# SIMULATING LEAN PRODUCTION PRINCIPLES IN CONSTRUCTION: A LAST PLANNER-DRIVEN GAME

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## ABSTRACT

Simulations and classroom games are effective hands-on learning tools for construction students and practitioners. This paper presents the background, methods and results of a new management game which simulates some aspects of the Last Planner System (LPS™) and lean production. LPS is central to the implementation of Lean Construction, an increasingly popular management approach based on the Toyota Production System. LPS requires continuous and collaborative effort from all stakeholders for the planning and control of a construction project, making it especially appropriate for the experiential learning allowed by simulation. The simulation game consists of the assembly of Lego™ pieces to form a schematic house, and it is played by teams meeting in rounds simulating one week of work. Each team is composed of stakeholders, such as a construction manager, resource suppliers and trade foremen, mirroring the planning and assembly process of a typical construction project. Participants build the Lego houses first using a traditional management approach and then using LPS and lean principles and procedures. This paper also describes the main components of the Toyota Production System as applied by Lean Construction, and provides an introduction to LPS as well as a description of the simulation rules and setup. A Case Study of the simulation game is discussed, including its implementation and effectiveness as a teaching tool. The implementation results of the simulation game demonstrated its capability to effectively teach LPS and lean-based management approaches in construction.

## KEYWORDS

Last Planner, Lean Construction, Learning, Management Games.

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## INTRODUCTION

Modern construction is becoming a complex business; construction projects are increasingly more technically sophisticated, requiring shorter schedules and lower costs due to market demands. During the construction phase, projects are commonly affected by uncertainty resulting from urgent requirements, inconsistent construction sequences, lack of supply chain coordination, project scope changes, poor quality, among others. Traditional project management ignores the production nature of construction and is established on a faulty understanding of work and control concepts in projects; as a result, it must be amended due to its inadequacy to deal with the problems affecting construction (Howell and Koskela, 2000; Koskela, 2000).

How planning decisions are made to manage uncertainty in construction projects is one of the most relevant theoretical issues in construction management (Laufer et al., 1994). In this regard, Ballard (1994) stated that the key to improved productivity is improved planning. In construction, the focus has been on the development of planning tools rather than on the theoretical issues underlying its improvement (Laufer et al., 1994). Planning problems in construction represent the norm and they can be related to: management focus is on control, planning is not conceived as a system design, crew level planning is neglected, planning system performance is not measured and planning failures are not analyzed to identify and act on root causes (Ballard, 2000). This has resulted in inadequately managed projects and poor performance (Ballard, 2000; Koskela, 2000).A construction planning and control technique called Last Planner System (LPS™) has been increasingly used for the effective management of construction projects (Mossman 2013). LPS is central to the implementation of Lean Construction, an increasingly popular management approach with origins on the Toyota Production System. LPS overcomes the limitations of traditional project management by providing a stable and reliable production environment in projects, decreasing workflow variability and creating reliable work plans to derive maximum project benefits (Ballard 2000). LPS is not purely a management tool, but a social enabler to change the organizational behavior of projects (Mossman, 2013; Pavez and González, 2012). As a result, LPS is able to improve workflow reliability and project performance (González et al. 2008).

LPS research has shown that its implementation is hindered by significant barriers such as: excessive information and inadequate approaches to manage it, lack of training, lack of committed time, complexity of the LPS framework, priority given to other improvement initiatives, low commitment of the upper levels of management, resistance to change, lack of self-criticism, short-term view, inadequate understanding and use of LPS components, and lack of integration of supply chain (Alarcón et al. 2002; Alarcón and Calderón, 2003; Alarcón et al. 2008). It is argued that one of the main reasons to prevent a successful LPS implementation can be the limitations of the approaches to transfer and share lessons learned within the organization. Porwal (2010) acknowledges that due to the complex nature of the LPS, current teaching methods are ineffective in communicating the theory behind it, consequently hindering the application and execution process (Porwal 2010).

This paper focuses on developing an interactive management game to simulate some of the LPS and lean principles and procedures in a classroom. Simulations and classroom games are effective hands-on learning tools for construction students and practitioners (Forcael et al. 2012). LPS requires continuous and collaborative effort from all stakeholders for the planning and control of a construction project, making it especially appropriate for the experiential learning allowed by simulation. Thus, the main goal of this research was the development and testing of an effective approach for the teaching and learning of the principles and implications of the LPS, leading to a wider use of LPS and lean-based management approaches in construction. This objective was achieved by simulating a construction event whilst contrasting Lean to Traditional to prove its benefits while also actively educating students and practitioners on key LPS and Lean principles. The simulation game was tested in a civil engineering graduate course at The University of Auckland, New Zealand, showing improvements in the learning process of LPS and lean principles after playing it. On-going research is being conducted to improve the structure and characteristics of the simulation game.

The following sections will address the background, the research methodology, the simulation game framework, the development of the test, and the main results and lessons learned.

## BACKGROUND

### MANAGEMENT GAMES

The implementation of Lean Construction principles and tools such as the LPS is not an easy task as it is surrounded by organizational and technical barriers (Alarcón et al. 2002; Alarcón and Calderon, 2003; Alarcón et al. 2008). The use of management games to simulate the LPS application can help to overcome some of its implementation barriers, especially those associated to the transferal of LPS knowledge.

In the literature, there are several simulation games for manufacturing and construction which illustrate different lean aspects. For instance, the airplane game focuses on educating lean manufacturing concepts. This game simulates a production line through constructing as many Lego airplanes as possible in a given timeframe. The initial approach utilizes traditional planning which is then switched to lean planning. In performing this, the simulation game teaches the concepts of push/pull and variable batch sizing (Visionary Products, 2014). The Parade of Trades illustrates the impact workflow variability has on the performance of construction trades and their successors. This is achieved by simulating the construction process where resources produced by one trade are prerequisite to work performed by the next trade. The main idea of the simulation game is to illustrate how throughput is reduced, followed by the project being delayed and the amount of waste increased as a result of increased flow variation. Hence, the simulation game endeavors to show the improvements to be made as a result of decreasing the work flow variability (Tommelein et al. 1999). LEAPCON is another simulation game addressing benefits of pull, work restructuring and multi-skilling. This is achieved through simulating the construction of a high rise apartment building with customized apartment designs (Sacks et al. 2007).

Despite the examples discussed above, there are few simulation games in construction illustrating the use of the LPS framework along with lean principles. Villego™ is one of the limited number of LPS-driven games. It has recently become available in the commercial market (Villego, 2014). This simulation game teaches core concepts of the LPS through simulating two rounds; one with traditional planning and one with LPS planning. The objective of the rounds is to construct one complex house. This simulation game has been shown to teach the concepts effectively but a number of issues exist. The simulation cannot be played in any time under 5 hours and requires a large number of people (14). This can create a time barrier to have people readily available for this length of time. The simulation is also run by building a complex house and using the LPS concepts in a high level of detail making it very complex to simulate. These limitations may cause it to be unsuitable for use within a university class environment in a short time frame and reasonable level of detail.

## RESEARCH METHODOLOGY

The following methodological stages were carried out in this research:

*Development of the Simulation Game*– Different simulation games and lessons learned from their application were reviewed from literature. Bearing in mind the nature of the simulation game to be developed, a new simulation structure with new rules and exciting features was proposed. There was an iterative process. At each stage of the development new ideas were thoroughly reviewed and the implications from these changes were discussed to ensure they would have a positive outcome.

*Ethics Approval*– In the interest of ensuring the manner in which the simulation was conducted was fair to the participants, approval was obtained from the University of Auckland Human Participants Ethics Committee.

*Case Study and Data Collection*– Data was obtained in an anonymous manner from a case study involving a postgraduate course taught in the Department of Civil and Environmental Engineering at The University of Auckland. One of the topics taught in this course is the LPS. Also, a large proportion of the students in this course were professionals. The data collection methods utilized were observation and pre and post-trial surveys. Each team's simulation game performance indicators such as the PPC, RNC and learning degree were also collected.

*Results*– The results obtained were analyzed and summarized to examine the success of the simulation game. To do so, two rounds of the simulation were analyzed: traditional and lean. Further use of these results highlighted areas where improvements could be made to remedy potential flaws in the simulation.

## LAST PLANNER SYSTEM SIMULATION GAME

### GENERAL OUTLINE

The Last Planner System simulation game is a lean construction management game that aims to actively educate practitioners on key LPS and lean concepts. Through simulating a real world construction environment by building Lego houses, it educates lean students and practitioners in a fast-paced, interactive way.

This is achieved through conducting two rounds; one using Traditional planning and one using LPS-driven planning. These two techniques are compared and contrasted to demonstrate the benefits and differences of LPS and lean principles and procedures while consecutively teaching them. The objective of the simulation game is to construct 9 houses during each round in the fastest time, with the highest accuracy and maximum PPC. Each house is composed of 4 activities: Flooring, Level

1, Level 2 and Roofing (see Figure 1). In turn, each round runs for twelve minutes and is broken down into 3, 4 minute long weeks. At the end of each week the simulation is paused so PPC can be calculated, with the addition of RNC during the LPS round. Upon completion of each round the extra cost is calculated.

The simulation game has eight specified roles, although it can be played with less than eight people through taking on multiple roles. Each role has a specific purpose in allowing the simulation game to function similar to a construction site. The roles are explained and listed below:

*The foreman*– There are four types of foreman; floor, level 1, level 2 and roof. The role of the foreman is to order the materials and to carry out the construction of the houses by completing their respective components. There are 3 different types of each component, these are listed on the master schedule and the foremen are informed of the relevant designs by the planner.

*The planner*– Represents the construction manager who is in charge of the information on the master schedule and construction sequence cards. The construction sequence cards visually inform the foreman of the required materials and construction technique for each component. They are also the main communicator during the traditional round and the coordinator of the lookahead meetings during the LPS round.

*The timekeeper*– The timekeeper is in charge of controlling the round times and enforcing the imposed uncertainty time penalties due to uncertainty cards. Uncertainty cards represent problems faced by the project such as transportation delays, late order of material and material delays, lack of workers, defective material, weather, and unforeseen soil conditions, among others. The in game implications are modelled through time and cost penalties due to the occurring uncertainty. They are to draw these cards every 30 seconds; upon which the result of the roll of a dice determines the outcome.

*The quality inspector*– The quality inspector's role is to check that the plans are followed correctly at the end of the round by referring to the construction sequence cards, while calculating the feedback metrics of the LPS such as PPC and RNC.

*The supplier*– The supplier controls and delivers materials to the foreman. Materials are delivered in a push manner during the traditional round and a pull manner during the LPS round. They also complete the extra cost register at the end of the rounds.

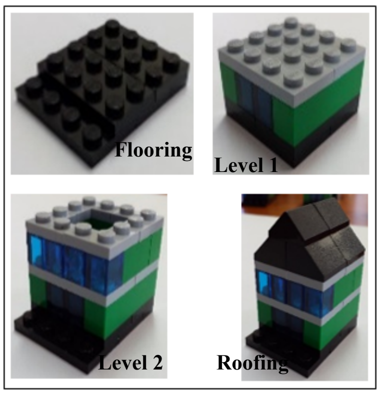


Figure 1: Lego house construction sequence.

## CONCEPTS TAUGHT

A number of LPS and lean concepts were focused on during the simulation. Note that the simulation only considers some of the LPS and lean concepts to keep it simple and manageable for a short period of time. These concepts are illustrated through implementing constraints in the traditional round and then releasing them for the LPS round. The concepts are explained and listed below:

*Push/Pull*– Taught through materials being pushed in the traditional round to the foreman regardless of if they are required or not. During the traditional phase all requests must be made through the resource request list from the planner. In the LPS round foreman may request materials when needed verbally and directly to the supplier.

*Prefabrication*– Allows the foreman to begin construction on their components before they receive the required components from the previous foreman. This is forbidden during the traditional round, although it is encouraged during the LPS round to prove its benefits.

*Transparent communication*– During the traditional round there is a non-communication restraint on the foreman. In the LPS round all players can communicate freely. This is to model the communication breakdowns in traditional planning and how the LPS can help to improve performance by promoting communication.

*Continuous flow*– Modeled through limiting the batch size in the traditional round; 3 houses must be completed before being passed on. In the LPS round teams discuss different batch size options based on their experience in the traditional round and the constraint is released. It can be varied between weeks to test different options.

*Continuous improvement*– Through completing an RNC table in the LPS round, the RNCs can be utilized in the Lookahead meetings and be remedied to avoid reoccurrences; hence striving for perfection.

*Multi-skilled crews*– In the LPS round, a number of delays due to uncertainty may be overcome by multiskilling labor. Thus, this is incorporated through passing a foreman's worker token (lending workers) to a delayed foreman. The worker tokens represent plant and labor utilized in the construction process.

*Lookahead planning*– Used to promote collaboration and teach the concept of lookahead planning. Lookahead meetings are used to discuss possible improvements such as different batch sizes, different ordering techniques and optimizing sequencing through sitting in different places. All roles are included and encouraged to put ideas forward. A restraint surrounding no collaboration exists in the traditional round. They also provide players with a chance to discuss how the lean changes are working.

## SIMULATION GAME DYNAMICS

During the "Traditional planning" round the aim is to complete as many activities as the team is able to perform in three weeks (up to 12 activities per week, 36 activities in 3 weeks to complete 9 houses). The plan considers a repetitive schedule starting with the Flooring activity and following with the Level 1, Level 2 and Roofing activities. In this round, it is considered a batch size of 3 production units. For instance, to start the Level 1 activity there should be 3 houses in place with their Flooring activities ready, and so on. No communication and collaboration are allowed during the round between the players (excluding Planner and Time Keeper). Upon pausing or completion of the round, team members may communicate.

In the LPS-driven planning round, the flow of the simulation is the same as in the Traditional round. However, a number of modifications take place:

*Communication and Collaboration*– This is now allowed between all players and encouraged during the entire round. Foremen may now communicate with the supplier verbally to order materials. Quality Inspector can fill in the reason for non-completion table (RNC) after a short team discussion possible reasons with teammates and referring to the traditional RNC table.

*Lookahead Meetings*– Team discussions regarding batch size, material ordering, etc. to be held during the breaks. The purpose is to look ahead the plan and make ready activities in an environment of uncertainty. Meetings occur every 4 minutes (lasting up to 3 minutes).

*Multiskilled Crews*– If a foreman does not have a worker token due to a delay; the team may implement a multi-skilled team strategy by sharing workers. In reality, not all construction workers have the skills to work on all areas of a project. For the purposes of this simulation, this has made it so that "workers" may be shared between two of the foreman. Floor foreman may share with level 2 foreman. Level 1 foreman may share with the roof foreman.

*Variable Batch Size*– The team must decide on a batch size during the lookahead meeting. The batch size is a constraint that can be released (e.g. reduced batch size). This depends on the outcome from the lookahead meetings.

*Pre-fabrication*– Once the foreman has materials and a worker token he/she may begin construction.

*Pulling work and checking soundness of activities*– All foremen may eventually work as soon as one batch is ready to be worked on. Complete a "sound assignment check" by checking if the subsequent foreman is active or idle: a) If next foreman is idle, pass on 1 batch of house(s), or b) If next foreman is busy, hold onto the house(s) until he/she is free. You will need to do a sound assignment check for each batch. A batch must be passed to the subsequent foreman, not left next to him/her to take when ready.

Uncertainty cards represent controllable and uncontrollable problems that can come up when playing the simulation. Some of the strategies that take place under the LPS round are meant to tackle some of these problems (Traditional round is unable to effectively face those problems). Figure 1 shows the main flow to play the Traditional and LPS round.

In addition, the agenda for the simulation game was as follows:

1. Briefing: 15 min
2. Mock Round (Traditional Simulation): 7 min
3. Round 1- Traditional Simulation: 28 min (each week 4 min; inspection and calculation after each week 2 min, final discussion 10 min)
4. Round 2- LPS Simulation: 31 min (each week 4 min; lookahead meetings, inspection and calculation after each week 3 min, final discussion 10 min)
5. Wrap up: 10 min

| Traditional Planning Round | LPS-driven Planning Round |
|---|---|
| -----ROUND STARTS----- | |
| 1) **All Foremen:** Complete the *Resource Request List* for the required materials. When completed you may order materials by passing your *Resource Request List* to the Planner.<br>2) **Planner:** Pass the *Resource Request Lists* to the Supplier, on behalf of the Foremen. You may only pass on **one** *Resource Request List* at a time.<br>3) **Supplier:** Deliver the materials and *Worker Tokens* to the Foremen. You may only supply **one** Foreman at a time.<br>4) **All Foremen:** Commence construction as outlined in the individual instructions.<br>5) **Timekeeper:** Perform a dice roll; prepare an *Uncertainty Card* every 30 seconds.<br>6) **Quality Inspector:** Pause the simulation every 4 minutes and record the amount of completed activities (PPC).<br>7) **Time Keeper & Quality Inspector:** Stop the timer upon completion of all 9 houses **or** upon reaching 9 minutes. | 1) **All Foremen:** When appropriate verbally order materials directly from the supplier<br>2) **Supplier:** Deliver the materials and *Worker Tokens* to the Foremen. You may only supply **one** Foreman at a time.<br>3) **All Foremen:** Commence construction as outlined in the individual instructions.<br>4) **Timekeeper:** Perform a dice roll; prepare an *Uncertainty Card* every 30 seconds.<br>5) **Quality Inspector:** Pause the simulation **every 4 minutes** and record the amount of completed activities (PPC).<br>6) **Look-ahead meeting every 4 minutes**: Team discussion, determine if anything can be improved. **3 minutes per meeting maximum**<br>7) **Time Keeper & Quality Inspector:** Stop the timer upon completion of all 9 houses **or** upon reaching 9 minutes. |
| -----ROUND ENDS----- | |

Figure 1: Outline of the LPS simulation game flow.

# CASE STUDY

## DESCRIPTION

The LPS simulation was trialed on The University of Auckland postgraduate course 'Advanced Topics in Project Management'. This course is part of the Master of Engineering (Taught) specialization of Construction Management, which is run in the Department of Civil and Environmental Engineering. A range of advanced management topics such as Dispute Resolution, Lean Construction, LPS, among others, are delivered. This course consists of 60 students both undergraduate and postgraduate, with at least 80% of the students having professional experience of 3 years or more. Preceding the simulation the class received a lecture that outlined the basic elements of the LPS. This allowed the students to gain a pre-existing knowledge of the LPS prior to the trial.

## THE SIMULATION

The simulation was run in one session scheduled for 1.5 hours. Only 17 students participated which were split up into two teams. These participants volunteered to take part and the trial occurred outside of class time. As a high percentage of the students had previous work experience, data was credible. In total, the number of participants allowed enough data to be analyzed. Upon entering the room each participant was handed an ethics form and pre-trial survey to complete. They were then briefed on the simulation game and handed the general instructions to read. The instructions were read and clarified, followed by the reading of the traditional round instructions which was then played. After the completion of this round the LPS instructions were read and this round was played. At the end of each round sheets for feedback were filled in. Once the trial had finished the players then completed a post-trial survey.

## MEASURED DATA

In order to better understand the functioning of the simulation game, measurements were made for the key parameters of the LPS (PPC and RNC) while also measuring the level of learning from playing the simulation game. A vast improvement in each area of measured data is expected when moving between the Traditional round to the LPS round, highlighting the benefits of the LPS.

The following measures were collected in the designated sheets in order to assess the performance of teams in the traditional and lean rounds:

*PPC*– The Percentage of Plan Complete or PPC was measured at the end of each week by the quality inspector. The number of completed activities was found by enquiring with each foreman about how many components they completed that week. This number was then summed up between foremen and divided by 12 to calculate the PPC. As 3 houses were to be completed per week with 4 activities per house; this meant that 12 activities were assigned each week (previously discussed). The PPC was used to give the team insight into how reliable their planning was.

*Extra Cost*– The extra cost register is completed by the supplier at the end of each round. The criterion used are the unused materials (including extra delivered) that are left on site at the end of the round, late completion of houses, rework for houses due to error and additional costs that are due to uncertainty cards. These criteria can also be affected through uncertainty cards by imposing a factor to be multiplied on certain criteria due to risk. This parameter is used to show the level of waste occurring within the simulation and the predicted reduction of waste in the LPS round.

*Learning Degree*– Each participant completed two surveys; prior to and after the simulation, these were used to measure the participants' degree of learning. Both surveys consisted of the same questions and were designed in a numerical manner so that the answers can be analyzed and compared in a quantitative manner. The questions were to do with their knowledge of the LPS and lean principles and procedures, and their implementation. A scale of 1-10 could be chosen to reflect a certain level of confidence. The questions revolved around the main concepts expressed in the simulation game.

*RNC*– The Reasons for Non-Completion or RNC in the simulation game provide the players with the option to record the RNC and then rectify the issues from reoccurring by discussing them during the lookahead meetings. RNC was only recorded during the LPS round by the quality inspector, as traditional planning has no components to understand why failure occurred.

## RESULTS

The results presented in each graph are the average values from both teams in the first time slots simulation. These results may present some form of error due to a number of reasons. Human error is a potential factor, since the nature of the simulation game revolves around human participation basic human error in the calculation of feedback metrics may have mistakes. Variation in the standard of self-judgment in the surveys can interfere with the accuracy of results. Bias between groups presents another issue; as participants were randomly allocated to groups there is a chance of uneven variability of prior knowledge or learning ability. Enhanced prior knowledge would cause the simulation game to be easier for those people than completely new players. In general, the authors argue that some bias may present, however, this can be neglected as it is affecting approximately at the same extent to all participants.

*Average Extra Cost Incurred*– The extra cost incurred is a measure of the extra costs that have been imposed on the project due to numerous factors that were previously explained. The extra cost results displayed in figure 2a showed a higher extra cost in traditional than LPS. The two teams had an extra cost of $6850 and $4150 in the traditional phase followed by $1900 and $600 in the LPS round. This shows an average decrease in the extra cost of 78% between the planning schemes. This can be largely credited to the reduction in batch size that the teams chose to implement after discussing it in their lookahead meetings. In the traditional round teams had to order for three houses at a time, any incomplete houses left a large pile of leftover materials which increased the extra cost. Other factors such as uncertainty can also affect the extra cost; therefore releasing some constraints such as lack of labor and allowing multi skilled labor in the LPS round also had a positive effect on the extra cost. Factors such as faster construction time and fewer errors in the LPS round equally contributed to the cost reduction.

*Average Throughput*– Throughput is a measurement of how many houses were completed in total for each round (Figure 2b). During the Traditional round, one team managed to complete four houses and the other team three houses, giving an average throughput for both teams of 3.5. This then improved in the LPS round with the teams completing eight house and seven houses, providing an average of 7.5 houses. This vast improvement is due to the release of constraints in the LPS round, once the teams had implemented their suggested changes the increase was observed.

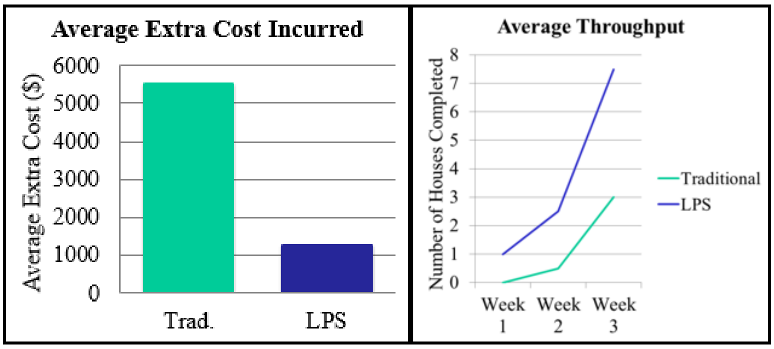


Figure 2: Cost and Throughput results. (a)Average extra cost incurred. (b) Average throughput.

*RNC*– Figure 3a shows that the main RNC that both teams experienced was supply delays, this was due to the supplier not being able to adequately match the speed the orders were being requested; ultimately bottlenecking the production. This highlights the key role that suppliers play in construction and the difficulties that will occur due to supplier issues. One way to overcome this issue was discussed in the lookahead meeting was through ordering for less houses at a time to match the reduced batch size, so other foreman can order and prefabricate. This improved the RNC but the issue still remained.

*Average PPC*– The main factor that increased each team's PPC was reducing the batch size in the lookahead meetings. Each team experimented with different batch sizes every week and the improvements showed. Figure 3b shows that the teams had an average PPC including each week of 67% and 46% in the traditional round, leaving a global average of 57.5%. By using the LPS the average PPC for the round increased on average to 79% and 92% with the global average being 85.5%. As the foreman could reduce the batch size to 2 or 1, the houses were being passed on faster which resulted in more being completed.

*Confidence in Understanding*– The pre-trial questionnaires indicated that each team was lacking in knowledge to do with the LPS, this was observed through determining the level of confidence from the pre-trial surveys (Figure 4). 70% of students had adequate prior Lean Construction and LPS knowledge, whilst 30% had inadequate prior knowledge. The post-trial questionnaire asked the same questions so that the responses could be compared and the improvements gauged.

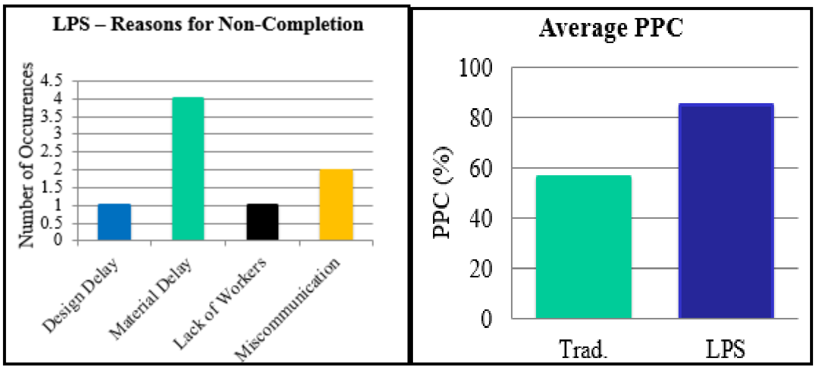


Figure 3: RNC and PPC results. (a) RNC distribution. (b) Average PPC traditional and LPS rounds.

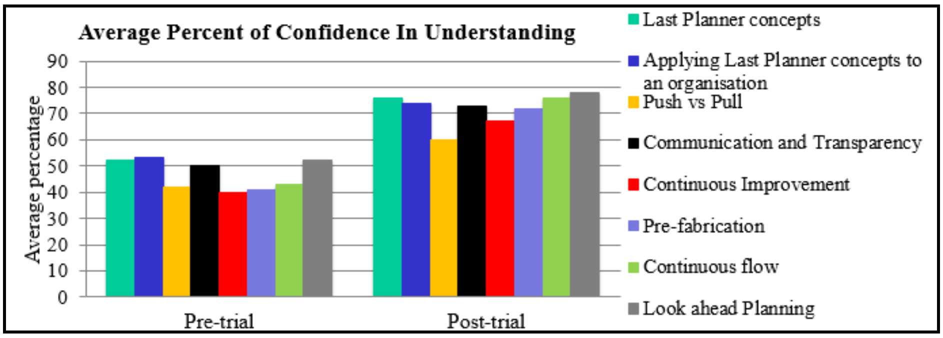


Figure 4: Average percent of confidence in understanding

On average, both teams showed an increase in understanding of 25% of lean and LPS concepts. This shows how effective the LPS simulation game was in portraying the concepts intended. The main improvements in understanding of concepts were transparency, prefabrication, continuous flow and lookahead planning. The reason for this may be due to the emphasis on them in the simulation game components.

## CONCLUSION

Analysis of the data shows that the simulation helped to teach the participants some LPS and lean principles and procedures. This illustrates the simulation game could be used as a learning tool to overcome the implementation barrier in transferring LPS and lean knowledge. This was proven by an average improvement of understanding of 25% of lean and LPS concepts after playing the simulation game. The concepts that were best taught were transparency, prefabrication, continuous flow and look ahead planning. The PPC increased by 29%, the extra cost decreased by 78% and the average throughput increased by almost five houses between rounds. Similar benefits

can be obtained in the construction industry by proper implementation of the LPS, helping to overcome the productivity issue. Positive feedback was given in regards to the simulation, although the simulation game would benefit from further work.
Although the simulation game was highly successful and fun, a number of improvements can still be added into it such as: test its development on a larger sample size, and/or at another educational institution or local community of practice, continue giving some form of LPS education prior to playing the game as it aids in the learning process and improves efficiency, and more even distribution of work between roles as some are consistently working hard while at other times some are not.

## REFERENCES


Ballard, G. (2000). The Last Planner System of Production Control. PhD Dissertation, School of Civil Engineering, Faculty of Engineering, The University of Birmingham, Birmingham, U.K.

Ballard, G 1994, "The Last Planner", Northern California Construction Institute, The Lean Construction Institute, Monterey, 22-24 April.

Forcael, E., Glagola, C. R. and González, V., (2012). Incorporation of computer simulations into teaching linear scheduling techniques. *J. Prof. Iss. Eng.-ASCE*, 138 (1) 21-30.

Howell, G. and Koskela, L. 2000, "Reforming Project Management: The Role of Lean Construction", Proceedings IGLC 8, Brighton, UK, 17-19 July.

Koskela, L. (2000). An Exploration Towards a Production Theory and its Application to Construction. PhD Dissertation, VTT Building Technology, Helsinki University of Technology, Espoo, Finland, 298 pp.

Laufer, A., Tucker, R. L., Shapira, A. and Shenhar, A. J. (1994). The Multiplicity Concept in Construction Project Planning. *Const. Mgmt. and Econ.*, 12 (1) 53-65.

Mossman, A. (2013). Last Planner – 5+1 Crucial & Collaborative Conversations for predictable design and Construction Delivery. (Available at http://dl.dropboxusercontent.com/u/3369275/Mossman-Last- Planner.pdf).

Pavez, I. and González, V. (2012). The Social Dynamic of Improvement when using Lean Construction Techniques: Last Planner System Analysis. Proceedings IGLC 20, San Diego, USA, 18 – 20 July.

Porwal, V. (2010). Last Planner System - Areas of Application and Implementation Challenges. MScThesis, Texas A&M University, 144 pp. (available at http://repository.tamu.edu/bitstream/handle/1969.1/ETD-TAMU-2010-12-8634/PORWAL-THESIS.pdf?sequence=2).

Sacks, R., Esquenazi, A. and Goldin, M. (2007). LEAPCON: Simulation of Lean Construction of High-Rise Apartment Buildings, *J. of Constr. Engrg. and Mgmt.-ASCE*, 133 (7) 529-539.

Tommelein, I., Riley, D. and Howell, G (1999). Parade Game: Impact of Work Flow Variability on Trade Performance. *J. of Constr. Engrg. and Mgmt.-ASCE*, 125 (5) 304-310.

Villego (2014). Villego-Last Planner Simulation. (available at: http://www.villego.com/).

Visionary Products (2014). The Airplane Game. (available at http://www.visionaryproducts.biz/Home/Products/LZPM/tabid/61/Default.aspx).