Shehab, Lynn, Malaeb, Zeina, and Hamzeh, Farook (2024) Harnessing LPS Metrics for Smarter Resource Allocation and Project Control through Gamification. Lean Construction Journal 2024. pp 01-15 (submitted 03Jan2024; Accepted 26Mar2024) www.leanconstructionjournal.org

# Harnessing LPS Metrics for Smarter Resource Allocation and Project Control through Gamification

**Lynn Shehab[1], Zeina Malaeb[2], and Farook Hamzeh[3]**

## Abstract

**Question**: What is the significance of Last Planner System® (LPS®) metrics in capacity planning and project outcomes?

**Purpose**: This study highlights the vital role of LPS metrics in optimizing resource allocation for improved capacity planning, lookahead scheduling, and waste reduction. Additionally, it showcases the efficacy of simulation-based serious games as an engaging and instructive pedagogical method.

**Research Method**: Simulation-based serious game developed using a discrete-event simulation engine and a user-friendly interface.

**Findings**: This study delineates the differences between individuals exposed to LPS metrics during capacity planning and those without such exposure, and the differences between individuals with and without prior LPS knowledge.

**Limitations**: It's essential to acknowledge that simulating real project conditions in a game necessitates certain assumptions.

**Implications**: This game can evolve into a valuable educational tool for assessing users' capacity planning and metric analysis competencies. Multiple versions could also be developed to assess diverse skills vital to project planning and control.

**Value for practitioners**: This paper not only highlights the importance of LPS metrics in capacity and lookahead planning, but also sheds light on the availability of educational and evaluative games. Such games can be embraced by organizations to enhance their current educational and training practices.

**Keywords**: LPS® metrics, capacity planning, resource allocation, serious games

**Paper type**: Full Paper

## Introduction

Project control involves a cycle of planning, measuring, monitoring, and taking corrective action to bridge the gap between project planning and execution (Rozenes et

1 PhD Candidate, Civil and Environmental Engineering Department, University of Alberta, Edmonton, Canada. lshehab@ualberta.ca

2 PhD student, Civil and Environmental Engineering Department, University of Alberta, Edmonton, Canada. malaeb@ualberta.ca

3 Professor, Civil and Environmental Engineering Department, University of Alberta, Edmonton, Canada. hamzeh@ualberta.ca

al. 2006). Effective project control not only enhances project performance but also plays a pivotal role in achieving project objectives and overall success (Hamzeh et al. 2019b). However, conventional project control methods are often considered reactive, as they primarily identify deviations after they occur and respond retrospectively, akin to a thermostat control model (Howell and Ballard 1996). Therefore, there is a growing need to shift towards a dynamic and proactive approach to detect problems and constraints during the project control process (Hamzeh et al. 2019a).

In this regard, the Last Planner System® (LPS®), rooted in Lean Construction principles, adopts a proactive stance toward project control. Within the LPS framework, various metrics have been developed to assess project performance and ensure planned success (Hamzeh et al. 2019b). Examples of these metrics are Tasks Anticipated (TA) and Tasks Made Ready (TMR), which provide proactive insights into the “soundness” of planned assignments (Ezzeddine et al. 2022). Moreover, these proactive metrics offer a more accurate reflection of project performance, with studies demonstrating a positive correlation between a high TMR and a high Percent Planned Complete (PPC) value (Ezzeddine et al. 2022; Hamzeh et al. 2015).

Capacity planning, on the other hand, is a critical element for enabling dynamic corrective actions (Hamzeh et al. 2019a). It entails the optimal allocation of workload, encompassing activities and tasks, to available capacity, including labor, equipment, and resources (Hamzeh et al. 2019a). In fact, imbalances between workload and capacity, such as overloading or underutilizing resources, result in wastage in the form of schedule delays, increased costs, and resource inefficiencies (Shehata and El-Gohary 2011). Accordingly, achieving a balance between workload and capacity through resource allocation is imperative in project management (Hamzeh et al. 2019a). Therefore, the integration of LPS principles and metrics with capacity planning is essential to enhance project control and achieve more favorable project outcomes.

Notwithstanding the extensive literature exploring capacity planning within construction, whether explicitly or implicitly (Ballard, 2000; González et al., 2010; Ramirez et al., 2004; Thomas and Horman, 2006; Tommelein et al., 1999), an apparent gap persists concerning the role of LPS metrics in underpinning capacity planning decisions and their ensuing impact on project time and cost performance. Considering this, the current study addresses the research question: "Do LPS® planning metrics aid in capacity planning and propel improvements in project outcomes?"

To address this question, a novel lean game designed to bridge the gap between theoretical knowledge and practical application in Lean Construction management. The game, developed as a simulation-based tool, serves as a dynamic educational platform for students and professionals alike. It facilitates a deep understanding of LPS metrics in capacity planning and project control, offering a hands-on experience in resource allocation and decision-making. The game focuses on educational outcomes, including the development of critical thinking, problem-solving skills, and the practical application of lean principles in real-life situations. The simulation game has been developed in two versions: one including LPS planning metrics and the other excluding them. These game versions have been tested through two case studies: one including two groups of users experienced in construction planning and scheduling, and one including graduate students with and without prior knowledge in LPS metrics. Their mission is to allocate weekly resources to the project based on project status and the provided metrics. Subsequently, the project's results, including schedule and budget, were analyzed to examine the correlation between the provision of metrics and improved project outcomes. Through this game, this paper aims to contribute significantly to the pedagogical tools available in Lean Construction education, fostering a deeper, more practical understanding of lean methodologies among learners.

# Literature Review

## Project Control Systems: Existing Deficiencies

According to Howell and Ballard (1996), project control is a vital element of project management which involves the detection of variations between the planned and actual progress and the subsequent implementation of corrective actions to maintain the project’s time, cost, and quality targets. In fact, effective project control is significant in determining project success (Rozenes et al. 2006).

Nevertheless, the widespread traditional methods of project control have proven to be unsatisfactory, mainly due to their reactive nature and inaccurate representation of the project status. The most frequently used method is the earned value management (EVM) system (Rozenes et al. 2006). EVM integrates project cost, time, and scope and monitors the work accomplished and cost expended to calculate cost and schedule variances and forecast project cost and schedule at completion (Hamzeh et al. 2019b). Nevertheless, various researchers have pinpointed major faults in the EVM system. For instance, Lipke (2003) highlighted the unreliability of EVM schedule indicators, noting that the metric for schedule variance (SV) is expressed as a monetary unit instead of a temporal unit. Moreover, since SV and schedule performance index (SPI) always converge to 0 and 1, respectively, at project completion, having such values reported does not make it clear whether the project is on schedule or has been completed (Lipke 2003). Cheng et al. (2019) reported that EVM is limited due to its inability to consider changes, such as changes in the labor market or weather conditions, which affect the time for completion and are integral to predict the schedule at completion (SAC). Further, EVM assumes all earned hours are equal (value-wise), does not differentiate between critical and non-critical activities, and fails to consider predecessor–successor relationships between tasks when measuring the productivity of each type of task (Hamzeh et al. 2019b; Kim and Ballard 2000). Thus, EVM does not consider the release of work downstream (Kim and Ballard 2000) and fails to support Lean Construction principles which focus on flow (Cândido et al. 2014). It is also largely reactive in nature, whereby variances from the plan are not detected until after they have occurred (Ezzeddine et al. 2022). Finally, EVM limitedly focuses on time and cost elements rather than on identifying the root causes of the detected delays (Ezzeddine et al. 2022).

## Need for Proactive Control: LPS and Capacity Planning

In line with the above, traditional control mechanisms are largely reactive in nature and function like a thermostat control model, whereby deviations are detected, and corrective actions are taken afterwards (Howell and Ballard 1996). Nevertheless, for more effective control, focus should be centered on proactive detection of possible constraints and issues (Hamzeh et al. 2019a). The Last Planner System (LPS) is a production planning and control system developed from lean principles that promotes proactive control in two phases: (1) early detection and removal of constrains to make activities ready for execution and (2) analysis of the causes of failed plans and tasks not completed to understand and remove those causes in the future (Hamzeh 2009). Moreover, LPS focuses on planning reliability throughout the project timeline, which has been identified as a keystone for successful performance (Alarcón et al. 2014). The core principles of LPS are to (1) plan in greater detail as tasks approach their planned start dates, (2) develop the plan collaboratively with those who will execute the work, (3) identify constraints early on and remove constraints ahead of time, (4) make reliable promises, and (5) learn from failures through detecting their root cause; as a result, the number of planned tasks that are completed will increase due to proactive constraint removal, coordination of all stakeholders, and implementation of prevention measures (Ballard 2000; Hamzeh et al. 2015). Using LPS, collaborative plans are developed through the participation and commitment of all involved stakeholders, which aligns short-term and long-term plans (Ballard 2000) and maintains a reliable workflow (Hamzeh et al. 2019a). LPS consists of four stages of planning:

1. Master Scheduling: work is presented at the project milestone level.
2. Phase Scheduling: project phases are defined.
3. Look-ahead Planning: a timeframe of 2 to 6 weeks is presented. This stage links the weekly work plan with the project schedule. It breaks down processes into operations while identifying and removing their constraints.
4. Commitment Planning: the most detailed plan is presented. In this stage commitments are made to deliver work from the weekly work plan and only quality assignments are made (Ballard 2000; Hamzeh et al. 2015).

In addition to adhering to plans and achieving proper workflow, reliable plans should also consider the appropriate assignment of the workload (activities and tasks) to the available capacity (labor, equipment, and other resources) (Hamzeh et al. 2019a). This is referred to as “capacity planning”, which, in lean terms and in the context of this research, means ensuring a balance between the chosen *workload* and the available *capacity* (Hamzeh et al. 2019a). Workload pertains to tasks that are added to the Weekly Work Plan, while *capacity* pertains to the resources that are made available to match the committed tasks. Capacity planning enhances crew production rates and reduces cycle times, thus decreasing the total process duration (Ballard 2000). Neglecting capacity planning may lead to increased costs, delays, and wasted resources (Shehata and El-Gohary 2011). Therefore, it is integral to implement both LPS and capacity planning to enable dynamic corrective actions for enhanced project control (Hamzeh et al. 2019a).

## LPS Metrics

Control in LPS includes the measurement of completed tasks, detection of incomplete tasks and investigation of the reasons for these failures, and the elimination of the identified reasons (Hamzeh et al. 2019b). While traditional project control measures performance through comparing the actual output to a standard baseline and using the variance to correct the process, LPS relies on several metrics to analyze project performance and allow continuous learning and improvement (Hamzeh et al. 2019b). Percent Planned Complete (PPC) is the most used metric, which measures planning reliability at the level of the WWP (El Samad et al. 2017). PPC is the ratio of tasks executed from the WWP to those that were committed (4). While a high PPC may correspond to improved performance, PPC alone is not representative and has shown certain shortcomings, such as its inability to account for critical tasks (Hamzeh et al. 2020), indicate work efficiency, or crew utilization (Chitla and Abdelhamid 2003). Accordingly, further metrics were developed, such as Tasks Anticipated (TA), which is the ratio of anticipated tasks to the total WWP tasks, and Tasks Made Ready (TMR), which is the ratio of completed tasks to the tasks that “Can” be performed as assigned in the lookahead planning stage (Ballard 1997). TA reflects the planner’s ability to expect tasks while TMR reflects the ability to screen tasks and make them ready for execution (El Samad et al. 2017).

To be executed successfully, it's crucial to ensure that tasks considered ready in the preceding week remain ready during the execution week. Therefore, Hamzeh (2009) introduced some additional definitions and metrics. Sometimes, tasks initially deemed ready face issues during execution, often due to misunderstandings about customer satisfaction conditions. This misunderstanding can occur when constraints are assumed to be removed but are, in fact, still present. On the contrary, “ReadyReady” tasks are those that are genuinely ready, free from constraints, and proceed for execution, unless an execution failure occurs. “NotReady” tasks are those not considered ready one week ahead of execution because they lack one or more prerequisites for execution, and “New” tasks are additions to the weekly work plan that were not part of the week 2 lookahead plan. These tasks were not initially foreseen during lookahead planning.

Three important additional metrics help gauge the readiness and transformation of tasks: **RR** (Ready to ReadyReady percentage) measures the percentage of tasks initially labeled as "Ready" that transition to the "ReadyReady" status. **NR** (NotReady to ReadyReady percentage) calculates the percentage of tasks initially classified as "NotReady" but later transformed into "ReadyReady" during the week. It reflects the efficiency in resolving constraints and making tasks execution-ready. Finally, **N** (New to ReadyReady percentage) measures the percentage of newly introduced tasks that transition into the "ReadyReady" status during the week. It indicates the ability to swiftly prepare and integrate new tasks into the execution process. These metrics provide valuable insights into the readiness and adaptability of tasks, ultimately impacting the success of project execution.

# Methodology

This study employs a Simulation-Based Research (SBR) approach as its primary research methodology to investigate the impact of exposure to LPS metrics on capacity planning performance within a discrete event simulation-based game. Following the taxonomy proposed by Cheng et al. (2014), this research aligns with the investigative facet of SBR, harnessing simulation as a robust tool to address the research question. Simulation is defined as “the process of designing a model of a real system and conducting experiments with this model to gain insights into system’s behavior and evaluate various operational strategies” (Shannon 1998). In the context of construction, AbouRizk (2010) defines simulation as "the science of developing and experimenting with computer-based representations of construction systems to understand their underlying behavior."

The application of simulation in this research allows for controlled experimentation in resource allocation within a simulated construction project, overcoming the inherent risks, costs, and logistical challenges associated with implementing such changes in a live project environment. Two versions of the simulation-based game were developed: one with LPS metrics and the other without. Both versions were tested through two case studies as shown in Table 1 below. In the first case study, participants were selected to form a representative sample of 39 individuals, comprising 12 members of the Administering and Playing Lean Simulations Online (APLSO) group and 27 graduate students enrolled in a Lean Construction course. Each participant was asked to play both game versions. In the second case study, 28 participants were graduate students enrolled in one of two courses: C1 which is a construction management course without Lean Construction or LPS teachings, and C2 which is a Lean Construction course that includes LPS metrics teachings. Each student in each course was asked to play only one game version. Data collection involved the documentation of final game scores, including schedule overrun, budget overrun, and average LPS metrics. Statistical and comparative analyses were employed to compare performance outcomes.

**Table 1:** Experiments Summary

| | Cast Study 1 | Case Study 2 |
|---|---|---|
| Participants | 12 APLSO members | 17 C1 course (not Lean related) students |
| | 27 Lean course graduate students | 11 C2 course (Lean related) students |
| Game | Both games per participant | Either Game 1 or Game 2 per participant |

# Model Development

Aligned with the “Rocks and Pebbles” planning process first introduced by Hamzeh et al. (2008), a discrete-event simulation model, which models the transformation of tasks from processes (rocks) to operations (pebbles) 2 weeks ahead of execution, was built. The model incorporates probabilities of new tasks, tasks that are ready, tasks that are not ready, tasks that can be made ready, and tasks that cannot be made ready, previously introduced by Hamzeh et al. (2008). The model also includes a specific number of tasks that the project starts with. Each week, a certain number of tasks are released for planning, and a user input is prompted through the interface to assign a user-selected number of resources; each resource representing one capacity unit required to perform an activity. Decisions regarding the number of resources to allocate are made based on the available information in each game version. In the first version without LPS metrics (Figure 1) users can only see the total number of tasks 1 week prior to execution. In the second version with LPS metrics (Figure 2), users can see the total number of tasks that are made ready (TMR) at the beginning of the week of execution, in addition to the RR, NR, and N ratios introduced by Hamzeh et al. (2008) and explained to the participants prior to playing the game.

Once resources are allocated, tasks are executed. If more resources than tasks are allocated, a late fee is added to the spending, increasing the chances of ending the project overbudget. If less resources than tasks are allocated, less tasks than scheduled will be executed, increasing the chances of ending the project behind schedule.

For clarification, the following example may be assumed:

For 400 tasks and an average of 40 tasks per week,

- **Time**: Average final time is 13. If you are early or on time, you are on schedule, otherwise, you are late.
- **Cost**: It depends on your schedule. Each extra resource costs $100, and each extra week costs $1,500.
  - If you are on time (within 13 weeks), and your over-utilization ($100 per resource) is <= $5,000, you are within budget. Otherwise, you are overbudget.
  - If you exceed the 13 -week limit, and your over-utilization ($100 per resource) AND late fee ($1,500 per extra week) are <= $5,000, you are within budget. Otherwise, you are over budget.
- Example: you assign 40 extra resources throughout the project, and you are 3 weeks late, you are (40*100 + 3*1500) = 8,500 over budget

After every week, the week's over- or under-allocation consequences in terms of budget or schedule are displayed on the interface (Figure 3.).

Once all tasks are executed, the results are displayed. Results include final budget overrun, final schedule overrun, average PPC, average TMR, and average TA.

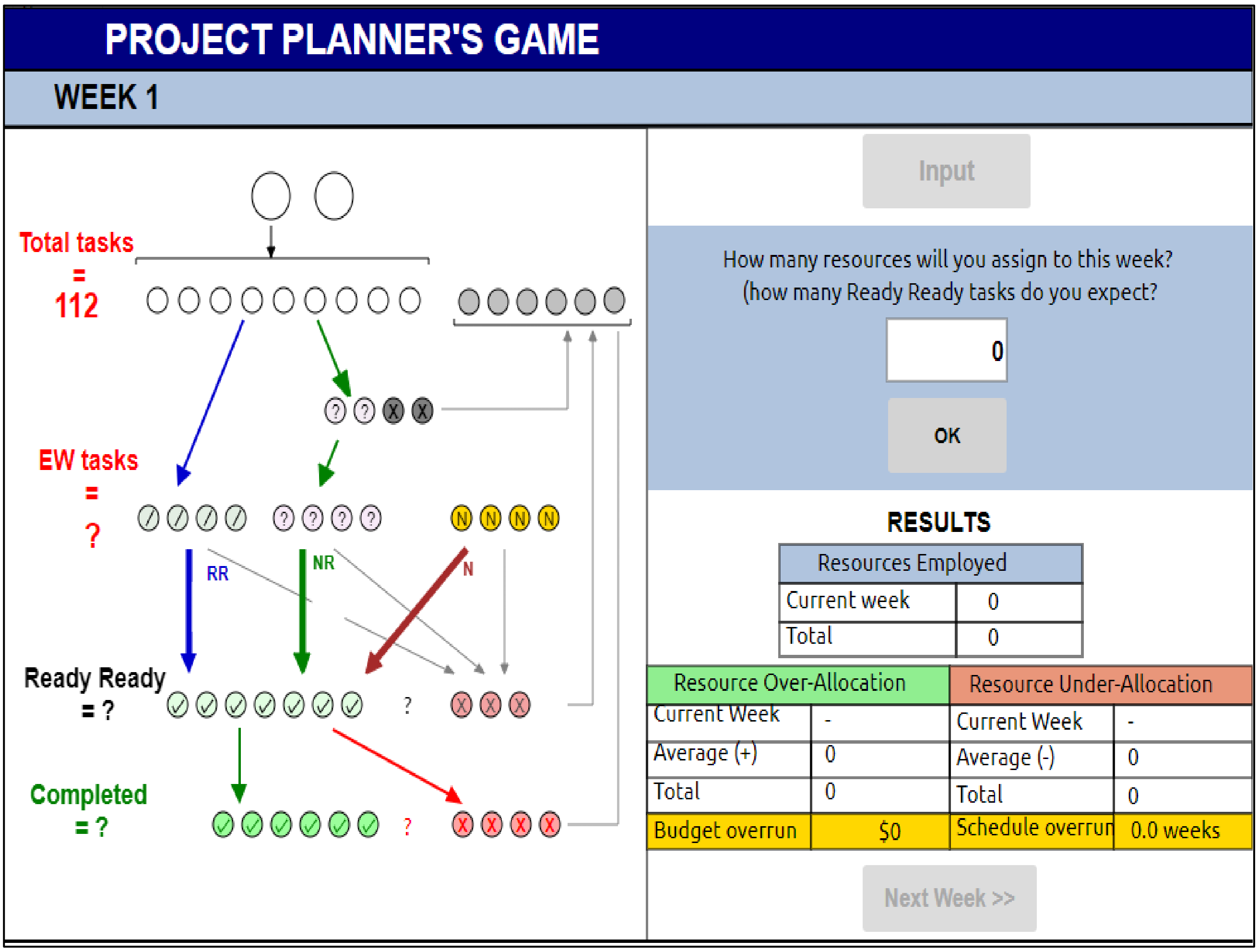


**Figure 1.** Interface of Game 1 with LPS® metrics

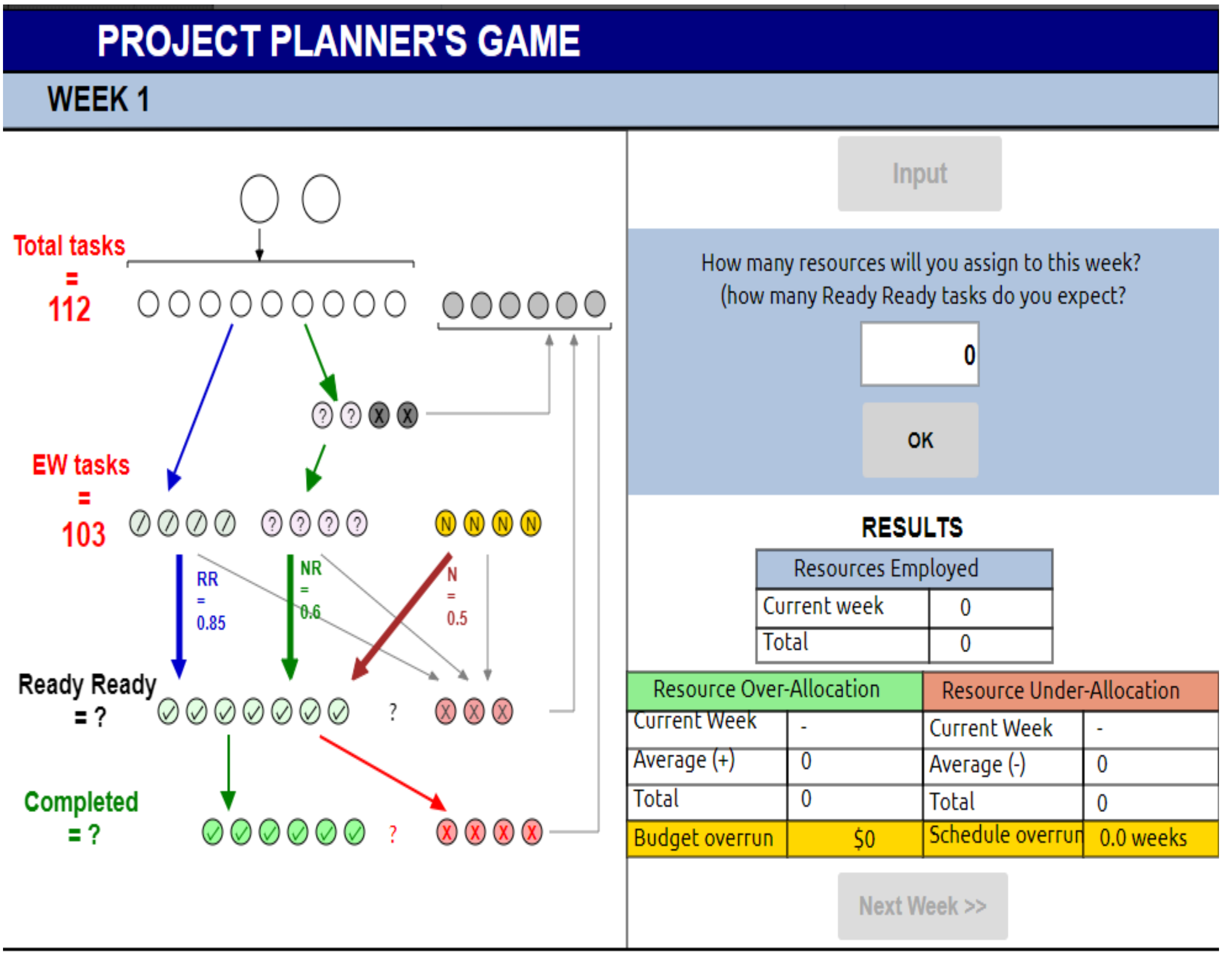


**Figure 2.** Interface of Game 2 without LPS® metrics

**RESULTS**

| Resources Employed | |
|---|---|
| Current week | 103 |
| Total | 103 |

| Resource Over-Allocation | | Resource Under-Allocation | |
|---|---|---|---|
| Current Week | 9 | Current Week | - |
| Average (+) | 9 | Average (-) | 0 |
| Total | 9 | Total | 0 |
| Budget overrun | $900 | Schedule overrun | 0.0 weeks |

**Figure 3.** Weekly Results

## Study Assumptions

The main objective of this study is to investigate the impact of LPS® planning metrics on capacity planning and, ultimately, the resulting project schedule and budget. Therefore, other factors that may affect project performance are ignored. For that, the below assumptions are made:

- Force majeure, unforeseen conditions, and weather fluctuations are neglected.

- A capacity unit represents the combined resources required to perform an activity (material, labor, equipment, etc.).
- One unit of capacity corresponds to one unit of tasks on the weekly work plan.
- The impact of capacity assignments on site congestion and safety is not considered.
- The impact of weekly capacity changes on the learning curve is not considered.

# Case Study 1 Results and Discussion

In the first case study, each participant was asked to play both versions of the game. All participants had theoretical and/or practical experience in construction planning generally and LPS metrics specifically. Game results from the 39 participants were collected through manual data entry of the results into a designated Google form. Final results per participant included final average schedule overrun, final average budget overrun, final average PPC, final average TMR, and final average TA. Game 1 and game 2 average results are shown in Table 2.

Based on the obtained results, Game 2, which involved exposure to LPS metrics, demonstrated lower schedule overruns compared to Game 1, where LPS exposure was absent, with a significant 31% average weekly difference. Additionally, Game 2 exhibited slightly higher average PPC and TMR results, with a marginal 2% difference for each metric. These findings provide compelling evidence that the vigilant monitoring of LPS metrics during resource allocation leads to more precise capacity planning. This precision is rooted in the ability to estimate the required resources based on the team's performance in preparing tasks throughout the week. By continuously tracking task readiness and the emergence of new tasks during the project's course, planners can construct an accurate representation of project progress. This comprehensive understanding empowers them to proactively avoid schedule overruns, execute a greater number of planned tasks, and ensure that tasks are made ready on time. In essence, the incorporation of LPS metrics into the resource allocation process emerges as a valuable tool for optimizing project control and enhancing overall project performance.

However, budget overrun results in Game 2 were higher than those in Game 1, with a notable 21% difference. This discrepancy suggests that planners, when exposed to LPS metrics, exhibited a tendency to over-allocate resources. This phenomenon warrants further investigation, as it may be attributed to several factors, including risk aversion, where planners, aware of the project's metrics, might have taken a conservative approach by over-allocating resources to ensure tasks are adequately covered. Another factor could be metric misinterpretation, as it is possible that some planners misinterpreted or misapplied the LPS metrics, leading to resource allocation decisions that did not align optimally with the project's actual needs. Understanding the underlying causes of the budget overrun in Game 2 is crucial to harness the benefits of LPS metrics effectively while mitigating any unintended consequences. Further research and refinement of resource allocation strategies based on these findings can lead to more precise and cost-effective project planning and control.

Paired t-test analysis is conducted to further compare and analyze results from both games. As a first step, the null (H0) and alternate (H1) hypotheses are set up.

*H0: The means of the results obtained from Game 1 and Game 2 are equal, indicating **no significant difference**.*

*H1: The means of the results obtained from Game 1 and Game 2 are not equal, indicating **significant difference**.*

**Table 2: Game 1 and Game 2 Average Results**

| Result | Game 1 | Game 2 | Relative Difference |
|---|---|---|---|
| Final Average Schedule Overrun | 2.26 | 1.72 | -31% |
| Final Average Budget Overrun | 9,703 | 12,208 | 21% |
| Final Average PPC | 0.75 | 0.76 | 2% |
| Final Average TMR | 0.72 | 0.73 | 2% |
| Final Average TA | 0.82 | 0.82 | 0% |

Afterwards, the mean, standard deviation, and p-value (with alpha = 0.05) are calculated. The results are shown in Table 3.

**Table 3: Paired t-test analysis results**

| Indicator | Mean | SD | p-value | p-value >? 0.05 |
|---|---|---|---|---|
| Schedule overrun | -0.538 | 1.570 | 0.039 | False, reject null hypothesis |
| Budget overrun | 2,505 | 23,815 | 0.515 | True, accept null hypothesis |
| Average PPC | 0.012 | 0.058 | 0.192 | True, accept null hypothesis |
| Average TMR | 0.016 | 0.068 | 0.164 | True, accept null hypothesis |
| Average TA | -0.001 | 0.036 | 0.818 | True, accept null hypothesis |

Based on the paired t-test analysis, significant differences among the schedule overrun results are evident. The mean schedule overrun in Game 2 was found to be -0.538, with a standard deviation of 1.570, and a corresponding p-value of 0.039. With a significance level set at alpha = 0.05, the p-value falls below this threshold, leading us to reject the null hypothesis (H0) and accept the alternate hypothesis (H1). This outcome suggests that there is a statistically significant difference between the schedule overrun results in Game 1 and Game 2.

On the other hand, when assessing budget overrun, the mean difference between Game 1 and Game 2 was 2.505, with a standard deviation of 23.815, and a p-value of 0.515. In this case, the p-value exceeds the significance threshold of alpha = 0.05, leading to the acceptance of the null hypothesis (H0). Consequently, it is concluded that there is no statistically significant difference in budget overrun results between the two games. Similarly, for average Percent Plan Complete (PPC), average Tasks Made Ready (TMR), and average Tasks Anticipated (TA), the p-values are 0.192, 0.164, and 0.818, respectively. In all three cases, these p-values exceed the alpha threshold of 0.05, indicating that there are no statistically significant differences in these metrics between Game 1 and Game 2. Thus, we accept the null hypothesis (H0) for these metrics.

These findings highlight that while there is a statistically significant improvement in schedule overrun results with the introduction of LPS metrics in Game 2, there are no significant differences in budget overrun, average PPC, average TMR, and average TA between the two games.

# Case Study 2 Results and Discussion

In the second case study, all 28 participants were graduate students. 17 students were enrolled in a graduate course related to construction managements but unrelated to Lean Construction or the LPS (C1), while 11 students were enrolled in a graduate course on Lean Construction and the LPS (C2). Each student was asked to play either Game 1 or Game 2, and they were not informed in advance which game they would be participating in. The results are shown in Table 4.

**Table 4: Case study 2 results**

| Metric | Avg (G1) | Avg (G1) | Avg (G2) | Avg (G2) |
|---|---|---|---|---|
| **Budget Overrun** | 25,550 | 33,350 | 32,133 | 24,180 |
| **Schedule Overrun** | 2.75 | 1.5 | 3 | 1.8 |
| **PPC** | 0.682 | 0.692 | 0.681 | 0.703 |
| **TMR** | 0.663 | 0.670 | 0.657 | 0.682 |
| **TA** | 0.788 | 0.790 | 0.780 | 0.783 |

To analyze the obtained results, comparative analysis is carried out and presented in Table 5 . The first three columns compare results among the two courses. Since budget overrun and schedule overrun results are desired to be low, and PPC, TMR, and TA results are desired to be high, values shown in green indicate lower budget and schedule overrun and higher PPC, TMR, and TA results in the course where Lean Construction and the LPS are taught (C2). Results show that while C2 students lagged in Budget Overrun in Game 1, they made significant improvements in Game 2, surpassing C1 students. In terms of schedule and LPS metrics (PPC, TMR, and TA), C2 students consistently outperformed C1 students in both game versions. These insights suggest that while C1 students initially managed their budget better in Game 1, C2 students demonstrated adaptability and improved their financial management in Game 2. Furthermore, when it comes to task management and schedule adherence, C2 students consistently outperformed C1 students across both games.

Going through Table 5, the second three columns compare results among the two game versions. Since budget overrun and schedule overrun results are desired to be low, and PPC, TMR, and TA results are desired to be high, green values indicate lower budget and schedule overrun and higher PPC, TMR, and TA results in Game 2. As the first column in this category (C1 (Game 2 – Game 1)) represents the performance of students with no prior knowledge or experience in LPS metrics, their performance was not improved in Game 2 with the exposure of LPS metrics. This indicates that lack of knowledge in LPS metrics hinders the proper usage and analysis of the metrics, despite being exposed to them. The second column in this category (C2 (Game 2 – Game 1)) represents the performance of students with prior knowledge or experience in LPS metrics. Their performance in Game 2 surpassed their performance in Game 1 for all metrics except schedule overrun with a minor increase of 0.3 days TA with a negligible decline of 0.006. This indicates that students with prior knowledge and appreciation of LPS metrics were able to utilize the exposure to such metrics to improve their overall performance. Regarding the last column, the performance of students in both courses was generally improved in Game 2 compared to Game 1, with the exception of the negligible 0.55 increase and 0.014 decline in schedule overrun and TA, respectively. These findings further suggest that there is an inherent value in LPS metrics exposure, but to extract the maximum benefit, *foundational knowledge is pivotal*.

**Table 5: Case study 2 comparative analysis**

| Metric | Game 1 (C2-C1) | Game 2 (C2-C1) | C2 - C1 | C1 (Game 2-Game 1) | C2 (Game 2-Game 1) | Game 2-Game 1 |
|---|---|---|---|---|---|---|
| **Budget Overrun** | 7800 | -7953 | -153 | 6583 | -9170 | -2587 |
| **Schedule Overrun** | -1.25 | -1.2 | -2.45 | 0.25 | 0.3 | 0.55 |
| **PPC** | 0.010 | 0.022 | 0.033 | -0.001 | 0.011 | 0.010 |
| **TMR** | 0.007 | 0.025 | 0.032 | -0.005 | 0.012 | 0.007 |
| **TA** | 0.002 | 0.003 | 0.006 | -0.008 | -0.006 | -0.014 |

# Proposed Learning Outcomes

The learning outcomes of this lean game are meticulously designed to synchronize with essential educational objectives in Lean Construction. Participants will not only gain a comprehensive understanding of LPS metrics but also enhance their ability to effectively allocate resources and control projects. The game rigorously emphasizes practical skills in lean management, fostering critical analysis and problem-solving abilities crucial in real-world applications.

Through interactive gameplay, learners will grasp theoretical concepts and apply them in simulated, realistic scenarios, thereby preparing them for the dynamic challenges in construction. Additionally, the game sharpens negotiation and strategic planning skills, vital for efficient project execution.

Participants will learn to make informed decisions in uncertain or rapidly changing situations, a frequent occurrence in construction projects. The game offers a deep dive into lean principles, applying them in diverse construction scenarios to reinforce understanding. It encourages adaptability and flexibility, traits indispensable in modern construction management.

Furthermore, the game integrates contemporary technology and tools, reflecting the evolving landscape of construction project management. It provides robust feedback mechanisms, enabling participants to reflect and continuously improve their approach. This comprehensive learning experience is designed to equip future professionals with a rich skillset, fostering a culture of lifelong learning and innovation in the field of construction management.

# Conclusions

In the ever-evolving landscape of construction project management, the need for dynamic and proactive control mechanisms has become increasingly evident. This study explored the potential of integrating LPS® metrics and gamification to enhance resource allocation and project control. The findings of this research shed light on the transformative power of this approach.

From the first case study and through the careful analysis of the two games—Game 1 without LPS exposure and Game 2 with LPS metrics—the impact of monitoring LPS metrics on project outcomes became evident. Game 2, where participants were exposed to LPS metrics, exhibited significantly lower schedule overruns, demonstrating the power of real-time monitoring and adjustment. The ability to assess tasks' readiness and adapt resource allocation based on these metrics allowed for more accurate capacity planning and, consequently, minimized schedule delays. While the results highlighted the benefits of LPS metric integration for schedule management, it also revealed a noteworthy trend in budget allocation. Planners exposed to LPS metrics tended to over-allocate resources, leading to budget inefficiencies. This observation points to the importance of addressing the nuances of resource allocation strategies when incorporating metrics into decision-making processes.

As for the second case study, a comparison between the two groups based on the game versions highlighted the differential impact of prior knowledge of LPS metrics. The observation that C2 students, with knowledge of LPS metrics, were adaptable and improved their performance, especially in financial management in Game 2, highlights the value of foundational knowledge in utilizing these metrics effectively. The consistent outperformance of C2 students in task management and schedule adherence in both game versions emphasizes the lasting benefits of foundational knowledge. Additionally, the differences in performance between Game 1 and Game 2 for both groups also highlight the importance of LPS metrics exposure from a different perspective. The observation that C1 students, even when exposed to LPS metrics in Game 2, did not show significant improvement, reinforces the significance of proper training and foundational knowledge. C2 students, on the other hand, with their prior knowledge, were able to capitalize on the LPS metrics exposure to enhance their performance in most areas during Game 2, which further validates the importance of foundational education. Case study 2 findings suggest that while LPS metrics inherently provide valuable insights, *the magnitude of benefits derived is greatly enhanced with foundational understanding*.

In summary, the integration of LPS metrics into construction project management, particularly when combined with gamification, not only offers promising avenues for enhancing resource allocation and capacity planning, but also emerges as a potent educational tool. This study highlights the importance of the exposure to these metrics and the foundational understanding required to harness their full potential. It also highlights the value of integrating these metrics into educational curricula, equipping future professionals with a profound understanding of their application. The evolving construction industry necessitates continuous educational advancements, suggesting the potential for more sophisticated gamified simulations that replicate complex scenarios. Such educational innovations promise not just improved project outcomes but also foster a culture of lifelong learning and innovation in construction management education. Future endeavors could focus on comprehensive training programs aimed at equipping project managers and planners with the skills to interpret and apply LPS metrics optimally. Moreover, the development of advanced gamified simulation tools that mimic real-world scenarios could provide a more immersive and practical learning experience.

## Acknowledgements

This research is partially supported by the Natural Sciences and Engineering Research Council of Canada (NSERC) Alliance grant ALLRP 549210-19 and Discovery grant RGPIN-2020-04420. It is also partially supported by Scholarship of Teaching and Learning (SOTL) Grant “Gamification in Education: Developing a Simulation Game to Teach Planning and Scheduling” at the American University of Beirut. All findings and conclusions expressed in this paper are those of the authors and do not reflect those of the contributors.

## References

AbouRizk, S. 2010. “Role of Simulation in Construction Engineering and Management.” *J Constr Eng Manag*, 136 (10): 1140–1153. https://doi.org/10.1061/(asce)co.1943-7862.0000220.

Alarcón, L. F., J. L. Salvatierra, and J. A. Letelier. 2014. “Using Last Planner indicators to identify early signs of project performance.” *22nd Annual Conference of the International Group for Lean Construction: Understanding and Improving Project Based Production, IGLC 2014*, 547–558.

Ballard, G. 1997. “Lookahead planning: the missing link in production control.” *Proceedingsof the 5th Annual Conference of the International Group for Lean Construction*, 1–14. Gold Coast, Australia.

Ballard, G. 2000. *The Last Planner System of production control. Ph.D. dissertation, Faculty of Engineerimg, The University of Birmingham, UK.*

Cândido, L. F., L. F. M. Heineck, and J. De Paula Barros Neto. 2014. “Critical analysis on earned value management (EVM) technique in building construction.” *22nd Annual Conference of the International Group for Lean Construction: Understanding and Improving Project Based Production, IGLC 2014*, 159–170.

Cheng, A., M. Auerbach, E. A. Hunt, T. P. Chang, M. Pusic, V. Nadkarni, and D. Kessler. 2014. “Designing and conducting simulation-based research.” *Pediatrics*, 133 (6): 1091–1101. https://doi.org/10.1542/peds.2013-3267.

Cheng, M., Y. Chang, and D. Korir. 2019. “Novel Approach to Estimating Schedule to Completion in Construction Projects Using Sequence and Nonsequence Learning.” *J Constr Eng Manag*, 145 (11): 04019072. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001697.

Chitla, V. R., and T. S. Abdelhamid. 2003. “Comparing process improvement initiatives based on percent plan complete and labour utilization factors.” *Proceedings of the 11th annual Conference of the International Group for Lean Construction*, 118–131. Blacksburg, USA.

Ezzeddine, A., L. Shehab, G. Lucko, and F. Hamzeh. 2022. “Forecasting Construction Project Performance with Momentum Using Singularity Functions in LPS.” *J Constr Eng Manag*, 148 (8). American Society of Civil Engineers (ASCE). https://doi.org/10.1061/(asce)co.1943-7862.0002320.

Hamzeh, F. 2009. “Improving Construction Workflow- The Role of Production Planning and Control.” Doctoral Dissertation, UC Berkeley.

Hamzeh, F., G. Ballard, and I. D. Tommelein. 2008. “Improving Construction Work Flow – The Connective Role of Lookahead Planning.” *Proceedings of the 16th Annual Conference of the International Group for Lean Construction*, 635–646. Manchester, UK.

Hamzeh, F., A. Ezzeddine, L. Shehab, S. Khalife, G. El-Samad, and S. Emdanat. 2020. “Early Warning Dashboard for Advanced Construction Planning Metrics.” *Proceedings of the Construction Research Congress*, 67–75. Reston, VA: American Society of Civil Engineers: Reston, VA: American Society of Civil Engineers.

Hamzeh, F., M. Al Hattab, L. Rizk, G. El Samad, and S. Emdanat. 2019a. “Developing new metrics to evaluate the performance of capacity planning towards sustainable construction.” *Journal of Cleaner Production 225,* 868–882. https://doi.org/10.1016/j.jclepro.2019.04.021.

Hamzeh, F., G. El Samad, and S. Emdanat. 2019b. “Advanced Metrics for Construction Planning.” *J Constr Eng Manag*, 145 (11): 04019063. https://doi.org/10.1061/(asce)co.1943-7862.0001702.

Hamzeh, F., E. Zankoul, and C. Rouhana. 2015. “How can ‘tasks made ready’ during lookahead planning impact reliable workflow and project duration?” *Construction Management and Economics*, 33 (4): 243–258. https://doi.org/10.1080/01446193.2015.1047878.

Howell, G., and G. Ballard. 1996. “Can Project Controls Do Its Job?” *International Group of Lean Construction*, 13. Birmingham, England: Proceedings of the 4th Annual Conference of the International Group for Lean Construction.

Kim, Y. W., and G. Ballard. 2000. “Is The Earned-Value Method An Enemy Of Work Flow?” *Proceedings of the 8th Annual Conference of the International Group for Lean Construction (IGLC-8)*, 17–19.

Lipke, W. 2003. “Schedule is different.” *The measurable news*, 31 (4): 31–34.

Rozenes, S., G. Vitner, and S. Spraggett. 2006. “Project control: literature review.” *Project Management Journal*, 37 (4): 5–14.

El Samad, G., F. Hamzeh, and S. Emdanat. 2017. “Last Planner System – the Need for New Metrics.” *Proceedings of the 25th Annual Conference of the International Group for Lean Construction*, 637–644. Heraklion, Greece.

Shannon, R. E. 1998. “Introduction to the art and science of simulation.” *Winter Simulation Conference Proceedings*, 7–14. Washington, D.C., USA.

Shehata, M. E., and K. M. El-Gohary. 2011. “Towards improving construction labor productivity and projects’ performance.” *Alexandria Engineering Journal*, 50 (4): 321–330. Elsevier. https://doi.org/10.1016/J.AEJ.2012.02.001.