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DEVELOPING AND TESTING MURI PUZZLE GAME

Jose Torres [1], Suryeon Kim [2], David Jeong [3], and Zofia Rybkowski [4]

ABSTRACT

Muri, a Japanese term meaning overburden, is often overlooked in construction projects due to its intangible nature. Project participants rarely have opportunities to reflect on Muri, and it is difficult to measure its effects on project performance—such as time and cost. One effective way to enhance awareness of Muri and help project participants understand its impact is through educational simulation games. This approach allows participants to actively engage in decision-making and observe the consequences of their actions through embedded feedback mechanisms. This research introduces the Muri Puzzle Game, an educational simulation designed to teach the concept of Muri and raise awareness of its impact on the time-cost trade-off. Specifically targeting Muri in labor, the game was tested with 43 participants, with data collected through pre-and post-questionnaire surveys. The experimental results indicate that the Muri Puzzle Game effectively enhances participants' understanding of Muri in labor and its influence on project performance, particularly regarding time-cost trade-offs. These findings contribute to the body of knowledge on Muri by providing a practical tool to facilitate its recognition and improve workforce management in construction projects.

KEYWORDS

Muri, Overburden, Educational Simulation Game, Time-Cost Trade-off

INTRODUCTION

Muri, a Japanese term meaning "overburden," describes situations where production systems—whether machines or workers—are pushed beyond their capacity or capability (Melo et al., 2020; Radin Umar et al., 2024). In the construction industry, Muri refers to excessive strain on resources, leading to inefficiencies, safety risks, and waste. It can affect critical resource flows in construction activities, including labor, information, tools, materials, space, and time (Liker, 2004). Minimizing Muri through balanced workloads, optimized processes, and prevention of resource overuse is essential for enhancing construction project productivity.

Paradoxically, the starting point for addressing Muri lies in the pursuit of continuous improvement (Katayama, 2017). Stakeholders often allocate additional resources, assuming that doing so will consistently improve outcomes. In construction projects, additional resources are often deployed to achieve specific goals, such as reducing construction time or minimizing costs. While this strategy can be effective within an optimal range, exceeding this range may result in diminishing returns and unintended consequences. Distinguishing between

[1] Undergraduate Student, Department of Construction Science, Texas A&M University, College Station, TX, USA, jtorr312@tamu.edu

[2] Postdoctoral Research Associate, Department of Construction Science, Texas A&M University, College Station, TX, USA, kimsuryeon@tamu.edu, orcid.org/0009-0002-2231-6674

[3] Professor, Department of Construction Science, School of Architecture, Texas A&M University, College Station, TX, USA, djeong@tamu.edu, orcid.org/0000-0003-4074-1869

[4] Professor, Department of Construction Science, School of Architecture, Texas A&M University, College Station, TX, USA, zrybkowski@arch.tamu.edu, orcid.org/0000-0002-0683-5004

overburdening and optimal resource allocation is a critical challenge in this context. Thus, understanding and applying the optimal balance between project resources and Muri is crucial.

Despite the significance of Muri and its impact on the dynamics of the key project performance indicators, particularly, the time-cost trade-off, it often goes unnoticed in construction projects. This oversight occurs because project participants rarely have the opportunity to reflect on Muri, given its intangible nature and the difficulty of recognizing and measuring its effects. Additionally, quantifying its impact on key performance metrics, such as time and cost, remains challenging, further complicating efforts to identify and mitigate it effectively. These challenges hinder the proactive prevention of Muri, increasing its potential to disrupt project efficiency, safety, and cost-effectiveness. To address this issue, it is essential to develop strategies that raise awareness of Muri and its influence on the time-cost trade-off.

One promising approach is the use of educational simulation games, which are specifically designed to enhance learning rather than simply entertain. These games provide immersive, hands-on experiences that actively engage learners while making complex concepts more accessible and enjoyable (Kim et al., 2025; Rybkowski et al. 2021). Educational simulation games are particularly effective for illustrating abstract concepts such as Muri, as they allow participants to experience and manage overburden in a controlled, risk-free environment.

In this context, this research develops and evaluates the Muri Puzzle Game, an educational simulation designed to raise awareness of Muri and its impact on the time-cost trade-off. The game specifically targets Muri in labor, one of the critical resources in construction projects. To assess its effectiveness, the game was tested with 43 participants, with data collected through pre- and post-questionnaire surveys. This study has two primary objectives: (1) To develop the Muri Puzzle Game as an educational tool to enhance awareness of Muri and its influence on time and cost in construction projects; (2) To evaluate the game's effectiveness in helping participants understand the concept of Muri in labor and its relationship to the time-cost trade-off. This research contributes to the body of knowledge on Muri by providing a practical tool to foster its recognition, ultimately supporting improved project efficiency and decision-making in the construction industry.

LITERATURE REVIEW

MURI-OVERBURDEN AND ITS IMPACT ON TIME AND COST

Lean can be defined as the systematic elimination of waste throughout a process. Waste in Lean is categorized into three types: Muri (overburden), Mura (unevenness or inconsistency), and Muda (waste) (Hamzeh, 2009; Schaefer et al., 2008). Among these, Muri refers to the overburdening of people and processes, often resulting from pushing humans or equipment beyond their natural limits. This overburden can lead to safety issues, quality problems, longer time and additional costs. Muri is particularly critical because it can trigger system breakdowns, generating both Muda and Mura, which ultimately undermine overall project performance (Smith, 2014). Addressing Muri is therefore essential for optimizing the use of resources and fostering an efficient Lean approach (Hamzeh, 2009; Shehab & Hamzeh, 2023).

Muri often originates from the pursuit of improved performance. As individuals and teams strive for better outcomes, they may unintentionally overburden themselves or the resources at their disposal (Katayama, 2017). In construction projects, this often involves allocating additional resources to reduce construction time or costs. While such investments can be beneficial within an optimal range where benefits outweigh costs, exceeding this range may lead to opposite results from the intended goals. Thus, distinguishing between overburdening and necessary resource allocation is critical. Identifying the optimal balance, particularly from a time-cost trade-off perspective, is essential for ensuring both efficiency and effectiveness in project execution.

In the construction industry, Muri affects nine critical resources: labor, information, time, tools/equipment, materials, space, prerequisite work, external conditions, and shared understanding (Liker, 2004). Among these, Muri in labor is particularly significant, as it directly influences productivity and project outcomes. Labor inefficiencies, such as idle time or underutilization, often arise when tasks are not appropriately scheduled or sequenced. Addressing Muri in labor requires ensuring that tasks are performed at the right time and place, while also optimizing workplace organization for maximum efficiency (Mishra et al., 2020). By effectively managing labor resources, construction projects can mitigate overburden, reduce waste, and enhance overall performance outcomes.

EDUCATIONAL SIMULATION GAME

Educational simulation games are experimental, rule-based, and interactive environments used for training, planning, and problem-solving (Bhatnagar, 2022; Mayer, 2009). These games create a dynamic learning experience where participants take actions and observe the consequences of their decisions through feedback mechanisms intentionally embedded within the gameplay (Mayer, 2009). By fostering this hands-on learning environment, educational simulation games effectively bridge the gap between theoretical knowledge and practical application (Bhatnagar, 2022). Given the abstract and conceptual nature of lean construction principles, there has been an increasing adoption of educational simulation games in the industry. These games provide an effective means to translate lean concepts into practical understanding, helping construction personnel address real-world challenges and internalize lean methodologies. Moreover, they offer a risk-free environment for experimentation, allowing participants to build confidence through practice and iterative learning (Bhatnagar, 2022).

Various educational simulation games have emerged as effective tools for teaching lean construction principles. For instance, the Tower of Infinity uses LEGO bricks to simulate integrated project delivery (Van den Berg et al., 2017), while the Parade Game demonstrates the impact of workflow variability on trade performance (Tommelein et al., 1999). The Construction Contracts in a Competitive Market Game introduces competitive bidding strategies and emphasizes the importance of market share (Nassar, 2003). Similarly, the Bidding Simulation Game replicates first-price sealed-bid auctions in construction contracting (Oo & Lim, 2016), and the Lean Apartment Construction Simulation Game (LEAPCON) teaches pull planning and lean principles for interior finishing in high-rise buildings (Sacks et al., 2007). The Marshmallow TVD Simulation Game introduces participants to Target Value Delivery (TVD), demonstrating collaborative approaches to achieve project outcomes (Munankami, 2012; Kim et al., 2025; Kim et al, 2023). Additionally, the Sustainability Challenge Game focuses on integrating sustainability concepts into construction practices (Dib & Adamo-Villani, 2014), while a game by Al-Jibouri and Mawdesley (2001) teaches project planning and control through role-playing scenarios. Recent advancements include VR-based lean simulations, such as virtual reality hazard inspection training (Pedro et al., 2016). These diverse games collectively contribute to the effective teaching and application of lean construction concepts.

Despite the growing body of literature of educational simulation games in construction, a critical gap remains in addressing Muri and its role in time-cost trade-off. While existing games effectively convey various lean principles, few specifically focus on Muri, the overburdening of resources and its impact on project performance. This research aims to fill that gap by developing an educational simulation game designed to teach the concept of Muri.

RESEARCH METHODOLOGY

MURI PUZZLE GAME

This research involved developing and testing an educational simulation game, the Muri Puzzle Game. The objective of the game is to help project participants understand Muri and its effects on time and cost in construction projects.

The Muri Puzzle Game consists of two rounds in which participants must solve a 60-piece puzzle as quickly and accurately as possible. The required materials for the game include identical 60-piece puzzles for each group, and a stopwatch. Participants are divided into groups of varying sizes, with each group tasked with completing the puzzle collaboratively. Before starting the first round, the facilitator divides the participants into multiple groups with different numbers of members. For example, if there are 15 participants, they could be split into five groups: Group A with 1 participant, Group B with 2 participants, Group C with 3 participants, Group D with 4 participants, and Group E with 5 participants. Participants are allowed to freely choose their group, provided there is space available in their desired group.

In the first round, each group receives an identical 60-piece puzzle and is asked to solve it. Using a stopwatch, each group records the time taken to complete the puzzle. At the end of the first round, the facilitator collects the recorded completion times from all groups and engages in a brief discussion. The facilitator asks questions to the smallest group (e.g., Group A) and the largest group (e.g., Group E), such as: (1) Why did you choose this group size? and (2) What do you think is the optimal number of participants to solve the 60-piece puzzle?

Following the discussion, the facilitator introduces the concepts of direct and indirect costs. Direct cost is tied to the number of participants and the time taken to complete the puzzle. For example, with a cost of $20 per second per participant, direct cost is the product of $20, number of participants, and time. Indirect cost is associated with the time spent solving the puzzle and increases proportionally with the completion time. For example, as shown in Table 3, indirect costs might be $75 per second, meaning longer completion times lead to higher indirect costs.

The second round follows the same process but with a different—yet similar—set of puzzles to ensure consistency. To minimize bias, participants are allowed to re-select their groups, and the group composition is mixed. Groups A through E are again available, and participants have the freedom to choose their group. As in the first round, each group completes the puzzle while recording their completion time. At the end of the second round, the facilitator gathers the recorded data and shows the results, as shown in Table 3 and Figures 1 and 2. The facilitator leads another discussion, asking questions such as: (1) What made you change your group (if applicable)? (2) What do you now think is the optimal number of participants to solve the puzzle? (3) Why do you think the largest group did not achieve the best results, despite having more participants?

The discussion after both rounds helps participants reflect on resource allocation and the trade-offs between group size, time, and associated costs. This fosters a deeper understanding of Muri and its implications for resource management, reinforcing the importance of balancing efficiency and overburdening in construction projects.

PRE-AND POST- GAME QUESTIONNAIRE SURVEY

The research team conducted pre- and post-questionnaire surveys to assess the effectiveness of the Muri Puzzle Game. Participants were asked to complete both questionnaires, which measured their background knowledge and knowledge retention using a 5-point Likert scale. Table 1 presents the structure of the pre- and post-questionnaires.

Table 1: Structure of Questionnaires

Questionnaire	Questions
Pre-Game Questionnaire	Experience on puzzle and game-based learning
Pre-Game Questionnaire	Level of understanding on Muri (overburden) in construction projects
Pre-Game Questionnaire	Level of understanding on time-cost trade-off
Post-Game Questionnaire	Overall satisfaction with the Muri Puzzle Game
Post-Game Questionnaire	Level of understanding on Muri (overburden) in construction projects
Post-Game Questionnaire	Level of understanding on time-cost trade-off

EXPERIMENT AND DATA COLLECTION

To evaluate the effectiveness of the Muri Puzzle Game, students from Texas A&M University's Construction Science program were recruited. Participants completed pre- and post-game questionnaires to assess their initial understanding of Muri and their experience after engaging with the game. In total, 43 valid responses were collected for both the pre- and post-game questionnaires. The data collection process was meticulously controlled to ensure accuracy and reliability. Detailed instructions were provided to all participants, ensuring they understood how to complete each questionnaire accurately. Additionally, during the gameplay, the time taken to complete the puzzle was recorded by the facilitator to gain further insights into performance trends and efficiency.

ANALYSIS AND RESULT

EFFECTIVENESS OF MURI PUZZLE GAME

To assess whether the Muri Puzzle Game effectively enhances participants' understanding of Muri in labor, a paired two-sample t-test was conducted. The analysis compared participants' understanding levels before and after the game, with the mean differences between pre- and post-questionnaire responses presented in Table 2.

The results indicate a statistically significant improvement in participants' understanding of Muri. Prior to the game, the mean understanding score was 2.05 (standard deviation = 1.18), whereas after the game, it increased to 4.26 (standard deviation = 0.72). This significant gain tells that the Muri Puzzle Game effectively enhances comprehension of Muri and its implications in labor-intensive tasks.

Table 2: Result of Paired Samples T Test – Understanding of Muri

	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		Significance	
				Lower	Upper	One-sided p	Two-Sided p
Understanding of Muri (Post - Pre)	2.21	1.42	0.23	1.74	2.68	<.001	<.001

MURI IN LABOR AND TIME- COST TRADE-OFF

To examine whether the Muri Puzzle Game effectively illustrates the relationship between Muri in labor and the time-cost trade-off, experimental results from the two rounds of the game were analyzed. Table 3 and Figure 1 present the experimental data collected during the study.

The results of the Muri Puzzle Game highlight the relationship between Muri in labor and time-cost efficiency.

Group A, with one participant, experiences "Low" Muri, indicating minimal overburdening and achieving the lowest total cost. However, this outcome is highly dependent on the competency of the individual worker, which may introduce variability in productivity. Group E (six participants) and Group F (seven participants) experience "High" Muri due to overcrowding, which negatively impacts efficiency and increases both direct and total costs. The time taken to complete the task varies across the groups, with Group B (798 seconds) recording the longest completion time, indicating severe inefficiencies. In contrast, Group C (three participants) and Group D (four participants) achieves a shorter completion time compared to other groups, demonstrating a relatively balanced performance between efficiency and cost.

Direct costs increase with the number of participants, as they are calculated based on both time and the number of workers. Group E incurs the highest direct cost ($76,680). Group C, with three participants, maintains a moderate direct cost ($25,740), striking a reasonable balance. Indirect costs, which are proportional to the time spent completing the task, are highest for Group B ($59,850) due to its long completion time (798 seconds) and lowest for Group D ($27,975) due to its shorter completion time (373 seconds). Group A exhibits the lowest direct cost ($7,120), as it had only one participant who completed the puzzle in the least amount of time. However, this result is an outlier, likely influenced by individual competency and task familiarity, suggesting that further experimentation is needed to validate these findings.

Table 3: Experimental Results of the Muri Puzzle Game

Team	**A**	**B**	**C**	**D**	**E**	**F**
Number of Members	1	2	3	5	6	7
Level of Muri in Labor (overburden)	Low					High
Time (sec)	356	798	429	373	639	519
Direct Cost ($20/sec/person)	$7,120	$31,920	$25,740	$37,300	$76,680	$72,660
Indirect Cost ($75/sec)	$26,700	$59,850	$32,175	$27,975	$47,925	$38,925
Total Cost	**$33,820**	**$91,770**	**$57,915**	**$65,275**	**$124,605**	**$111,585**

Total cost, which combines direct and indirect costs, serves as an indicator of overall efficiency. Group C ($57,915) achieves a relatively low total cost compared to the other groups, whereas Group E ($124,605) and Group F ($111,585) exhibit the highest total costs due to labor inefficiencies. Although Group D ($65,275) does not have the absolute lowest total cost, it demonstrates an effective balance between labor allocation and time efficiency.

The experimental results indicate that an optimal group size minimizes both direct and indirect costs, resulting in the lowest total cost. Group C (3 participants) demonstrates this balance effectively, achieving moderate efficiency at a relatively low total cost. This finding underscores the importance of managing Muri in labor to achieve cost-effective resource allocation and improve project performance.

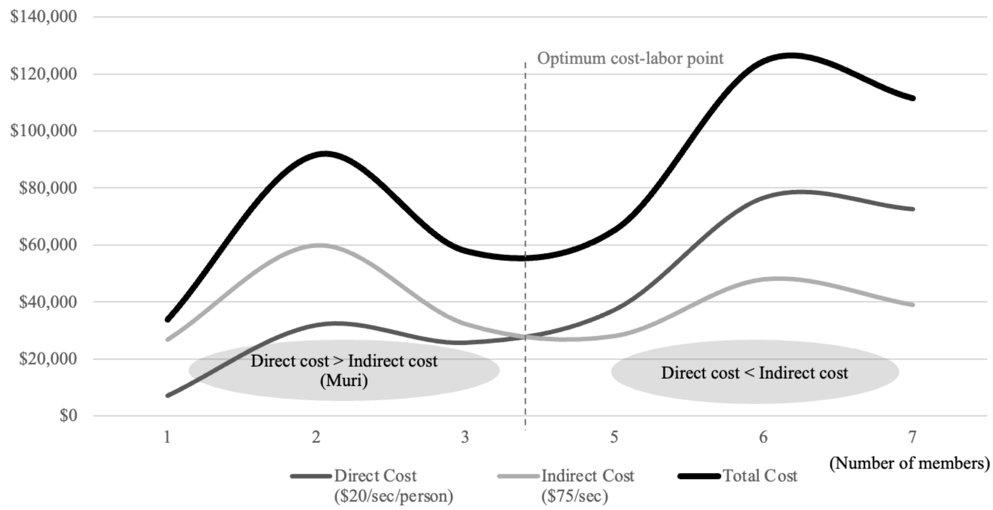

Figure 1: Muri in Labor and Cost

To assess participants' understanding of the Time-Cost Trade-Off, two statements were presented in the pre- and post-questionnaires: (1) "We can complete work FASTER if there are MORE PEOPLE in a construction project." and (2) "We can complete work with LESS MONEY if there are MORE PEOPLE in a construction project."

Before playing the Muri Puzzle Game, participants expressed mixed opinions on these statements. For the first statement, 50% of participants agreed, while 27% disagreed, indicating that many initially believed adding more people would speed up work, though some remained skeptical. For the second statement, 47% of participants disagreed that adding more people would reduce costs, while 24% agreed, suggesting that a considerable portion of participants recognized that increasing workforce size could lead to higher costs rather than savings.

After completing the Muri Puzzle Game and the debriefing session, participants reconsidered their views based on the experiment's outcomes. Many noted that simply increasing the number of people does not necessarily lead to greater efficiency or lower costs. Some key responses included:

- *"In the experiment, we found that adding more people does not directly reduce costs."*
- *"If there are a lot of people, efficiency increases, but costs also increase."*
- *"There is an optimal number of workers for a project; having too many or too few increases both cost and time."*

The responses highlight a shift in participants' understanding after engaging with the game. While many initially assumed that adding more people would lead to faster completion and lower costs, the experiment demonstrated that optimal team size, coordination, and strategic resource allocation play more critical roles in achieving efficiency.

Interestingly, many participants emphasized the importance of collaboration, coordination, and communication in project efficiency:

- *"Coordination is the key, followed by efficiency and resource allocation."*
- *"Productivity depends on efficiency, planning, delegation of work, and skill level."*
- *"More people can lead to confusion and leave some members standing around doing nothing. A smaller team that divides the work into manageable pieces is more cost- and time-effective."*

These insights reinforce the idea that simply increasing labor does not guarantee better outcomes. Instead, effective workforce management, proper task distribution, maintaining an optimal team size, and effective communication and collaboration plans are essential for balancing time and cost efficiency in construction projects.

DISCUSSION

While this game is not an exact simulation of a construction project, it effectively represents key project elements. On a job site, there are materials (the puzzle), labor (the participants), cost, and time, all of which are mirrored in the game. After playing the game and comparing their time and cost with those of other groups, participants expressed that they experienced an "A-ha" moment as they recognized the implications of Muri. As participants engaged in the game, they typically reached key conclusions about Muri in labor. Whether working with too many people or too few, students realized the consequences of both overburdening and under-resourcing, leading to a deeper understanding of optimal workforce allocation.

A critical takeaway for the construction industry is recognizing how Muri influences every aspect of project delivery. Muri should be identified early in the project and monitored consistently throughout execution. Doing so helps minimize cost and duration, which can have a domino effect on reducing rework, improving quality control, enhancing safety, and mitigating potential liability.

One interesting finding of this research is the impact of Muri on the time-cost trade-off in construction projects. The time-cost trade-off is a fundamental concept in project management, playing a crucial role in construction planning and control. Traditionally, the time-cost trade-off curve follows a convex shape, illustrating the relationship between direct costs, indirect costs, and total costs relative to project duration. The total cost curve is typically U-shaped, where the lowest point represents the optimal time-cost balance, minimizing both direct and indirect costs (Burns et al., 1996). However, as illustrated in Figure 2, the Muri time-cost trade-off forms a sideways S-shape in terms of direct and total costs. This sideways S-shape highlights how overcrowding, excessive coordination efforts, and resource misallocation can disrupt the expected time-cost efficiency. Even when more workers are available, factors such as miscommunication, workspace congestion, and inefficient task delegation may prevent optimal performance, leading to higher-than-expected costs and extended durations.

In addition, insights from motivation and behavioral science help explain this deviation, suggesting that performance on cognitive or problem-solving tasks does not scale linearly with the addition of resources—unlike simple, repetitive tasks (Pink, 2011). Traditional time-cost trade-off models often assume that adding more workers improves efficiency up to a certain point before diminishing returns occur. However, this assumption fails to account for tasks that require planning, strategic thinking, and real-time coordination. The Muri Puzzle Game introduced a cognitively demanding activity, rather than a mechanical one, which likely contributed to the atypical time-cost trade-off curve observed in this study. In such contexts, adding more participants can actually create inefficiencies due to increased communication overhead, loss of individual accountability, or cognitive overload, rather than improving performance (Pink, 2011). Variability between individual performance due to cognitive loading also introduces a confounding variable that would likely not occur for a simple, repetitive task.

This finding underscores the need for careful workforce planning and balanced labor distribution to achieve an optimal time-cost trade-off, rather than assuming that more resources will always lead to better outcomes. Future research should explore larger datasets and real-world project applications to validate these insights and refine workforce management strategies. Conducting additional Muri Puzzle Game simulations with varied task types could also help uncover the mechanisms behind these effects. Furthermore, the findings suggest that task complexity must be carefully considered when applying time-cost trade-off models in construction. Many construction activities require not only physical labor but also cognitive engagement, coordination, and decision-making—making the influence of Muri even more pronounced. Future studies could investigate whether the type of task—cognitive versus mechanical—affects the shape of the time-cost trade-off curve, offering deeper insights for optimizing labor strategies in construction management.

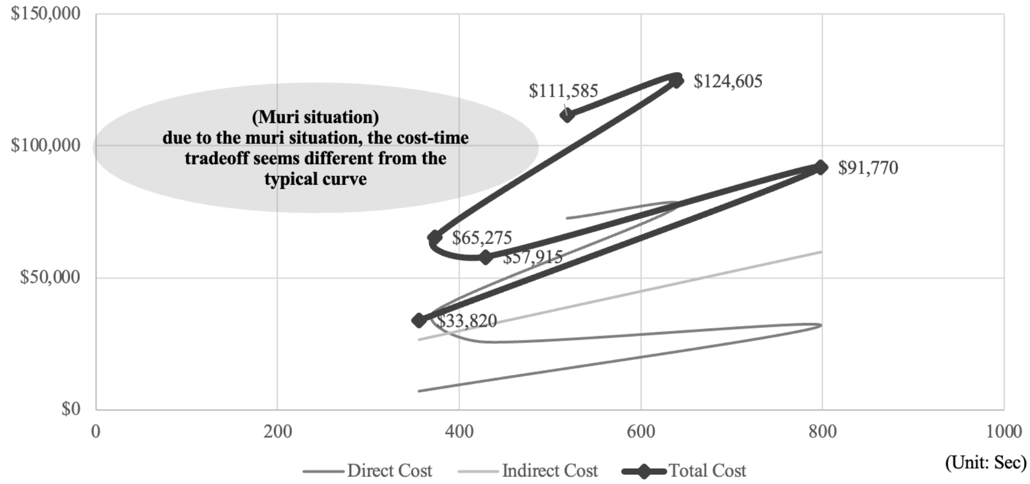

Figure 2: Time-Cost Trade-Off in Muri in Labor Situation

CONCLUSION

Muri is often overlooked in construction projects due to its intangible nature and the difficulty of recognizing its effects on time and cost efficiency. This study underscores the importance of identifying and managing Muri to improve workforce allocation and cost-effectiveness. The Muri Puzzle Game, developed as an educational simulation tool, successfully demonstrates how Muri in labor influences the time-cost trade-off, providing a hands-on learning experience for project participants.

The experimental results indicate that engaging in the game significantly enhances participants' understanding of Muri, particularly in labor perspective. The findings indicate that by playing the game, the players can understand that increasing workforce size does not necessarily lead to improved performance, as overcrowding can create inefficiencies and raise costs. Conversely, under-resourcing places excessive strain on individuals, resulting in variability in productivity and increased completion times. Through direct and indirect cost analysis, the study highlights the critical role of optimal labor distribution in achieving a balance between cost and efficiency in construction projects.

Future research can expand on these findings by exploring the effects of Muri across diverse construction environments, examining its interplay with other Lean principles, and developing additional simulation-based tools to support experiential learning. Further studies involving larger and more diverse participant groups, as well as real-world case studies, could enhance the generalizability and applicability of the insights gained from this research. In addition, controlling for participants' prior knowledge of Muri and Lean Construction would help mitigate potential biases and provide a clearer understanding of the game's educational impact. Finally, it would be worth repeating the experiment with a simple, repetitive task, such as inserting pegs into a pegboard, to eliminate the confounding variable of cognitive loading.

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