of work in 20 minutes with a variation (plus/minus) of 4 minutes, amounting to 80% reliability.

**Table 3.** Reliability rating and variability associated with grades for Blue Diamond Suppliers

Grade	Reliability Rating	Variability
A	80%	4
B	70%	6
C	60%	8
D	50%	10
E	40%	12

Based on the productivity factor and reliability rating a price-list is developed for each type of equipment and labor resource. The prices for labor resources are expressed as hourly rates (\$/Hour) and those for equipment are expressed as daily rates (\$/Day). These prices increase with increase in productivity and reliability rating. The sub-contractor price-list also follows the same approach as equipment or labor resource and the prices are expressed as daily rates.

### **Implementation**

The game was implemented in a class of forty-six students that were enrolled in the construction planning and scheduling course at a University. The game was administered via e-mail. Eight teams were formed among the students. A team leader was chosen for each team by the team members. A game manual was compiled and distributed to each team. The game and its simulation methodology were explained to them. Further, an orientation was held for team leaders to answer their specific questions about the game. Based on the discussions with the team leaders, the following was decided.

### ***Play duration***

- The game would be played for ten days.
- There would be two trial days for each team to get accustomed to the gaming environment.

### ***Responsibility of the team***

- Review the jobsite report (output from simulation) from the previous day.
- Hold discussions among the team members to analyze the project progress.
- Determine the work packages to schedule resources (for the next day).
- Identify the resources required.
- Schedule the resources, indicating the choice of supplier and grade on the purchase order form.
- Send the purchase order form via e-mail before 1900 hours each day for the next day's play.

### ***Responsibility of the game moderator***

- List the scheduled resources for each team along with the collective productivity factor and the variability factor that would be obtained from the conversion table in the schedule work form.
- Simulate the construction for each of the teams.
- Send all the outputs (jobsite reports) via e-mail to all the teams within four hours of receipt of the purchase order forms.
- Prepare a progress report for all the teams with comments.

### ***Result and inference***

The statistics from the game were recorded to present the daily expense incurred by each team and the daily project progress of every team in terms of the number of job units completed. As shown in Figure 5, time represented in the x-axis and the quantity of work done expressed in job units in the y-axis were plotted to identify pattern, if any. The resulting plot showed an encouraging pattern – an increase in the productivity of most of the teams during the second-half of the duration of play.

### ***Student feedback***

An online survey was created to obtain feedback, comments and suggestions on various areas of the game from the students. The questions in the survey focused on areas such as the game in general, the orientation session, the game manual, the implementation of the game, pre-project planning of the students, etc. The students were encouraged to participate in the survey at the end

of the game.

Twenty-six students answered the survey which provided valuable insight for assessment purpose. Approximately 70% indicated their proficiency with computers to be between good and extremely good on the survey while the remaining 30% rated themselves as being average.

Among those who answered the survey 65% indicated that they had no prior experience with computer-based games for academic purpose.

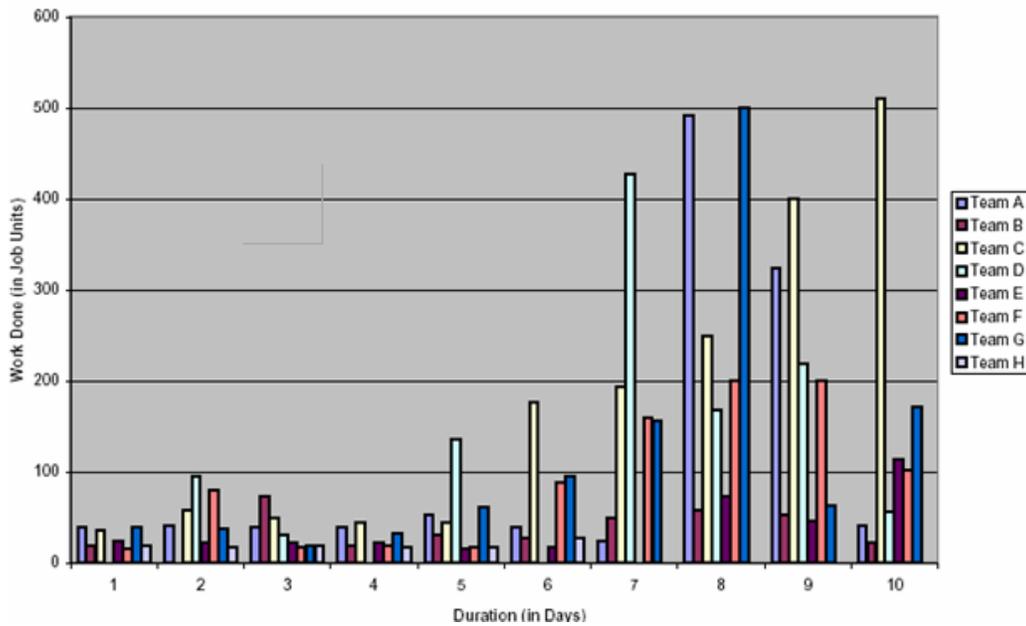


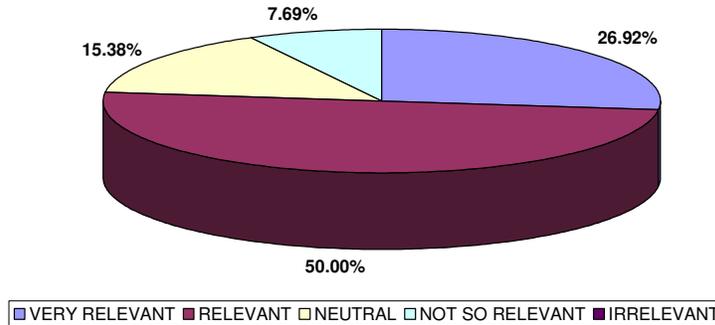
Figure 5. Project Progress Chart

Incidentally, the students were advised at the start of the second-half of the game's duration, to match the productivity of their resources instead of having one crew extremely superior in productivity to the others on the job site for better results. The increase in their rate of productivity may be a direct result of the advice.

## Conclusions

The game was implemented as a supplementary tool in construction planning and scheduling course. The results, inference and feedback from the first-run of the game were encouraging. A little over 75% of students who answered the survey indicated their appreciation of the use of the simulation game as a supplementary tool while no one indicated the game as being irrelevant as shown in figure 6.

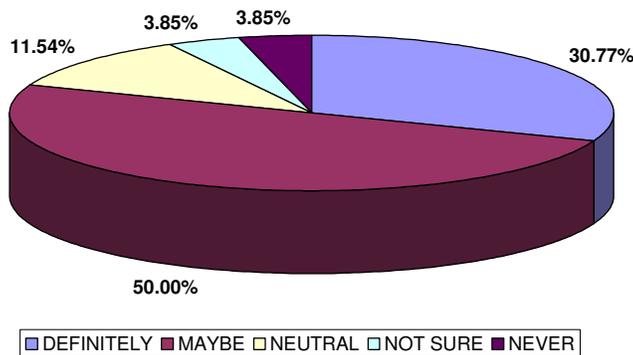
**RELEVANCE OF THE GAME TO PLANNING & SCHEDULING**



**Figure 6.** Response to Survey Question on Relevance of the Game

From figure 7 below, it may be noted that while 7.69% discouraged the use of similar simulation based games in other courses offered in the construction management program, an overwhelming majority of 80.77% seemed to find this approach to construction management education appealing and indicated that they would recommend the use of such games in other courses. A little over a tenth of those who answered the survey chose to remain neutral on this question.

**RECOMMENDATION OF USE OF SUCH GAMES IN OTHER COURSES**



**Figure 7.** Response to Survey Question on Recommendation of the Game Usage

Based on the feedback received from the students and the game moderator's observation, areas

where the game and its implementation can be further developed are as follows:

- Develop a graphical-user-interface (GUI) for the game to be fully automated for its various functions;
- Improve the timing of the game with respect to its duration of implementation; and
- Introduce the game earlier in the semester as represented in table 4.

**Table 4.** Student’s evaluation of key areas

Survey Question Number	KEY AREA	Very Good	Good	Neutral	Bad	Very Bad
4	Concept of the game	34.62%	46.15%	19.23%		
23	Implementation	34.62%	38.46%	23.08%	3.85%	
5	Organization	11.54%	53.85%	26.92%	3.85%	3.85%
3	Overall GAME RATING	7.69%	53.85%	30.77%	3.85%	3.85%
24	Timing of implementation		26.92%	26.92%	26.92%	19.23%

As is evident from the survey results 80.77% felt the concept of the game was between good and very good while 19.23% chose to stay neutral.

The survey response appears to move slightly towards an unfavorable direction when asked about the implementation. This may be due to a wide variety of reasons. When the survey seeks opinion about the organization of the game itself, the responses spread out even more between the five responses categories.

The overall game-rating is encouraging with 61.54% positive response and 30.77% remaining neutral. A key observation was the negative slide in response to survey question number 24 concerning the timing of the implementation of the game during an academic semester.

Developing a graphical-user-interface and automating the game would considerably save the purchase order processing time on the game moderator’s end. This would make it possible for the game to be implemented during the lab session allotted for the course. Implementation of the game during the lab session would encourage all the team members to participate in the team discussions more actively and be a part of every decision that is made by the team.

The first-run of the game was implemented in the actual construction management course in a University. Due to time-constraints, selected areas where majority of students were applying the concepts learned in the lecture session of the course were ineffectively identified. Discussions on those areas were held with the students which proved productive as shown in the results. Thus introducing the game earlier in the semester is an option to be considered. It would give students more time to concentrate on, evaluate their grasp of concepts taught in the lecture sessions and address their concerns.

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