

A Simulation Game for Construction Scheduling

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Performance of repetitive construction projects is affected by work flow size between subcontractors and by productivities of subcontractors. While scheduling for repetitive construction project can be prepared by the Line of Balance (LOB) method, impact of size of work flow (batch size) on project performance should be taught to construction management students. A simulation game is developed to help construction management student understand impact of batch size and related topics. The game simulates construction processes of residential projects by using building blocks. Benefits and expected learning from the simulation game are discussed.

Key Words: Line of balance method, Simulation game, Batch size, Game-based learning

Introduction

Many construction projects include construction processes which are repetitive and contractors need to repeat similar processes in multiple units (or locations). In a highway construction project, contractors need to repeat excavation, construction of subgrade, and pavement in multiple sections. In a multi-unit residential project, contractors need to move around multiple units to install similar (or same) products. Even for a high-rise building construction project contractors are required to perform a degree of repetition for multiple floors. These projects are typically performed by subcontractors who are specialized in specific items (or activities).

Subcontractors in repetitive construction projects need to build (or install) their products on a preceding subcontractor's product: a prerequisite for starting a job is work completed by a preceding subcontractor. If a subcontractor does not have enough work amounts for the prerequisite, the subcontractor cannot start the job, but has to wait. Therefore, work-flow between subcontractors in repetitive construction projects affects overall project's performance as well as each subcontractor's duration and cost (Alves & Tommelein, 2003; Ward & McElwee, 2007).

Line of balance (LOB) method is one of the scheduling methods for construction projects, and is used for repetitive construction projects due to its key feature, relationship between quantity of units delivered and the rate of unit production (Kenley & Seppanen, 2009). The LOB method is based on work-flow of single unit (i.e., each floor of a high-rise building). The LOB methods are typically taught in Construction Management (CM) programs in addition to the Critical Path Method (CPM). However, teaching the LOB method is based on single piece flow and is not combined with consideration of size of work-flow based on the authors' experience. Teaching the LOB method along with consideration of size of work-flow can enhance students learning and get the students better prepared for their career.

Therefore, a simulation game is developed to help CM students learn the LOB method with consideration of size of work-flow in one of authors' institution. The game simulates construction processes of a construction project for building multiple residential houses with building blocks. This game is used to help the students prepare a better schedule for a repetitive construction project.

The purpose of this paper is to present the simulation game developed. This paper is composed in the following sequence. First, features of repetitive construction scheduling are discussed and limitation of LOB method is explained. Then, benefits of game and simulation based teaching are discussed and the current games and simulations for teaching construction are discussed also. Next, the simulation game is explained followed by description of what is expected to be learned from playing the game. Then, applications of the game are presented.

Scheduling for Repetitive Construction Projects

Construction projects are performed by several contractors who have specialties in a given activity (subcontractors, hereafter) to minimize duration or cost of projects (Walsh, 2007). And in repetitive construction projects such as multi-unit residential building construction or highway construction project, subcontractors install or build for the job in one unit (or location) and travel to a next unit (or location). Then, a succeeding subcontractor takes the unit (or location) and installs (or builds) the work. Therefore, it is of interest to contractors to maintain the continuity of each subcontractor's labor over construction unit (Mendes & Heineck, 1998).

Batching Production in Repetitive Construction Projects

Batching production means making products in lots, not by piece (Alves & Tommelein, 2003). Batching production related management is of interest in manufacturing industry, because setup costs of work stations can be reduced by decreasing number of setups and batching production. Some construction processes are considered as batching production. For example, a subcontractor (a work station in manufacturing) repeats same construction process in multiple units in a multi-unit residential building construction project. If there are four residential units on each floor, and if subcontractors are to finish the work on four units on one floor and to move up to a next floor, then subcontractors produce four products (units) in a lot and size of work-flow represents batch size of four units.

Since batch size affects construction project performance, batch size in construction project planning or scheduling has been of interest in research (Alves & Tommelein, 2003; Nielsen & Thomassen, 2004; Sacks & Goldin, 2007; Shim, 2011; Ward & McElwee, 2007). In repetitive construction projects it is practical and reasonable to consider multiple batch size. For example, Ward and McElwee (Ward & McElwee, 2007) examined a case of hotel construction project in England and proposed using a small batch size (4 rooms) instead of a big batch size of 20 rooms which was used in the real construction processes. Also Sacks and Goldin (2007) 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 is reported by several researchers and practitioners that using a small batch size has advantages against a bigger batch size: 1) faster project delivery, 2) cost reduction and 3) reduction in rework and defects (Ward & McElwee, 2007).

While small batch size can lead to early completion of project and reduced cost as mentioned above at overall project level, a batch size preferred by one subcontractor may be different from a batch size preferred by another subcontractor depending on production rate. Using a small batch size can cause waiting time to one subcontractor, if the subcontractor's production rate is faster than the preceding subcontractor's production rate. Also, a subcontractor in a construction project may use a batch size which is different from other subcontractors' batch size (Ward & McElwee, 2007).

In addition to batch size, buffer is another important factor to be considered for 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" (Horman & Kenley, 1998). Using a small batch size leads to a small amount of work-in-process inventory in front of an activity, and a small amount of work-in-process inventory may cause lost productivity or idle workers due to insufficient amount of work-in-process inventory. Therefore, it is recommended to allocate a buffer along with a small batch size (Nielsen & Thomassen, 2004; Ward & McElwee, 2007).

Teaching Scheduling for Repetitive Construction Projects

The LOB method is one of scheduling methods for construction projects and it is also called as Linear Scheduling Method (LSM), Linear Scheduling, or Repetitive Scheduling Method (Kenley & Seppanen, 2009). Since the LOB method can plot visually repetitive operations, it helps contractors schedule to keep work continuity. The main features of the LOB method include simple graphical presentation and easy understanding of progress of each activity and when, where and what activities are done at any time (Kemmer, Heineck, & Alves, 2006). Due to these features, the LOB method is reported to have advantages of maximized resource utilization and minimized interruption (Kenley & Seppanen, 2009).

Unit (or location) is a critical component of the LOB method and represents numerical sequence of repetitive operations. Thus, it is critical to select appropriate units (or locations) in the LOB method (Kenley & Seppanen, 2009). For example, in the case of multi-unit residential building construction project, each floor can be an appropriate unit for the LOB method. Once an appropriate size of unit or units (or locations) is determined, it is of interest to plan/manage resources efficiently in the LOB method. It means that the LOB method is based on single unit flow and does not consider a different size of units (or size of work-flow).

While the LOB method is a practical and easy tool for scheduling in repetitive construction projects, it does not consider options regarding varying batch sizes. Incorporation of different batch sizes into the LOB method will provide a more detailed and realist tool for scheduling in repetitive construction projects.

While there is no current software or program for the LOB method along with consideration of different batch size, the LOB method along with different batch size can be taught in construction management (CM) programs. This idea initiated the need for development of a simulation game used for teaching.

Game & Simulation Based Teaching

Game and simulation are one of instructional methods which can enhance students' learning through active participation (Rafig & Easterbrook, 2005). While the benefits and disadvantages of game and simulation in academic learning environment in general are discussed by Ncube (Ncube, 2010), simulation games are an excellent tool for practical decision-making and management experience (Nassar, 2002). Especially, in construction industry and construction education, simulation is a very useful tool due to the complex interaction among various participants or processes (Hassan, 2006).

Due to the benefits of game and simulation and features in construction industry, educators for construction have developed, or used several game and simulation: for example, *Super-Bid* (AbouRizk, 1992), Equipment Replacement Game (Nassar, 2002), *CONSTRUCTO* (Halpin & Woodhead, 1973), Negotiation Game (Dubziak & Hendrickson, 1988), Parade of Trade game (Tommelein, Riley, & Howell, 1999), LEAPCON game (Sacks, Esquenazi, & Goldin, 2007).

The LEAPCON game is to simulate the interior finishing processes of a high-rise apartment building with customized design in each unit and it is used to help students understand benefits of some of the LEAN construction management principles: 1) pull flow (to construct what the immediate downstream activity needs, not to build a product from what are available), 2) small batch size, and 3) multi-skilled workforce. While the LEAPCON game can provide insight about 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 is developed to help students' learning about the LOB method along with impacts of batch size.

The Simulation Game

The main objective of the simulation game developed is to help Construction Management (CM) students prepare a schedule for repetitive construction projects. Under this objective, the students can understand 1) features of construction processes in repetitive construction, 2) impacts of batch size on project performance, 3) role of buffer and 4) need for cooperation among subcontractors.

This game is to simulate actual construction processes for building residential houses by using building blocks. As shown in Figure 1, each house in the game is to be built on a plate and requires different colors of building blocks. Different colors represent different activities to be constructed by subcontractors.

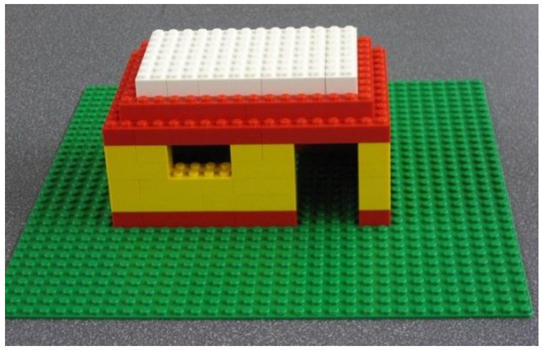

Figure 1: A house to be built with building blocks

Each house is designed to be built by six different subcontractors. Subcontractors required for the game are as followings:

- Building layout surveyor (to identify four corners of buildings)
- Subcontractor for construction of the foundation (the first (bottom) course of building blocks)
- Subcontractor for construction of the wall (next four courses of building blocks)
- Subcontractor for installation of doors and windows
- Subcontractor for roof framing (next two courses of building blocks)
- Subcontractor for roofing (the top course of building blocks)

The above six subcontractors (or game players) are to be sequenced based on physical relations among the building components: layout→ foundation→wall→doors & windows→roof framing→ roofing.

The four house to be constructed are different each other in terms of location and colors. Each player is to be provided with a simple specification for the four houses to be constructed. The specification is easy to follow, and includes information about location and colors of each building as shown in Figure 2, and 3.

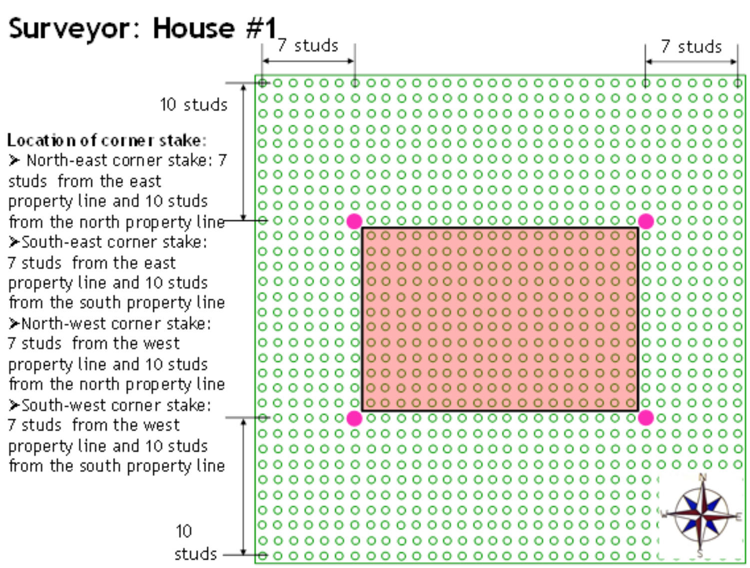

Figure 2: An example of specification for a subcontractor (building layout)

Figure 2 shows a specification for surveyor whose job is to locate the corners of each building. The surveyor is to be provided with small circular stickers and is required to put the stickers for the corners according to the specification as illustrated in Figure 2.

Figure 3 shows an example of specification about how to lay building blocks. The payers are required to use blocks of specified size for each course according to the specification.

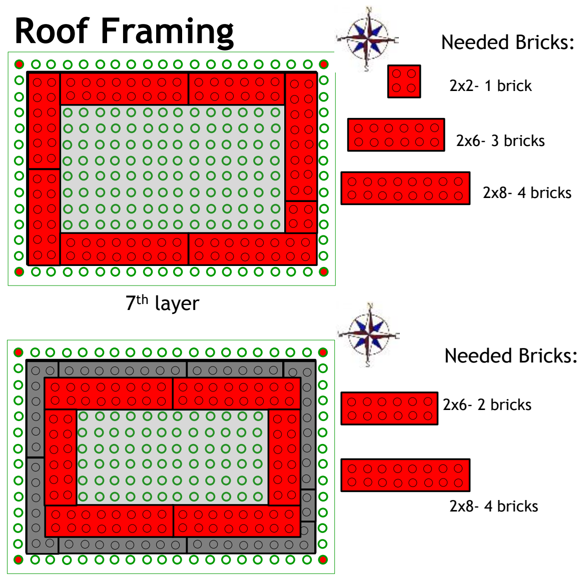

Figure 3: An example of specification for a subcontractor (roof framing)

Each player is required to perform the job (or to build the layers) for each house, thus needs to travel from a site to a next. Players need to wait until an immediate upstream player finishes the job for a given batch size. And players are given with information (design or specifications) about works both for himself (or herself) and for an immediate upstream player. They need to make sure the work completed by an immediate upstream player is correct: if they detect erroneous work, then the work should be immediately corrected by the player who made erroneous work.

The game is designed to be played in two rounds with regard to different batch sizes. In the first round, it is assumed that batch size for all subcontractors is four houses: a subcontractor cannot start the job until the preceding subcontractor finish the job for all four houses. In the second round, the batch size is assumed to be one house: a subcontractor can start the job for a house after a preceding subcontractor's job is finished for the house.

The performance of players is measured by time players spent for building process and waiting time. Each player is given with a sheet for time recording and they are required to keep record for start time and finish time of the job for each house. At the end of game players need to calculate total amount of time all six players spent (overall project duration), and waiting time each player experienced (additional cost to each subcontractor).

Learning from the Game

This section is for discussion about the expected lessons from playing the game. Also, insight which can be obtained from the game is discussed.

Figure 4 shows an expected result of the game with batch size of four houses. In this case, each subcontractor starts the job once after the all prerequisite work (for four houses) is done and can get uninterrupted and continuous work flow. Therefore, subcontractors don't need to wait and productivity is not lowered due to waiting time. Notice that the bar charts below the x-axis for time show amounts time subcontractors need.

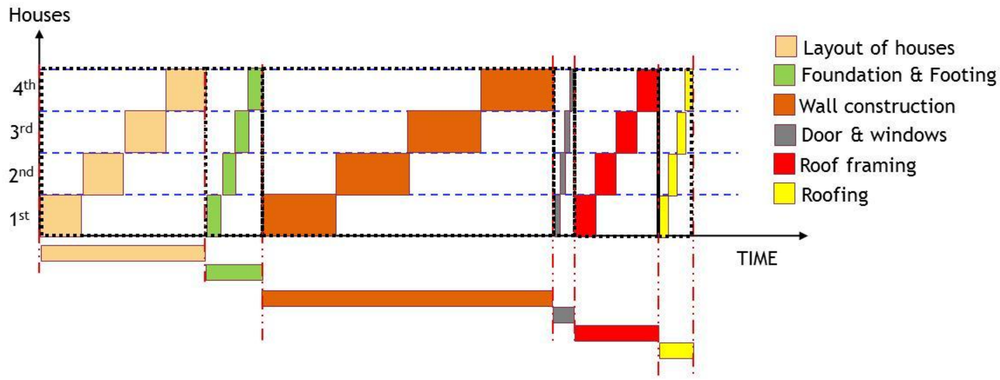

Figure 4: Expected result from batch size of four houses

Figure 5, on the contrary, shows an expected result of the second round with batch size of one house. Overall project performance in terms of time is much better than the round #1: the construction of four houses is finished much earlier than the previous case. However, when looking at the bar-charts below x-axis, some of subcontractors need to wait and their time is longer than those from the first round. It represents that costs for some subcontractors are increased.

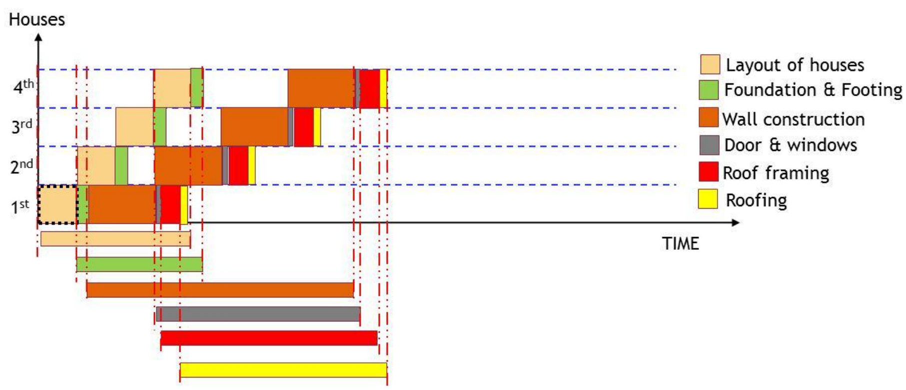

Figure 5: Expected result from batch size of one house

By comparing the results from the two rounds, students can learn the impacts of batch size on project performance. Small batch size can lead to shorter duration for overall project. However, due to different production rate (or productivities) between subcontractors, small batch size may cause waiting time, thus additional cost to some subcontractors.

To reduce adverse impact of small batch size, use of buffer is to be discussed in the game. If the batch size is one house (small), and the productivity of preceding subcontractor's is lower than one subcontractor's productivity, the subcontractor needs buffer (time buffer). For example, in Figure 5, the second subcontractor for foundation has to wait, if he follows the progress of the surveyor. The subcontractor for foundation may want to start his job late to reduce amount of waiting time.

Another issue to be learned and discussed in the game is who develops a schedule. If a project manager or general contractor is to develop a schedule, then small batch size would be preferred due to early completion. However, from the subcontractors' view point, small batch size may cause additional cost, thus a bigger batch size is preferred by subcontractors. A centralized project manager (or general contractor) has a long-sighted viewpoint, but a less reliable view. On the other hand, decentralized manager (or subcontractors) has myopic viewpoint, but a more reliable view (Shim, 2008). Furthermore, it should be discussed that coordination among project participants becomes more important and preparation of a schedule would need coordination among subcontractors and general contractor.

The game was developed and tested in a pilot study at the author's institution in Spring 2011. Then, the game is in the process for evaluation of the efficiency in students' learning.

Conclusion and Discussion

Subcontractors (or specialty contractors) in repetitive construction projects need to repeat same production process in multiple units and it is of interest to subcontractors that they have continuous work flow to minimize idle time for their resources. Due to this feature of repetitive construction projects, the line of balance (LOB) method is widely used for repetitive construction projects.

While the LOB method is focused on keeping continuous work flow with allocation of buffer, it is based on work flow of single unit. However, contractors can choose a bigger size of work flow than one unit depending on project rates and other factors in repetitive construction projects. The size of work flow is a batch size and using a small batch size can lead to early completion of a project and a lower expense. Thus, consideration of batch size under the LOB method can help contractors prepare a better schedule or more realistic plan of construction processes.

A simulation game was developed to help construction management students understand impacts of batch size as well as the LOB method. The game simulates building processes by several subcontractors for multiple units and building blocks are used to construct the buildings. From comparison between two rounds in which a batch size is different each other, students can understand impacts of batch size on project performance. In addition to impact of batch size on project performance, the game can help CM students understand other topics: 1) role of buffer, and 2) different decision-making approaches for scheduling.

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