Bhaidani, N., Rybkowski, Z., Smith, J., Choudhury, I., Hill, R. (2016). "Percent Planned Complete: Development and Testing of a Simulation to Increase Reliability in Scheduling." In: *Proc. 24th Ann. Conf. of the Int'l. Group for Lean Construction*, Boston, MA, USA, sect.7 pp. 33–42. Available at: <www.iglc.net>.

PERCENT PLANNED COMPLETE: DEVELOPMENT AND TESTING OF A SIMULATION TO INCREASE RELIABILITY IN SCHEDULING

Noorien Bhaidani,[1] Zofia Rybkowski,[2] James P. Smith,[3] Iftekharuddin Choudhury,[4] and Rodney Hill [5]

ABSTRACT

This research responds to a perceived need to help construction management students and industry stakeholders develop a solid understanding of the impact of Percent Planned Complete (PPC) during their first exposure to the Last Planner System of Production Control™. Although the practice of implementing PPC is becoming more widespread, the benefits of its use are arguably not yet fully appreciated by industry practitioners. The QUESTION this research seeks to address is: How can the impact of PPC be clarified to those who are exposed to it for the first time? The PURPOSE of the research is to develop and test a new simulation to better understand how participants perceive the impact of using PPC as a tool to measure and subsequently improve reliability in planning. With respect to RESEARCH METHODS, a simulation was iteratively developed and a questionnaire was administered to participants both before and after playing the simulation to perceive any change in their understanding of the PPC method. The simulation was tested using students as subjects from two universities, as well as industry professionals, and questionnaire results were analyzed. RESULTS demonstrate that playing the simulation led to a 718%

[1] Graduate Student, Department of Construction Science, College of Architecture, Texas A&M University, College Station TX 77843-3137, e-mail: noorienbhaidani@tamu.edu

[2] Assistant Professor, Department of Construction Science, College of Architecture, Texas A&M University, College Station TX 77843-3137, tel: 979-845-4354, e-mail: zrybkowski@tamu.edu *corresponding author

[3] Assistant Professor, Department of Construction Science and Management, College of Architecture, Art and Humanities, Clemson University, Clemson SC 29634-0507, tel- 864-656-7473, e-mail: jps7@clemson.edu

[4] Associate Professor, Department of Construction Science, College of Architecture, Texas A&M University, College Station TX 77843-3137, tel: 979-845-7000, e-mail: ifte.chodhury@gmail.com

[5] Professor, Department of Architecture, College of Architecture, Texas A&M University, College Station TX 77843-3137, e-mail: rhill@arch.tamu.edu

enhanced understanding of how applying PPC to schedule planning can lead to improved reliability of performance. LIMITATIONS include time constraints which necessitated a limitation in the number of test subjects, and the disregard of cultural differences in test subjects. Underlying the need for this work is the assumption that comprehending the impact of PPC helps facilitate application of it. IMPLICATIONS and VALUE of this work is that it has the potential to assist instructors and project managers to more effectively and efficiently transfer understanding of PPC and its capacity to measure (and therefore enhance) reliability, as part of the larger process of continuous improvement.

KEYWORDS

Percent Planned Complete/PPC; Lean simulation; Last Planner System of Production Control; Teaching Lean Construction

INTRODUCTION

Two major issues faced by the construction industry are time and cost overruns. These overruns are likely due in part to a lack of proper planning of schedule. Although collaborative planning helps industry professionals promise reliability, regular production evaluation and planning adds accountability and helps maintain an agreed timeline. Percent Planned Complete (PPC) has been shown to be an effective method of measurement of--as well as motivator for--production reliability. This paper addresses the need to transfer understanding of PPC as a way to increase reliability fundamental to continuous improvement processes.

For the Last Planner System of Production Control, the fundamental components of a planning system define what SHOULD be done, what CAN be done, and what WILL be done (Ballard 1993). Subsequently completed work should be compared to planned work (DID you do it?) to improve process planning. These concepts can be related to traditional project planning levels (**Figure 1**). The Last Planner System, developed by Ballard (2000), is a planning and control system based on lean production principles. This system strives to improve reliability in planning and reduce the negative impacts caused by variability by monitoring Percent Planned Complete on a regular basis.

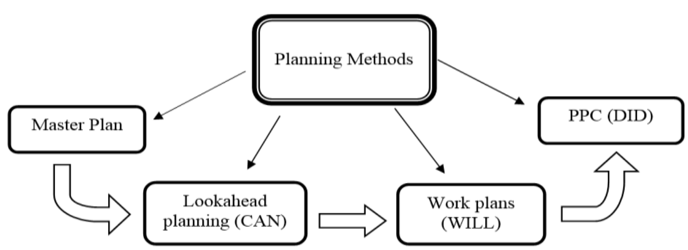

Figure 1: Project Planning Levels
Adapted from Ballard and Howell (1998)

The concept of PPC is integral to the Last Planner System by Ballard (2000). PPC measures the effectiveness of a planning system and is calculated as the ratio of work performed to work planned as a percentage. The reliability of workflow can be computed using PPC as shown in **Figure 2**. Regular tracking of PPC provides an excellent means to check the variability in project planning. It indicates the current status of work, and highlights areas which require more attention.

$$\text{Percent Planned Complete} = \frac{\text{Work performed}}{\text{Work planned}} \times 100$$

Figure 2: PPC calculation

Various studies suggest there is a positive correlation between reliability (PPC) and project profit, early completion, safety, and client satisfaction. From a more advanced perspective, highly reliable projects allow project managers to decrease batch sizes, reduce inventory on job sites, develop consistent workflow, and increase accuracy of estimation of planned durations (Skender 2012).

By measuring and monitoring the completion of activities, the variability of performance decreases, thereby increasing reliability. Ignoring the causes of variability reduces performance, which almost always brings a contractual penalty (Ballard 1993).

After implementing a plan, it is important to check the efficiency of the plan. Monitoring the progress of the plan helps identify drawbacks that can interrupt the smooth flow of the plan. PPC plays the same role in the Last Planner System. Throughout the duration of the project, PPC is tracked consistently and Production Evaluation and Planning (PEP) meetings are held involving all the Last Planners to discuss and evaluate the PPC of the project. The purpose of these meetings is to review and learn from the previous work periods and their respective PPCs. During these meetings, the 'root causes' for why planned work was not completed are identified. This is primarily orchestrated by front line superintendents and foremen who are directly responsible for plan execution.

This research investigates fundamental aspects of PPC, with the assumption that a better understanding can help project managers utilizing this technique improve project performance, thereby contributing to continuous improvement. The improvements realized from these discussions are not only made in the processes and functions at the Last Planner level, but also at the organizational level. PPC analysis can become a powerful focal point for breakthrough initiatives.

EXISTING SIMULATIONS ON PPC

Currently, there are few existing simulations related to the concept of reliability. Iris D. Tommelein, David R. Riley, and Gregory Howell designed the Parade of Trades simulation (Tommelein et al. 1999), with the intent to understand how variances in work flow affects the final productivity of the overall process. PPC emerged as a countermeasure to variability and is integral to the Last Planner System. However, there is still a need for a hands-on simulation to help understand and validate the usefulness of PPC.

ASSUMPTIONS

It was assumed that the lesson learned from the simulation can be directly implemented in the construction industry. The simulation was based on the postulation that PPC is the primary tool used to measure the reliability of the schedule.

LIMITATIONS

There are many other production planning systems to increase the predictable work flow and rapid learning in any project. This research only dealt with the Last Planner System of Production Planning™ formulated by Glenn Ballard and Gregory Howell. There are various factors that affect the work flow in a project. This research limited its focus on reliability as an influencing metric and PPC as its measurement tool.

RESEARCH METHOD

Figure 3 shows the methodology used for the simulation development and testing.

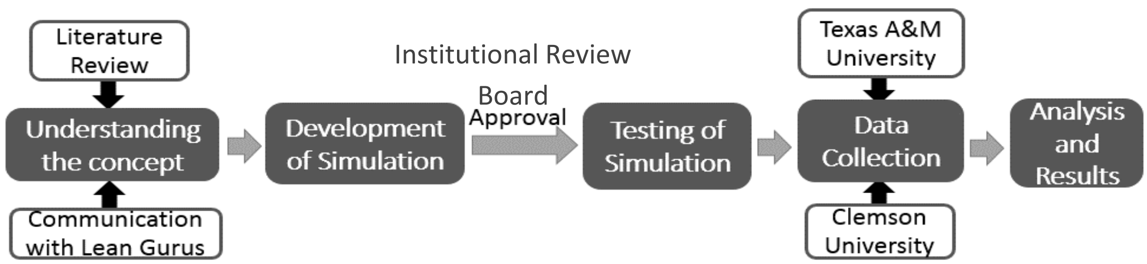

Figure 3: Research method used to develop and test simulation

SIMULATION

PROCEDURE AND SET-UP

Before the simulation, a questionnaire was administered to participants inquiring about their educational and work background, and their knowledge about lean and their previous participation in lean simulations. The participants were then introduced to the concept of PPC and reliability. Facilitators explained how PPC is measured and the importance of PPC. The participants were then presented a scenario where they, as construction individuals, were to provide an owner a supply of work units. This work unit consisted of a pyramid made with marshmallows and sticks as shown in **Figure 4.** The construction of these work units was divided into three 2-minute rounds.

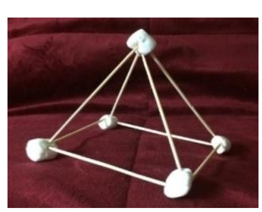

Figure 4: Structure made using marshmallows and sticks

DIVISION OF GROUPS AND SCOPE OF WORK

Participants were divided into groups of four, each group consisting of 1 General Contractor (GC) and 3 Subcontractors.

SCOPE OF WORK FOR GENERAL CONTRACTOR

- The GC independently prepared a work schedule for each subcontractor, supervised the work, and ensured smooth flow of the task.
- The GC was also responsible for documenting the amount of work done by each subcontractor and calculating the PPC after each round.

SCOPE OF WORK FOR THE SUBCONTRACTORS:

- At the beginning of each round the subcontractors estimated the amount of work they believed they would be able to perform.
- They performed the work of making pyramids during the time allotted.

MATERIALS AND HANDOUTS

After facilitators explained participant roles and responsibilities, each group was provided with the following materials:

1. Marshmallows to serve as joints and 5 inch mini skewers to serve as structural struts for the pyramids.
2. Schedule of work to be completed by the GC (**Figure 5**)
3. PPC calculation chart and graph to be completed by the GC (**Figures 6 & 7**)

	Estimated work for the allotted time
Subcontractor 1	
Subcontractor 2	
Subcontractor 3	

Figure 5: Schedule of work

	Work Planned	Work Performed	PPC=Work Performed/ work Planned x 100
Round 1			
Round 2			
Round 3			

Figure 6: Calculation of PPC

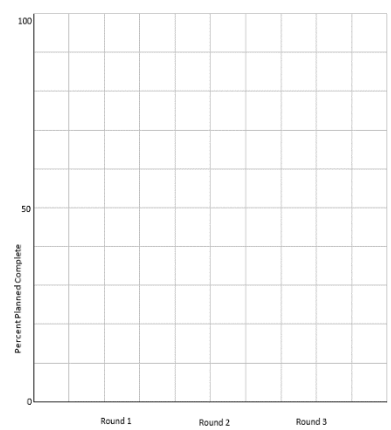

Figure 7: Plotting the PPC

SCHEDULE OF WORK

Before the rounds started, the GC estimated the capacity of work of each subcontractor and independently prepared a schedule of work for the project. Each pyramid was counted as one work unit as shown in figure 3. Incomplete units were counted as a half work unit as shown in the **Figure 8**.

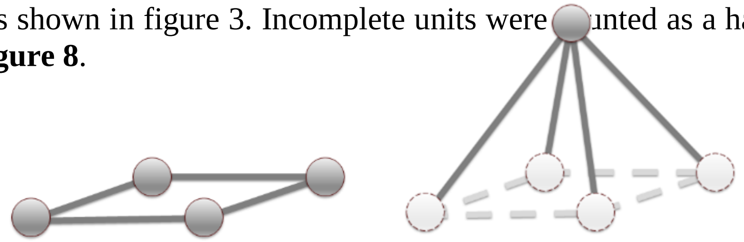

Figure 8: Figure showing half a unit

ROUNDS 1, 2, AND 3

The subcontractors declared the amount of work they predicted they would be able to perform for that round. The GC recorded the work planned by the subcontractor on the sheet provided. The subcontractors were then allotted 2 minutes to complete their planned work. At the end of the allotted time, the amount of work performed by the subcontractors was measured by the GC and PPC for each subcontractor was calculated and plotted on the graph.

DISCUSSION

The graph plotted during the entire activity showed the PPC of each subcontractor for each round. The graph showed an increase or decrease in the PPC with each round. The variation in their planning reliability in relation to each round was discussed and the participants speculated potential causes for variations. Finally, the participants were introduced to the application of PPC in the construction industry as a way to enhance schedule and to serve as a stepping stone toward continuous improvement.

RESULTS

EDUCATIONAL BACKGROUND OF THE PARTICIPANTS

The participants of this study primarily included students of Construction Science from Texas A&M University, College Station, Texas (60 participants) and Clemson University, Clemson, South Carolina (32 participants). Before the simulation was played, the participants were asked whether they had previously played lean simulations. 78 (85%) out of 92 participants stated they were playing a lean simulation for the first time.

WORK PLANNED VS. WORK PERFORMED

At the beginning and end of every round, the GC of the group documented the work performed and the work planned for each subcontractor. With each round, a difference in the gap between work planned and work performed was noted as shown in the figure 9. The gap between average work planned versus average work performed decreased with each round. With every round, the subcontractors became increasingly accurate about predicting their work capacity. This helped them plan their work better and subsequently decrease the gap between work planned and performed (**Figure 9**).

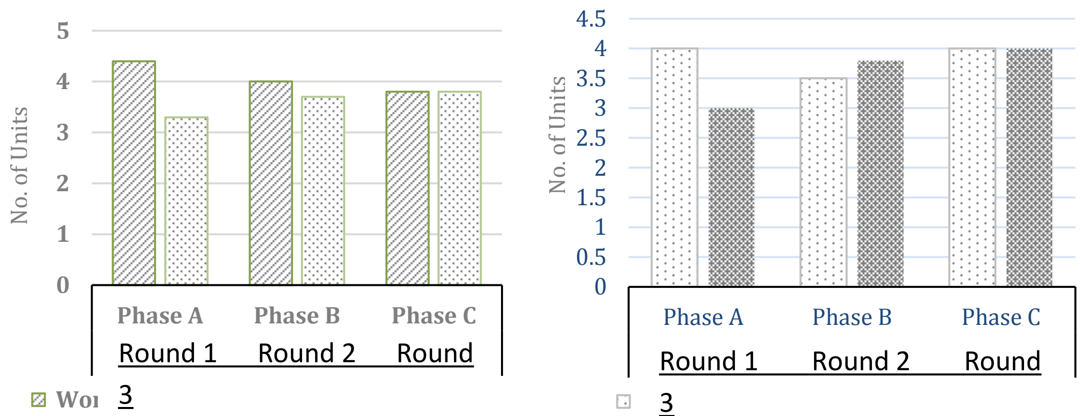

Figure 9: Work Planned vs. Work Performed

PPC BY ROUND

PPC was calculated and plotted at the end of every round for each subcontractor. A difference in PPC was noticeable for most of the participants as shown in **Figure 10**. The average PPC of the subcontractor approached 100% with each successive round as work predictions became increasingly accurate (**Table 1**). As the game moved through subsequent rounds, the subcontractors developed a better understanding of their work capacity and this enhanced planning reliability.

Table 1: Table showing data collected from each round

	Round 1	Round 2	Round 3
Min	33.3	50.0	75.0
Median	80.0	100.0	100.0
Average	81.5	105.6	100.8
Max	250.0	175.0	125.0

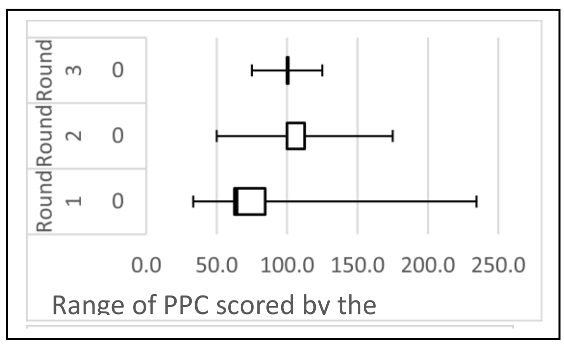

Figure 10: Box and Whisker plot showing the PPC scored by participants during each round

RELIABILITY OF THE GENERAL CONTRACTOR VS. SUBCONTRACTOR

The data collected from the simulation shows a difference between the work planned by the GC at the beginning of the simulation and the work planned by the subcontractor in each round (**Figure 11**).

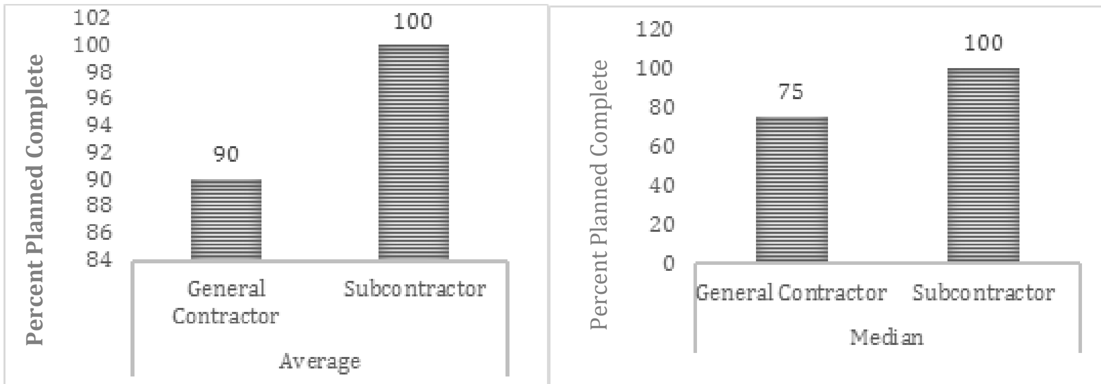

Figure 11: Reliability of the General Contractor vs. Subcontractor

Figure 11 shows the average and median reliability of the GC in comparison with average reliability of subcontractor. The results from the data show that the subcontractor's planning is more reliable than the GC's.

UNDERSTANDING OF THE CONCEPT OF PPC

A post-simulation questionnaire was administered to the participants to assess their comprehension of the term PPC and its use during scheduling in construction projects. Results are shown in **Table 2**.

Table 2: Understanding of the concept of PPC

	Before Playing	After Playing
Aware/Understand	11	90
Not aware/ Did not understand	59	0
No response	22	2

UNDERSTANDING THE CONCEPT OF LAST PLANNER SYSTEM

The questionnaire administered before and after playing the simulation also queried participants about their understanding of the Last Planner System. For example, participants were asked the question, "Who do you think can more accurately predict the time it takes to complete the task?" and they were asked to pick between "person who does the work" (Last Planner) and "an experienced scheduler." **Table 3** includes the results of the questionnaire. According to the data collected, the number of participants who picked "person who does the work" increased after the simulation. Thus, the simulation appeared to facilitate an increasing awareness of at least one key component of the Last Planner System among the participants.

Table 3: Understanding of the concept of LPS

	Before Playing	After Playing
Those who do the work	49	83
An experienced Scheduler	39	6
Both	4	2

RATING THE SIMULATION

At the end of the game, the participants were asked to rate the simulation based on the effectiveness in explaining the concept and application of PPC. On a scale of 1 to 10, a majority of the participants rated the simulations in the range of 6 to 10. The average score the simulation received was 8.3.

According to **Figures 12** and **13**, the simulation was successful in demonstrating that PPC helps in track the work performed and work planned, and increasing the reliability of Last Planners. Furthermore, it effectively explained the concept to the participants.

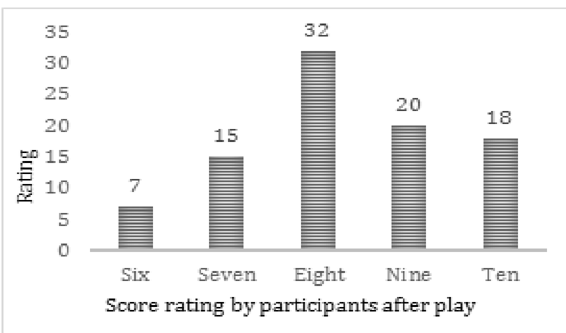

Figure 12: Distribution of the score

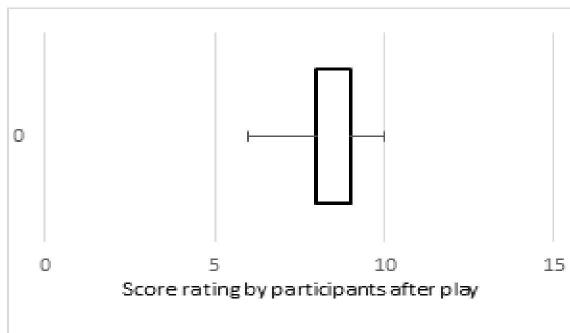

Figure 13: Box plot showing the distribution of the scores

DISCUSSION

During the analysis of the results, an observation was made about the measurement of PPC with each round. In the round 1, both the average and median of the PPC achieved by the participants was lower than 100%, whereas in round 2 the average PPC was lower than 100% and median PPC was higher than 100%. While the participants overestimated their capacity in the first round, it was observed that participants underestimated their capacity in round 2. Additionally, an interesting relationship between the previous exposure of the participant to the lean simulations and their observance of instructions was observed. The participants with less experience with the simulations were more willing to follow instructions. Moreover, the participants playing the role of the subcontractors pushed themselves to surpass the commitments they had made.

The current simulation concentrates on the application of PPC in projects and its direct impact on planning reliability with time. However, the indirect advantages of PPC such as smooth flow of the project, promotion of culture of trust, and its role in continuous improvement were not addressed. Therefore, a new dimension can be added to the simulation by introducing pre-requisite work by others for the subcontractor to start their work. Through this, the concept of inter-dependencies of work in the industry can be investigated. This exploration would usher in new dimensions to the identification of work-flow patterns and subsequently reliability in planning.

CONCLUSION

Reliability plays a fundamental role in project delivery. It is a key factor for improving project performance. Work reliability can be improved through PPC, a measurement tool promoted by the Last Planner System. The journey to improve project performance begins by recognizing existing problems. Measurement of reliability is a key tool for accomplishing this. This simulation helps reinforce an understanding among participants that measurement of work *and* work reliability is crucial to continuous improvement.

The simulation designed and developed though this project was used to investigate how participants perceived the importance of using PPC as a tool to measure and improve reliability. The results from the data collected through the simulation indicated a 718% increase in the level of understanding of the concepts of PPC.

ACKNOWLEDGEMENTS

The authors of this paper would like to thank the faculty and students of the Department of Construction Science at Texas A&M University and Clemson University, as well as extend their gratitude to Dr. Glenn Ballard and Dr. Gregory Howell for their guidance in advising during the preparation of this paper.

REFERENCES

Ballard, G. (1993). “Lean construction and EPC performance improvement.” *Proceedings of the 1st Annual Meeting of the IGLC*, Espoo, Finland, Aug. 1993

Ballard, G. (2000). “The last planner system of production control.” Ph.D. dissertation, Univ. of Birmingham, Birmingham, UK.

Gilbreth, L. M. (1973). *The psychology of management; the function of the mind in determining, teaching and installing methods of least waste*. Hive Pub. Co., Easton.

Tommelein, I. D., Riley, D. R., and Howell, G. A.(1999). “Parade Game: Impact of Work Flow Variability on Trade Performance.” *J. Constr. Eng. Manage.*, 125(5), 304–310

Hamzeh, F. R., Saab, I., Tommelein, I. D., and Ballard, G. (2015). “Understanding the role of ‘tasks anticipated’ in lookahead planning through simulation.” *Automation in Construction*, 49, 18–26.

Skender, M. (2012). “How Planned Percent Complete (PPC) Affects Traditional Metrics in Construction.” *Lean Perspectives Skender Construction*, <http://www.skender.com/blog/how-planned-percent-complete-ppc-affects-traditional-metrics-in-construction-2/> (Nov. 3, 2015).