

A Last Planner System (LPS) Simulation Game in a Construction Schedule Course

Euysup Shim¹, and Chengyi Zhang²

¹California Baptist University, ²University of Wyoming

The Last Planner System (LPS) is one of the Lean Construction methods. The LPS is to develop a more reliable project schedule through collaboration among multiple ‘Last Planners’. A reliable work schedule in the LPS can be developed through different levels including weekly schedule. A weekly schedule should include the works which are ready for installation and screen out the work items which are not ready. This ‘make-ready’ process in developing weekly schedules is one of the key components in the LPS. Several simulation games had been developed to educate the LPS to construction practitioners and construction major students. The current LPS simulation games include simulation of several different components of the LPS. However, no current LPS simulation game simulates all the major processes in the LPS including the ‘make-ready’ process. A new LPS simulation game was developed to include all the major LPS processes and components including management of uncertainty. It was implemented in a construction schedule course in a Construction Management (CM) program at a college in the U.S. As a pilot study, students’ perception of the effectiveness of the game was evaluated. The results show that the newly develop LPS game was effective in learning.

Keywords: Last Planner System, Simulation game, Project scheduling

Introduction

The Last Planner System (LPS) is one of the Lean Construction methods to enhance the value to a project owner by minimizing the amount of waste. The LPS was developed by Ballard and Howell in 1992 with emphasis on reducing the uncertainty in construction workflow (Ballard and Howell, 2003). The LPS considers different levels of constructions (master plan, phase planning, make-ready process, and production planning) and integrate them to develop a more reliable production schedule and to enhance predictability of planned construction activities (Mossman, 2015).

Due to its beneficial features, the LPS has been adopted and implemented in many construction projects (Bellaver et al., 2022). Some of the benefits of the LPS have been identified as followings:

- More reliable planning or reduction of variability in projects (Alarcón et al., 2005)
- Enhanced project performance in terms of time (Mossman, 2015; Alarcón et al., 2005)

- Significant improvement in project safety, predictability, profit and feelings of wellbeing among project staff (Mossman, 2015)

For better project results, the LPS requires all project participants such as the general contractor, all trade partners (specialty contractors), and key engineers to collaborate and develop reliable production schedules and better control of the production (González et al., 2014). Furthermore, the Lean Construction concepts which the LPS is based on may appear counterintuitive compared to traditional project management concepts: encouragement of collaborative interdependence rather than siloed and fragmented interactions. Due to these requirements and non-traditional management concept, the LPS and other Lean Construction concepts have been taught through simulation exercises or games (Tsao and Howell, 2015). The format of simulation exercises are effective hands-on learning tools which enable practicing business skills in a risk-free process and by accelerating the learning process especially for complex lessons (Clarke, 2009; Forcael et al., 2012).

Several simulation games had been developed to educate the LPS to construction practitioners and construction major students (Tsao et al., 2014; Rybkowski et al., 2018; Drevland, 2022). The current LPS simulation games include simulation of several different components of the LPS (such as determining a work sequence and preparing a (weekly) work plan) or focus on only one component of the LPS. However, no current LPS simulation game includes simulating the ‘make-ready’ process through which only ready work items are selected for a next week work plan and non-ready work items are attempted to be prepared along with simulation of the LSP components.

A new LPS simulation game was developed to teach Construction Management (CM) major students the LPS and related concepts including the ‘make-ready’ process by the authors. The game was played in a CM course to test the effectiveness of the new simulation game in teaching the LPS.

Literature Review

Components of the LPS

The LPS incorporate different levels of schedules and/or planning to produce more reliable work schedule and the followings are the main components of the LPS implementation (Ebbs and Pasquire, 2019):

- Master schedule (or milestone schedule)
- Phase schedule and pull-planning
- Look-ahead schedule and make-ready process
- Weekly work planning and commitment
- Daily huddles and coordination
- Learning and actions from measuring performance in term of Percentage Plan Complete (PPC) and identifying reasons for non-completion (RNC)

As Daniel et al. (2015) explained, schedules for construction projects are developed in different levels of details (from master schedule through phase schedule and look-ahead schedule to weekly work plan) as planned tasks approach closer in the LPS. More detailed schedules in the LPS (such as phase schedule, look-ahead schedule, and weekly work plan) should be developed by those people who will install or implement the planned tasks, or ‘last planner’ (for example, foreman for a trade). The ‘last planners’ are required to participate in development of a phase schedule through backward planning by identifying prerequisites (or immediate preceding activities) for each task and sequencing from the last activity to the first activity in one construction phase (Phase scheduling and pull-planning). The

LPS requires last planners to detect any constraints (or barriers) to start their activities, and the activities identified to have any constraints should be made ready for installation through collaboration among all project participants. This process to detect and resolve any constraints for activities planned for incoming weeks is called ‘make-ready process’ (Ballard and Howell, 2003; Mossman, 2015; Daniel et al., 2015). The LPS should include only the tasks which are ‘constraints-free’ and ready for installation so that the planned schedule becomes more reliable. Then, the ‘last planners’ are required to monitor the progress of their planned activities and calculate the percentage of activities completed (Percentage Plan Compete, PPC). Also, they are required to analyze and identify the reasons why they were not able to complete planned activities (reasons for non-compliance, RNC) each week.

The ‘make-ready process’ in look-ahead planning links front-end planning (phase schedule) with detailed and short-term production planning (weekly work schedule) and is regarded as a first step in production control in construction projects (Bellaver et al., 2022; Hamzeh et al., 2012). The ‘make-ready process’ is an essential step to ensure the crews work on activities without idle time (Koskela, 2004), and thus, making it a core process to produce reliable and dependable schedule of construction activities (Hamerski et al., 2021).

Construction projects are commonly impacted by a variety of uncertainties (for example, adverse weather condition, or delay in material delivery). Therefore, planning to manage uncertainty in construction projects is one of the most crucial issues (Laufer et al., 1994). The ‘make-ready process’ in the LPS is one way to reduce adverse impacts of uncertainty on project performance by detecting and resolving uncertainty related constraints (such as delayed delivery of materials).

Existing Simulation Games for the LPS

Several simulation games for the LPS and/or pull-planning have been developed: DPR Pull Planning Game (King, 2011), Villego® Game (Villego, 2013), Last Planner Driven Game (González et al., 2014), and Pull Planning Game (Pons, 2016).

The DPR Pull Planning Game is very simple and helps educate pull-planning in development of a phase schedule. The objective of this game is to build a tower with building blocks. This game is concise and straightforward for the pull-planning concepts (Tsao et al., 2014). However, this game only focuses on pull-planning in the LPS processes.

The Villego® Game requires players in different roles to build a building with LEGO™ blocks in two rounds: the traditional planning approach with a schedule developed by the critical path method in the first round and through pull-planning and look-ahead planning process in the second round. The Villego® Game is a cost-effective and useful hands-on simulation tool for teaching the LPS (Warcup and Reeve, 2014). However, the game only covers limited LPS aspects well such as pull-planning and weekly coordination meetings (Rybkowski et al., 2018). Specifically, the ‘make-ready process’ (or removal of constraint through look-ahead planning process) is not clearly incorporated in the game (Drevland, 2022). Another disadvantage of the Villego® Game is the lengthy duration of playing time: suggested duration of 5.5 to 6 hours including lecture on introduction of the LPS between two rounds of game play (Villego, 2013). The game does not incorporate uncertainty.

The Last Planner Driven Game is to build 9 schematic houses (which is much simpler than the building in the Villego® Game) with LEGO™ blocks. The game design is similar to that of the Villego® Game: two rounds of play with players in different roles. The game covers the concepts of look-ahead planning and make-ready process, weekly coordinating meeting, and learning & action

(calculation of PPC and identification of RNC) related to the LPS. In addition, it incorporates aspects of push and pull production, prefabrication and continuous workflow which are emphasized in the Lean Construction approach (Drevland, 2022). Also, the game design includes a component of uncertainty by using ‘uncertainty cards’. However, the game does not include a component of pull-planning to develop a phase schedule.

The Pull Planning Game by Pons (Pons, 2016) is to build a house using PLAYMOBIL® pieces in two rounds similar to the Villego® Game and the Last Planner Driven Game. The design of the Pull Planning Game by Pons includes the concepts of pull planning, look-ahead planning, and weekly work planning in the LPS. The game is focused on pull planning. However, the look-ahead planning session is required only one time at the start of the second round. The break between game play for each week is limited to learning and action (calculation of PPC and determination of RNC): not representing make-ready process to continuously detect and resolve constraints. The recommended duration of this game (including lecture for the LPS) is 8 hours (Pons, 2016).

All of the existing LPS or pull-planning games discussed include the process of pull-planning process: determining sequence of construction activities from the last activity to the first one by finding ‘what I need for my job’ for all participating trade partners. The reason all construction participants are required to collaborate to develop a phase schedule through pull-planning session is based on their expertise in each specific construction activity: ‘what are prerequisites for start of my job?’, ‘how long will my job take?’, and ‘what will be my end products which a next trade contractor requires?’. However, all the existing games provide drawings or plans for the building assembly which include exactly the same information to all of the players. All of the players are able to understand and develop a schedule (or sequence) of assembly with blocks or pieces in multiple colors: no ‘expertise’ is considered in the game. This setting of the game does not facilitate learning development of more accurate & reliable phase schedule by expertise in ‘last planners’.

The Table 1 summaries the LPS components included in each of the existing LPS and/or pull planning games. There is no existing LPS simulation game teaching all components of the LPS as well as managing uncertainty. No existing LPS simulation game teaches successfully more complex interactions like LPS concepts and components (Drevland, 2022).

Table 1. LPS components included in the existing LPS games

| LPS components | DPR Pull Planning Game | Villego® Game | Last Planner Driven Game | Pull Planning Game by Pons |
|--|------------------------|---------------|--------------------------|----------------------------|
| Phase schedule and pull-planning | Yes | Yes | No | Yes |
| Look-ahead schedule and make-ready process | No | No | Yes | Yes/No |
| Weekly work planning | No | Yes | Yes | Yes |
| Learning and action (determination of PPC and RNC) | No | Yes | Yes | No |
| Uncertainty | No | No | Yes | No |

Research Objectives

It is very critical to use all functions (or components) in the LPS to make sure project planning and scheduling and implementation lead to project milestones (Warcup and Reeve, 2014). Therefore, the objectives of this research include:

- To develop a LPS simulation game which includes all the components (as mentioned in the previous sections) of the LPS for a CM course
- To test effectiveness of the LPS simulation game in teaching LPS concepts

Methodology

The following methodological stages were carried out in this research:

- 1) Development of a LPS simulation game
With reference to the existing LPS simulation games, a new simulation game was developed to be played in 2-hour college course.
- 2) Game play as a case study
The game was played in a construction scheduling course in the CM program at a university in the U.S in Fall 2023. The number of students who played the game in Fall 2023 was 28 students.
- 3) Questionnaire survey to measure the effectiveness of simulation game
Effectiveness of the newly developed LPS game in their learning was evaluated by students' perception through a questionnaire survey. The students were asked three questions:
 - Level of past experience or exposure to the LPS
 - How they perceive the effectiveness of the game in their learning
 - How they perceive the importance (or criticality) of the LSP components: collaboration, breaking down construction activity for detailed schedule, make ready process, and learning and acting

Development of a New LPS Simulation Game

A new LPS simulation game was initially developed by the first author in Spring 2022 targeting to use to teach the LSP in a Construction Scheduling course. The game was taught in Fall 2023 as well and has been updated and modified based on the author's observation and feedback from the students who played the newly developed game.

Similar to the Villego® Game, Last Planner Driven Game, and the Pull Planning Game by Pons, the game includes two rounds of play: the traditional project planning and scheduling approach in the first round and the LPS approach in the second round. Since the Construction Scheduling course has 1 hour 50-minute duration, the game was designed for two class sessions. The agenda for the first class session included a brief introduction to Lean Construction and the LPS (15 minutes), game play-round #1 (30 minutes), discussion (10 minutes), lecture on pull planning (10 minutes) and pull planning session (30 minutes). In the second class session, the game was played in the second round (30 minutes) followed by wrap up and discussion (10 minutes). Total amount of time for this game was around 130 minutes.

The objective of the game is to build a building with wooden toy blocks within given time. This game requires six players in different roles (each of the six players installs their own building materials: red, yellow, green, and blue wood blocks, straws and clays) as shown in the left figure in Figure 1. The amount of time spent to install each type of materials are intentionally set to be different. Both the player for straw and clay need to 'fabricate (or mold)' their building components according to the dimensions in drawings. Specifically, clay player should 'fabricate (or mold)' their pieces in a shop location which is far from their building site location. Due to the hardness of the clay used in the game the job by the clay player takes the longest among the six players' jobs.

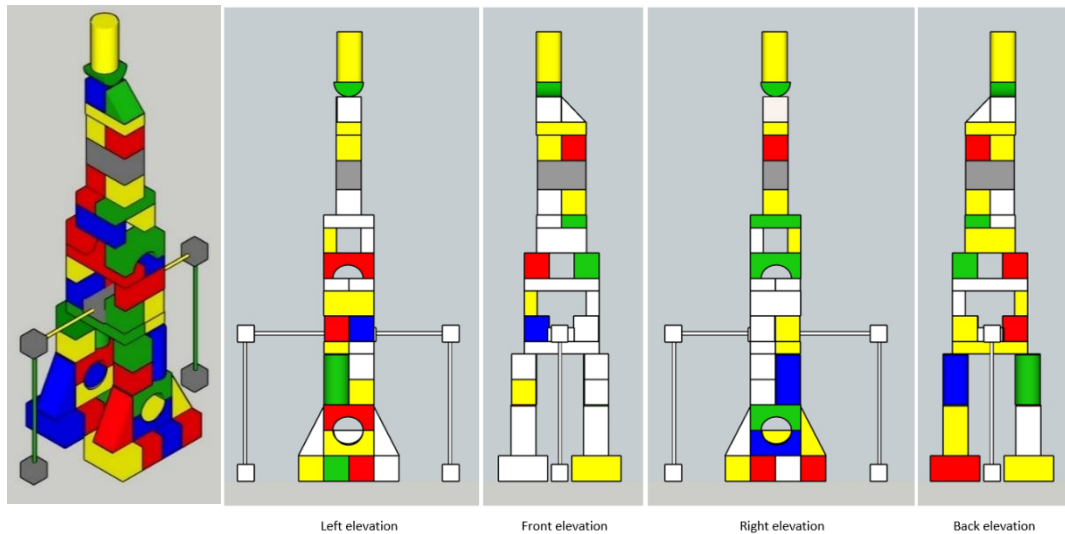


Figure 1. Design of the building for the game and drawings

The first round of this game is to build a building using the traditional approach without pre-planning and collaboration. Also, the player in the first round of this game is expected to help game players who are more familiar with the design of the building and the game rules.

After the first round of the game play and discussion, students in the game are introduced to the LPS and instructed on how to develop a pull-planned schedule online. The Mural, an online whiteboard application, is used to identify handoffs between players and determine sequence of installation. The online whiteboard application allows six team members to add, delete, or change their schedule in real time. A template for the pull planning session for each team was created by the first author. The template includes a sticky note for each piece of all required building, and students can copy & paste and move them as needed. The application is easy to learn in the beginning and can save time developing multiple weekly work schedules.

The second round of the game play is composed of time for installation of materials and weekly coordinating meeting time. Each weekly meeting time is for 5 minutes between weeks (each week is for 2 minutes). Players of this game are required to participate in weekly meetings, perform the make-ready process for upcoming weeks, and prepare a weekly work plan (or schedule) for the next coming week in their Mural page. The left figure in the bottom in Figure 2 shows a template for weekly work plan. Also, they are required to measure the number of building pieces to install in the past week and calculate Percentage Plan Complete (PPC) and identify reasons for non-completion (RNC), if there is any. The right tables at the bottom in Figure 2 show a template for the 'Learning and Action' process in the LPS.

Due to the size and complexity of this building installation, only weekly work schedule is required, not look-ahead schedules. The game is supposed to be completed within 5 weeks at the latest in the second round of the game. All the players are required to check if their tasks (installation of building pieces) are ready for the next week. If not, they are required to detect and resolve any constraints on their tasks. Then, they need to prepare a weekly work schedule which includes only the 'make-ready' tasks. To represent the typical prerequisite works in construction activities (material, labor,

equipment, tools, space, and external conditions such as weather), the game includes the following items of ‘hidden constraints’:

- Missing wood blocks to represent insufficient materials or late delivery of materials
- No information on color(s) of clay to represent missing or insufficient design/engineering information
- Incorrect site plan/layout to represent different site conditions
- Building design which is not possible to be constructed to represent the need for constructability review

Players of this game are required to detect these ‘hidden’ constraints during make-ready process through a ‘Request for information (RFI)’ process. All constraints can be resolved only through submission of a RFI form and response to the RFI by the game facilitator. These ‘hidden’ constraints will delay the building process due to RFI process time and may cause rework and idle time, if not detected and resolved in advance enough.

Similar to the Last Planner Driven Game, this game incorporates several unfavorable (unexpected) events to represent typical uncertainties in construction projects. Each team is required to flip over one field event card at the beginning of each week and follow the instruction regarding a specific (unfavorable) event. The events include time delays due to accident or rain, uninstalation of already completed building pieces due to poor quality and change of team players’ roles (based on assumption of one bankrupt contractor).

In addition to the game setting regarding the LPS components, the location of team’s weekly coordinating meeting should be far from their building site. Also, only one person is allowed to install on a building site and no talking or discussion is allowed on building sites.

Implementation of the New LPS Simulation Game

The updated version of the LPS simulation game was played in Fall 2023 in a Construction Scheduling course through two class sessions. Total 28 students participated in this game play. The left photo in Figure 3 shows the pull-planning session through Mural page in the first class session. The right photo in Figure 2 shows installation of building blocks in the second round of the game. A cardboard presentation board (to represent a temporary site fence) was used to limit the access to the building site.



Figure 2. Photos of the game play

Students' Perception on Effectiveness of the LPS Simulation Game

14 students out of total of 28 who played the LPS game took the online questionnaire survey. Out of the 14 responses, one student (7.14%) had participated in a pull-planning session and a make-ready process for the LPS. Four students (28.57%) answered that they had observed a pull-planning and a make-ready process in-person. One student (7.14%) had heard or watched a video about the LPS, and the other eight students (57.14%) did not have any previous experience at all with the LPS.

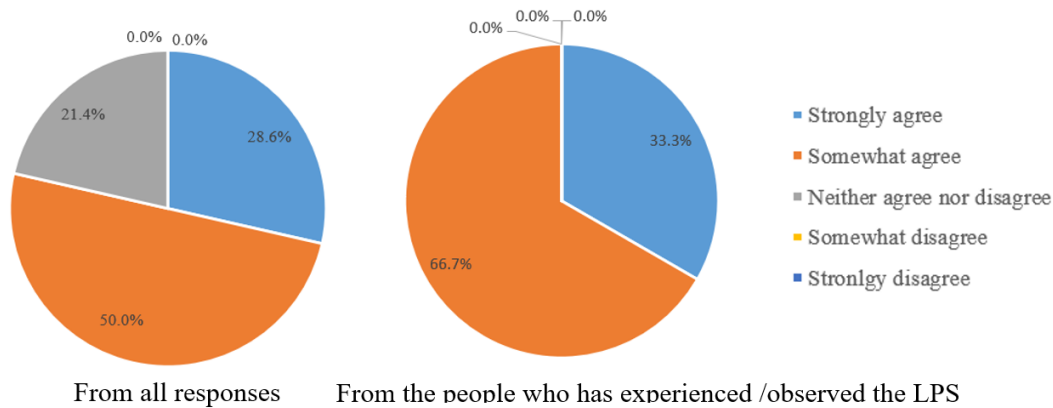


Figure 3. Students' perception on the effectiveness of the LPS game

The students were also asked about the effectiveness of the LPS game in their learning in the survey. Figure 3 shows the results on the effectiveness of the LPS game. The left chart in Figure 3 shows the result based on all 14 responses. Around 79% of students agreed that the LPS game was effective in learning. The right chart shows the results only from the students who had experienced the LPS (participated, observed in-person, or watched a video, total 6 responses). All the students who had experience of the LPS agreed that the LPS game was an effective tool.

In addition to the quantitative evaluation of the effectiveness of the game, the students provided open-end comments about the games. Followings are two positive comments:

- "I thought that this game was super fun and resembles a real jobsite."
- "Was like real life management, as you had to take risks, do RFI's, and also breakdown what needs to be done and scheduled."

Conclusion

The LPS is one of the Lean Construction implementation methods to produce more reliable schedule of construction activities through multiple processes. While several simulation games have been developed and used to teach the LPS to either college students or industry practitioners, no existing LPS related simulation games incorporate and teach all the major components of the LPS: phase schedule and pull-planning, look-ahead schedule and make-ready process, weekly work planning and commitment, and learning and actions.

Therefore, this research aimed to develop a new LPS simulation game to teach CM major students in a CM program at a university in the U.S. and to test the effectiveness of the LPS simulation game in students' learning. The new game was developed with emphasis on inclusion of the make-ready process with four 'hidden' constraints and consideration of uncertainty. Also, the game includes a pull-planning session through an online whiteboard application. The game was developed to fit in two sessions of 1 hour 50 minutes long course. The game has been improved through three semesters based on students' feedback and observation by the game facilitator.

The effectiveness of the simulation game was studied with regard to students' perception through online questionnaire survey. The survey result shows that the simulation game is an effective tool for teaching the LPS. Especially, all the students who had experienced the LPS agreed that the game was effective. However, the number of responses in the survey is small (14 responses). The authors plan to continue to use the simulation game to teach the LPS and evaluate its effectiveness in the future. The authors believe that this simulation game can contribute to construction education not only to college students but also to construction practitioners.

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