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Published in:
Proceedings of the 2014 International Conference on Construction and Real Estate Management, held in Kunming, China, September 27-28, 2014

DOI (link to publication from Publisher):
10.1061/9780784413777.066

Publication date:
2014

Document Version
Accepted author manuscript, peer reviewed version

This is a pre-published version
Lindhard, S., 2014 "Learning by experience: a game approach to teaching construction scheduling", Proceedings of the 2014 International Conference on Construction and Real Estate Management, held in Kunming, China, September 27-28, 2014.. Wang, Y., Ye, H., Shen, G. Q. P. & Bai, Y. (red.). American Society of Civil Engineers, s. 566-572, **https://doi.org/10.1061/9780784413777.066**

Leaning by experience: a game approach to teaching construction scheduling

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ABSTRACT

To introduce students to the complexity of on-site management a game-approach has been developed for teaching purposes to simulate the production control challenges site management is phasing. The simulation model have been both alpha and beta tested to ensure the validity of the model. The simulation model takes its outset in 9 on-site constraints which is used to identify key requirements of the simulation model. The game consists of three phases a scheduling phase, a construction phase and a follow up phase. During the scheduling phase it is decided what needs to be completed in the next construction "window" and the necessary resources are ordered. In the construction phase the actual output is determined. Finally, in the follow up phase time usage and PPC is calculated and the schedule is updated. The feedback from the game session was positive where the game was found to be both amusing, engaging and an instructive experience at the same time.

INTRODUCTION

On-site construction is characterized as a unique (Salem *et al.* 2006), complex (Bertelsen 2003a; Dubois and Gadde 2002), and labour depended process. Constructions are fixed in position; thus, the craftsmen move through production instead of the product (Ballard 2000; Ballard 1998; Schmenner 1993). This creates a dynamic construction process where work areas move and material and crews vary; thus, all is based on the demands from the current activities completed on-site (Choo and Tommelein 1999). Moreover, completion is complicated by the limited space, the multiple components, the many interdependencies, and a general lack of standardization which dominates on-site construction (Ahmad and An 2008; Bertelsen and Koskela 2004; Bertelsen 2003b; Ballard and Howell 1995).

The practice of time management has to be learned by experience; therefore, to create an opportunity for learning to students on the construction management program a practical simulation model is developed and applied as a teaching instrument. To create a realistic experience, the simulation needs to incorporate the characteristics of on-site production. The importance of simulation as a teaching

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technique is underlined by Lateef (2010) which point out that it can be used as a platform to create knowledge, skills, and attitudes which have to be learned in practice. Long et al. (2009) elaborates by stating that some aspects of engineering are requiring experiences to gain a fully understanding and that this could be achieved by applying simulation into teaching.

METHODS

In order to make a realistic simulation of on-site production a crucial task is to identify and define the requirements to the simulation model. The key requirements to the simulation model are based on the constraint model presented in Lindhard and Wandahl (2012). The model divides the constraints into nine main categories and is an expansion of Koskelas 7 preconditions (1999). The nine categories are described in the introduction section and are as follows: 1) Known surroundings; 2) Construction design and management; 3) Connecting works; 4) Workforce; 5) Materials, 6) Machinery; 7) Working Conditions; 8) Climate; 9) Safety.

Based on the identified requirements, derived from the nine constraints, a simulation approach is developed. In this process complexity is reduced by keeping the simulation as simple as possible while still keeping it as close to real on-site construction as possible.

To ensure the trustworthiness of the simulation, the simulation model has been reviewed and discussed with peers (Lincoln and Guba 1985). Moreover, both alpha and beta testing of the simulation model has been carried out.

Introducing constraints and requirements

The goal is to create a simulation model which reflects real construction projects. Based on the key constraints, the requirements to the simulation model are identified. The requirements are listed in Table 1.

Table 1: Identified requirements to the simulation model: *Importance is categorized into low, medium or high based on an immediate estimation.

Constraint	Requirements:	Importance*	Included	
			Yes	**No**
Known surroundings	The surroundings need to be known.	Low		√
Construction design and management	Task specifications and drawings needs to be present	High	√	
	Changes in design are possible.	Medium		√
Connecting works	Previous activities needs to be completed	High	√	
	Interrelationship between activities	High	√	

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Workforce	Workforce needs to be present	High	√	
	The workforce move through the production instead of the product	Medium		√
	Different contractors are responsible for different tasks	High	√	
	Restricted by travel time.	Medium	√	
Material	Materials need to be present.	High	√	
	Multiple of different materials exists	High	√	
	Materials are depleted	High	√	
	Deliveries and storage of materials are restricted	Low	√	
Machinery	Machinery needs to be present	High	√	
	Machinery is necessary to complete certain tasks	High	√	
	Different tasks requires different machinery	Low	√	
	Only one contractor can utilize the machinery at the time.	Low	√	
	Restrictions of rental time and delivery time	Low	√	
Working conditions	Satisfying working conditions needs to be present	High		√
	Activities restricted by space	High	√	
Climate	External climate can influence the production	High	√	
	Climate precautions can be installed to minimize the effect.	Medium		√
Safety	A safe working environment needs to be present	High		√
	Safety issues can stop the production	High	√	
	Safety can be improved by incorporating safety precautions.	Medium		√
Variation	Variation is introduced in the model to make the schedule unreliable.	High	√	

Introducing variation

A real life construction project is dominated by variations, making the project difficult to manage and to schedule. Therefore, to assist the constraints, variation is emerging in the simulation and thus imitating a real life construction process by being unpredictable and complex. Variation is included by introducing events during the simulation, these events covers both positive and negative variation. At every work day a productivity and an event card is drawn. The productivity card is stating the individual contractor's actual productivity while the event card is presenting an unexpected event or scenarios such as illness in the work force, breakdown in machinery, changes in deliveries, dwelling materials, and climate and safety hazards.

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THE DESIGN OF THE GAME

In the following the game rules is presented. The presentation is constructed around the nine constraints mentioned above: Known surroundings; Construction design and management; Connecting works; Workforce; Materials, Machinery; Working Conditions; Climate and Safety, an in-depth description can be found in Lindhard (2014)

Known surroundings (Geometric restrictions):

The outer edge which is shared by the foundation and the exterior walls, the horizontal division and the exterior walls, and the roof and the exterior walls is considered as a part of the exterior walls.

The edge shared by the foundation and the interior walls, the horizontal division and the interior walls, and the roof and the interior walls is respectively considered as a part of the foundation, the horizontal division, and the roof.

Construction design and management

The model consists of triangles in four different colors. The triangles are made of GEOMAG bars and panels which are connected by means of magnetism. The students are handed out drawings of the constructions facades and sectional views. A 3d drawing of the construction can be viewed at Figure 1. A contractors daily production is a normal distribution with a mean value at 2.5 and a can take the values (0,1,2,3,4,5) with the possibility of a production boost, introduced by the event card.

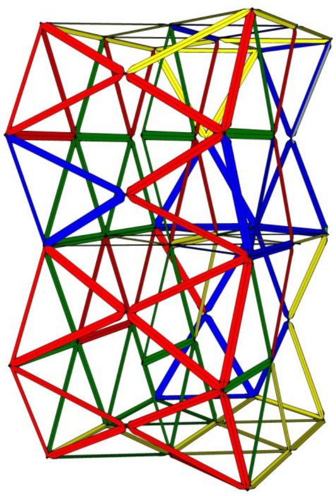

Figure 1: The model which is to be constructed.

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Connecting works

The construction is constructed as a "real-life" building; thus, the physical relationship between activities creates restriction which is ensuring that previous activities has to be completed before the successive activities can progress (Echeverry *et al.* 1991). Based on the physical restriction, the overall sequence is drawn, see Figure 1.

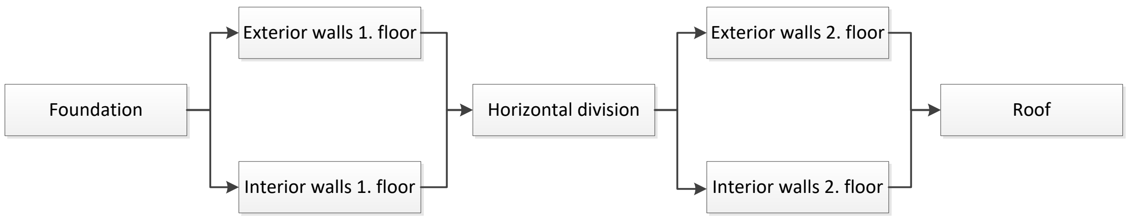

Figure 2: Interrelationships between activities

Only the exterior and interior walls may be completed concurrent and in relation to "normal" physical restrictions. In any other cases a "section" (e.g. foundation, exterior walls 1st floor, horizontal division, etc.) of the building needs to be completed before the successive can begin.

Workforce:

In the simulation the work is, as in real life, driven by the present labour. In the simulation four contractors is completing a specific task. Each contractor is responsible for one color, e.g. either: red, green, yellow or blue, and is restricted by the other contractors work on-site. Thus, only construction on the building is allowed. A contractor has to be booked 1 day before he arrives on site. One exception exists, a workforce can be present at simulation start; thus, the travel time is considered to take place before simulation start.

Materials:

In order to complete a work activity the correct material needs to be present. To simplify the simulation every contractor only has only one type of materials: bars. As in real life materials are depleted during the construction, and new materials are needed. At maximum 15 pieces of materials can be delivered simultaneously; the next delivery can take place next work day. The delivery time to all materials is 3 work days. One exception exist, materials can be delivered at site when the simulation starts; thus, the delivery time is considered to be before simulation start. Materials delivered to site are stored and used when needed. The maximum storage

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capacity is 20 pieces of material.

Machinery:

Certain work activities require machinery to be present. The tasks include foundation, exterior walls above the 1st floor, and roofing. The required machinery is depending on the work activity; thus, the foundation, the exterior walls 2nd floor south, the exterior walls 2nd floor vest, the exterior walls 2nd floor east, exterior walls 2nd floor north, and roofing all require different machinery. Moreover, only one contractor can utilize a given machinery at the time. Rental of machinery has to be considered in advance since the delivery time is 5 work days. One exception exist, machinery can be delivered at site when the simulation starts; thus, the delivery time is considered to be before simulation start.

Working conditions:

Working conditions are affecting work pace as in real life. Space is in particular important and is further restricted. At maximum three contractors can work on the project simultaneously and only two contractors can work on each ”section” (foundation, exterior walls xx, roof, horizontal division, interior walls xx).

Climate and safety:

The external climate is together with safety important and both can influence the production. Hazards both climate and safety is introduced through the event card.

FEEDBACK AND DISCUSSION

The simulation model was developed in an attempt to put the students as close as possible to a real life situation. This helps the students in understanding the challenges, the reasoning, and behavior of a construction manager (Lateef 2010).

The simulation model was applied at the first semester of the master program, and the students had the following feedback:

+ Amusing
+ Engaging
+ Learning outcome great.
+ Knowledge about what can happen
+ Importance of control
+ Effect of variation
+ Good with complexity

% Drawings need more work
% Clearer rules - especially regarding machinery.

In general the feedback was very positive, and as the teacher I could really see the commitment increase among the students, thus; the result very much confirm Lateef

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(2010) statement that simulation approaches can make theory and lecture material come alive and thereby enhance the learning output (Gaba *et al.* 1998).

The simulation did serve as an eye-opener to many of the students where the complexity and dilemmas a construction manager is phasing while scheduling were experienced. Especially the “destructive” effect of variation was an instructive experience but in general getting the hands on were helping the students to fully understand the problem. Lateef (2010) points out that while fully understanding an issue your flexibility will increase helping you to adapt and understand new situations.

According to Lateef (2010) simulations can be used for: a) Technical and functional expertise training; b) Problem-solving and decision-making skills, and c) Interpersonal and communications skills or team-based competencies. Off cause teaching method should be selected in relation to subject and simulation is not the best approach for each lecture. Moreover, it had been very time consuming to develop and set-up the simulation game.

CONCLUSION

A simulation model has been applied to teach scheduling dilemmas to master students at the construction management program. Using a simulation approach in teaching has proven very beneficial in relation to the learning outcome from the students. Therefore, the key output from this study is that, practical simulations shall be viewed as a well-functioning technique which can help in stimulating engagement and learning amongst students. The technique is especially useful while teaching concepts applied in practice, in this case scheduling.

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