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Article

A Conceptual Model for Safety-Based Theory of Lean Construction

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Abstract: The construction industry is one of the most fatal industries, so it is important to pay more attention to safety solutions. Even though work-related accidents are known as major waste in construction projects, little attention has been paid so far to incorporating safety into the lean construction framework. In this research, lean construction theory is reviewed through the lens of safety. That being so, the identified challenges in previous research on improving safety in construction projects are categorized and those related to the concept of lean project delivery are introduced. Then, the principles of the lean construction framework are explained and the relevant changes for incorporating safety into the framework are introduced and discussed. It is expected that this hybrid model would further enrich the lean construction framework. The careful attention of project executives to this model may improve the safety situation in construction projects.

Keywords: Prevention through Design; Safety Climate; Lean Construction; Transformation-Flow-Value; Lean Project Delivery System.

1. Introduction

Despite extensive research on safety in the construction industry, the incidents are still one of the main problems of the industry and the mortality rate is about 5 times the average of other industries [1], causing about 8 to 15 percent increase in project cost in countries such as the United States [2]. With regard to these consequences, some researchers have focused on proactive and preventive approaches such as safety climate or Prevention through Design (PtD) that can prevent the occurrence of about 40% of accidents [3]. On the other hand, in recent years, some studies have studied the effects of lean construction techniques on safety performance of projects [4-6]; however, there is lack of a comprehensive approach that explains the relationship between the lean construction framework and safety improvements. Accordingly, this study attempts to introduce a conceptual model by reviewing the theory of Transformation-Flow-Value (TFV) with a safety approach for demonstrating the relationship between this theory and improving safety in the construction process.

At first, the literature on safety issues, and more specifically the PtD approach, safety climate and Cost of Safety (CoS) are investigated and barriers to PtD implementation and factors affecting the positive safety climate are extracted. Then, the theory of TFV in lean construction is studied and the Lean Project Delivery System (LPDS) and its benefits are reviewed. Finally, the relationship between LPDS with PtD and the safety climate, and the TFV approach based on safety, will be presented in the form of a conceptual model.

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2. Safety in construction projects

Over the past decade, the focus for safety improvement has been changed from using passive to active measures such as safety climate. This shift has happened by understanding that organizational, managerial, and human factors are the main culprits of the construction industry's incidents rather than purely technical factors [7]. Numerous studies have been done on the effects of safety culture and safety climate on safety outcomes. Wiegmann et al. [8] described the climate of safety as a psychological phenomenon, which includes the general understanding of team members of the safety situation at a specific time in the workplace. Mohamed [9] identified ten potential factors that could affect the safety climate of Australian construction projects; including: (1) management commitment; (2) communication; (3) employee participation; (4) supportive environment; (5) personal awareness of risks; (6) work pressures; (7) supervisory atmosphere; (8) risk assessment; (9) competency of employees; and (10) safety rules and regulations. A positive and constructive safety climate is created when appropriate interactions between project partners and project team members are created to support safety at the front-end of the project.

On the other hand, according to Howell et al. [4], there are two basic ways to prevent injuries: (1) prevention through design, and (2) prevention through task planning. In other words, improving product design and construction planning can play a decisive role in preventing incidents in the project. While a large percentage of safety research has focused on the construction phase of the projects, much less attention has been paid to the early phases, including the planning and design phases [e.g. 10, 11]. Research findings in this area indicate that safety planning and careful attention at the pre-construction stages has significant impacts on safety in terms of reducing the incidents throughout the life cycle of the project [3, 12, 13]. For example, Abdelhamid and Everett [14] proposed a model for identifying the root causes of accidents which could provide a template for systematic and rapid determination of areas requiring more investigations, so that labour and management may put more effective measures in place for preventing probable accidents. Safety in Design (SiD) or Prevention through Design (PtD) can be defined as "the integration of hazard analysis and risk assessment methods early in the design and engineering stages, and taking the necessary actions to keep risks of injury or damage at an acceptable level" [15]. Gambatese & Hinze [16] indicated that the use of knowledge of construction workers and designers in the early stages of a project can be a positive step towards improving safety performance. Another problem is the designers' reluctance to engage in safety due to the avoidance of litigation and claims [12]. Having this said, the clients can play an active role in safety improvements by choosing an appropriate contract method, since the emphasis on safety during contracting phase with a contractor or designer has a significant impact on their safety performance [12, 17]. Some studies have also shown that contract type has an impact on safety performance. For example, Huang [17] showed that Design-Build contracts have better safety practices, since in these types of contracts the contractor and the designer play on the same ground and the design team has more motivations to devise safe plans in the design phase.

The effective and optimal use of preventive approaches to achieve the best results can be estimated through the concept of CoS. Most of clients believe that spending money on safety does not create value for their business unless it is required by governmental regulations and standards [18]. This view has made problems for safety managers to provide financial justification for the investments. The most common and effective cost model that has been developed to describe the cost-benefit concept of accident prevention is the CoS model [19]. Behm et al. [20] used Cost of Quality (CoQ) classification for categorizing the safety cost into four categories of prevention and inspection costs, and internal and external failure costs. They studied the CoS model in several case studies and the results showed that the accident prevention strategy provides an optimum safety cost plan. As shown in Figure 1, the cost of safety is equal to the total cost of prevention and inspection, and direct and indirect costs of damage and the optimal point occurred at the intersection of two charts, although the location of this point can vary in different projects [21].

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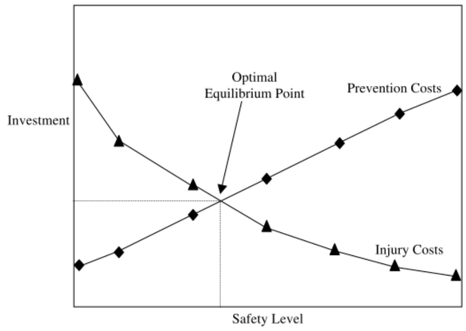

Figure 1. Cost of Safety Model [19, 20]

3. Lean construction

In general, the purpose of a lean approach is to create the highest value for the customer and reduce or eliminate the waste. Koskela [22] introduced a new theory of production in construction context called TFV, which resulted in the integration of three theories of transformation, flow and value creation. In this theory, transformation means the conversion of input into output in production, and the management method is based on using hierarchical transformation of smaller components (Figure 2-A). However, this method has limitations in recognizing the original source of value in conversion process which is the extent to which the conversion is adapted to the customer's needs and demand. Also, there is weakness in how to avoid loss and ensure customer satisfaction.

The flow view considers production as a stream of materials and a combination of transformation, inspection, moving, and waiting (Figure 2-B). In this view, in order to achieve the main goal of eliminating waste, some methods are used to reduce the production process time (lead time), reduce variability, and increase simplification [22, 23].

Finally, in the value creation view, the creation of the highest possible value is measured by taking into account the customer's expectations (Figure 2-C).

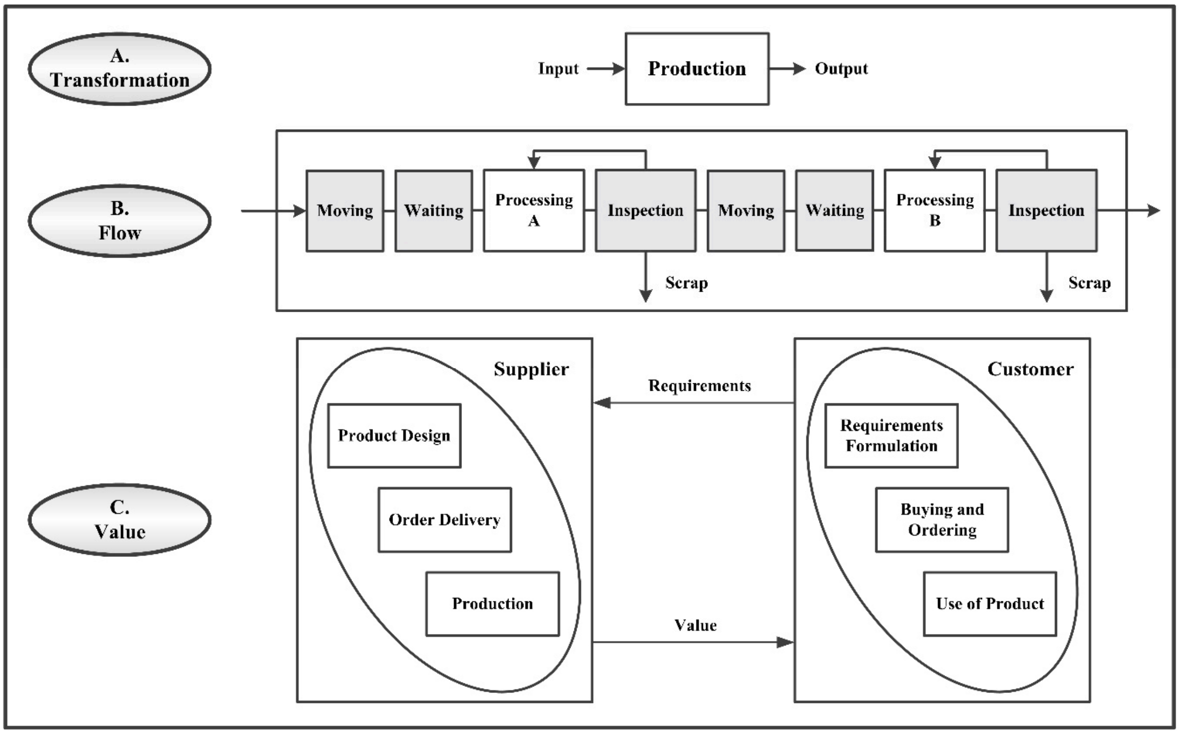

Figure 2. Transformation, Flow and Value creation [22, 24]

In this perspective, the endeavour is to identify the customer's needs by adopting appropriate methods and tools and to create the expected value for the customer by defining the appropriate

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processes for designing, ordering and producing. The theory that integrates and combines the three above-mentioned views is the TFV theory and any system in the field that pursues the TFV's goals is approaching the lean system [22]. On the other hand, it is difficult to maximize value and reduce waste at project level when the contractual structure impedes the coordination and creativity of project team members. Therefore, choosing the right method of procurement can help overcome many of the construction problems. In this regard, Integrated Project Delivery (IPD) and Lean Project Delivery System (LPDS) have been defined as lean approaches to designing a delivery system. LPDS which was presented by Ballard [25] aims to form an expert team in the early stages of the project, driven by principles such as collaboration, trust, communication, transparency, and the use of the best available technology for achieving optimal project success [26].

4. lean construction and safety performance

As explained, the adoption of preventive approaches to design and planning processes can play a decisive role in improving safety in the construction and operation phases of the project. The question now is how the barriers to implementing preventive approaches, including negative safety climate, the knowledge gap between designers and contractors, the lack of interactions between project participants in the early phases, and the litigation risks among key stakeholders can be resolved.

Previous research showed that lean techniques and practices have the potential to improve safety performance of projects and reduce accidents as noticeable sources of waste [10, 27]. For example, Nahmens & Ikuma [5] showed that continuous improvement which is embedded in lean approach can significantly reduce the rate of accidents in construction projects. Lean perspective can also help manage safety, which is dependent on the management of uncertainty, as it contributes to preventative planning and reducing work flow variability [27]. On the other hand, LPDS can prompt all key stakeholders to participate actively in the risks and benefits of the project and consider themselves part of a team and become sensitive to the performance of other members [28]. As a result, LPDS, not only has the potential to promote the positive safety climate in the project, but also can improve the PtD performance with providing the opportunity for two-way communications between designers and contractors and transferring knowledge and experience between them (Figure 3).

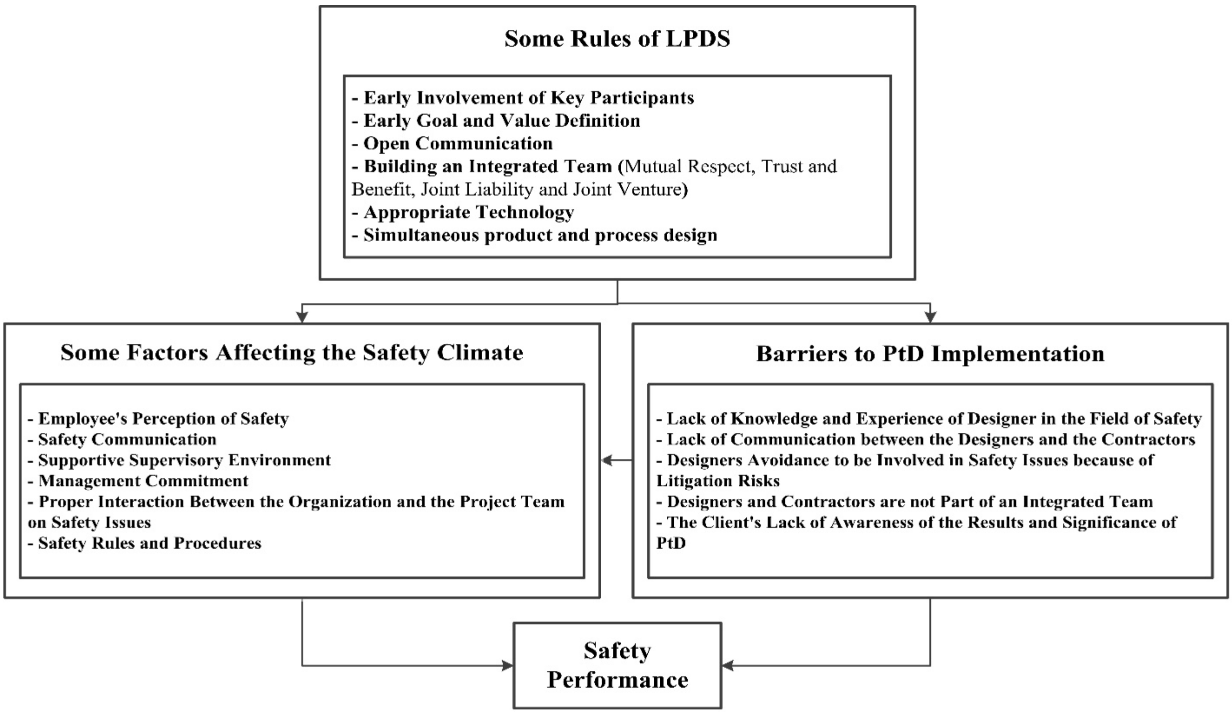

Figure 3. Improving safety performance through LPDS

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In addition, given the fact that one of the principles of LPDS is the simultaneous design of the product and the process, adopting preventive approaches at the early stages of the project would be more probable and safety risks can be identified and mitigated more effectively [23]. As mentioned earlier, despite the studies on the effect of lean approach on improving safety performance, the effect of incorporating safety in the principles of lean theory has not been studied. So, we will try to examine the possible changes in any of the transformation, flow, and value approaches by examining the theory of TFV from the perspective of safety and in the context of LPDS.

4.1. safety-based transformation

It is expected that by improving the quality of the production system, safety be significantly improved [29]. By introducing the T-view on LPDS, it is possible to increase the clarity of conversions in different phases of the project at the front-end of the project. For this purpose, it would be possible to take advantage of the existing methods available in this field, such as Building Information Modelling (BIM). The striking point here is how the transformation can be implemented at the safest possible way. One of the possible solutions can be modularization and pre-fabrication, which can reduce a significant portion of the site's risks and incidents. On the other hand, by defining the work breakdown structure and determining different work packages during the life cycle of the project - including the stages of construction, operation and recycling- we can estimate the probable risks of accidents in each work package and provide an optimal safety strategy in accordance with each package (Figure 4-A). For example, Aslesen et al. [30] developed a model for integrating safety analyses with systematic planning of production progress. In this model, certain principles were attached to each of the planning levels in the system of collaborative planning with respect to factors such as an extra consideration towards WBS to avoid hidden hazards.

4.2. safety-based flow

In the flow view, it is desired to improve the flow process and developing a reliable workflow which is dependent on waste (Muda), variability (Mura), and overburden to workers and machines (Muri), and on the other hand, reliable workflow cannot be achieved without safe work practices [6]. For example, Abdelhamid and Everett [31] asserted that the successful implementation of lean approach and developing a reliable workflow is dependent on the decrease in variability (Mura). Accordingly, they studied the workers' physical performance degradation as one of the most important causes of variability.

Ohno [32] identified 7 waste items including: (1) rework, (2) overproduction, (3) inventory, (4) overprocessing, (5) motion, (6) transportation, and (7) waiting, and the loss of employee's potential was later added to list by Womack & Jones [33]. According to Waehrer et al. [2], cost of injury was about 15% of the total cost incurred in private industry in the US. Therefore, it is worthwhile to consider accidents as one of the serious sources of waste in the construction industry. In this regard, it is proposed to add accidents as the 9th source of waste. We contend that the evaluation of the eight possible cases of waste cannot be accurate without considering safety and any attempt to reduce them may result in damage to the safety performance of the project. That is, some of them may not be considered as waste if we look at them through the lens of safety. For example, the route which is designed for the movement of machinery at the site can be different in length if it is viewed through the lens of safety or not. In this regard, safe planning may result in a longer route to mitigate the risk of crash with other vehicles or site workers, however, without considering this risk of accident, the shortest route may be preferred and any extra movements may consider as waste.

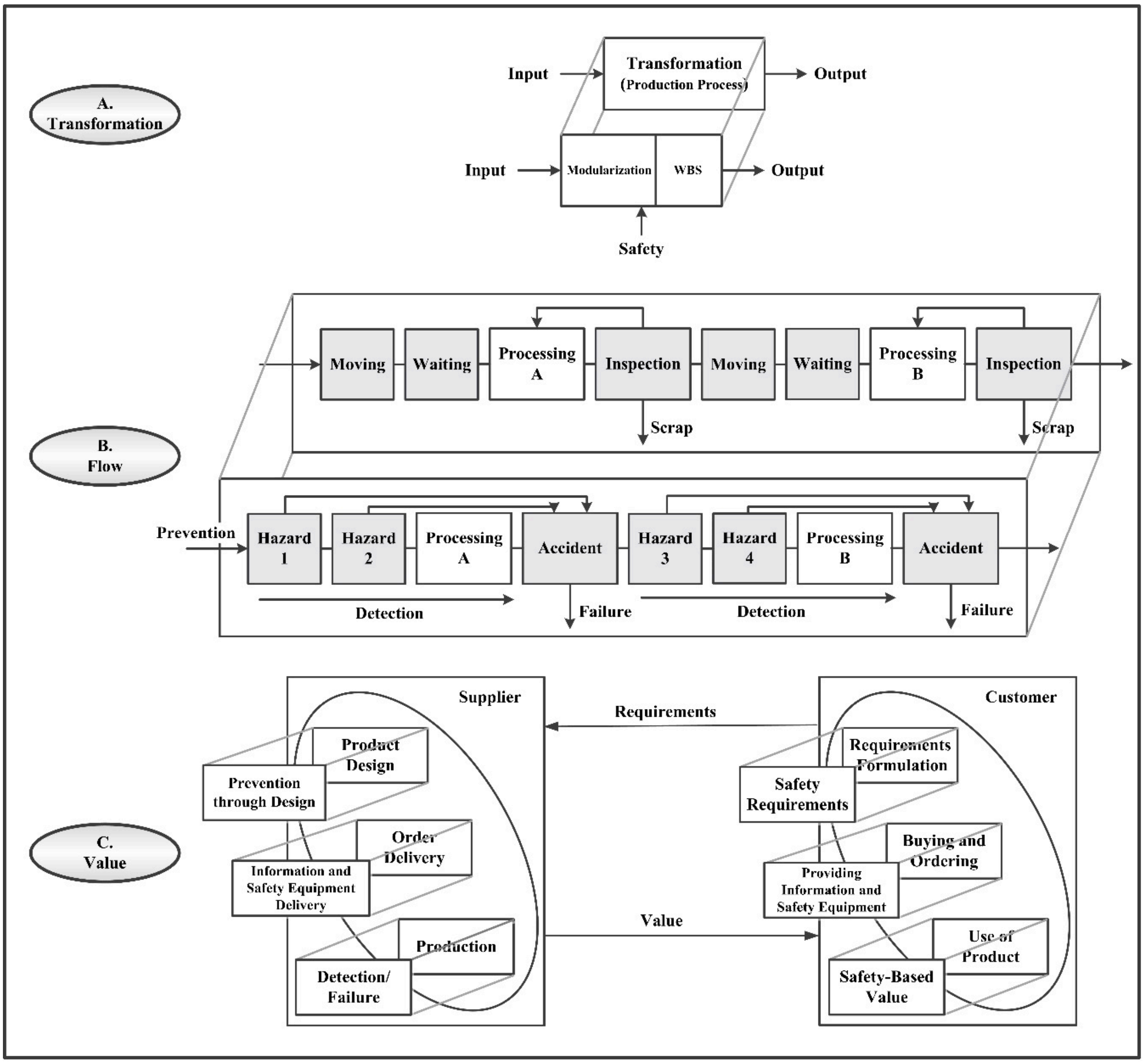

Figure 4. Safety-based theory of lean construction

Another point that can be taken into account in this view is CoS. As stated earlier, CoS considers four sources of cost including cost of prevention and inspection, and internal and external failure costs [20]. One of the points which is addressed in Figure 4-B is the possibility of preventing some of the incidents that are predictable through preventative measures at the start of the process. When the necessary measures to prevent accidents are not sufficient, it is more likely to have accidents. Safety risks can be identified and eliminated through inspection and detection measures. However, if the risks are not mitigated, they may eventually lead to an accident, in which case the project will bear the direct and indirect costs of the incident or failure. The point here is to estimate the optimal point in conformance and non-conformance costs of safety.

4.3. safety-based value creation

As discussed in the previous sections, if we can change the client's point of view on safety, we can expect to improve safety performance. To this end, the concept of V can be used, because its main purpose is to create value for the customer. The remarkable point here is the possibility for identifying and extracting this value. In this regard, it is necessary to pay attention to a few points. Firstly, the value should be defined in the long run, because in some cases, the short-term view for safety performance improvement will be considered a costly activity. However, studies have shown that with a long-term approach, incident costs are far higher than prevention costs. Therefore, finding the optimal point in this regard is necessary. Secondly, in addition to paying attention to creating value for the customer, the value required for stakeholders should also be considered. Finally, it should be noted that the definition of value is long-term and can be integrated among all stakeholders when it is possible to have all the stakeholders as an integrated team. To achieve this, LPDS approach can be used. In order to examine the concept of V from the point of view of safety, the concept of CoS can also be used. The CoS is equal to the total cost of prevention and inspection, and direct and indirect costs of incidents. Each organization must determine its risk appetite and risk tolerance according to its strategies and then find the optimum CoS in the organization [20]. For example, in some projects, the achievement of zero-accident may even be desirable [21]. Therefore, in this context, it is important to achieve customer requirements and create the highest value for the customer (Figure 4-C).

5. Conclusions

In this study, we reviewed the literature related to the challenges of implementation of safety in construction projects and the principles related to lean construction, and then examined the interaction effects of applying these two approaches to each other. In this regard, the effects of using LPDS on PtD implementation and safety improvement of the project was studied. In addition, the TFV theory was reviewed through the lens of safety. Studies have shown that key stakeholders can be entered into the project through LPDS and as a result, they can create an integrated team with effective communications in which all the key stakeholders are engaged in the risk-taking and benefits of the project and feel themselves responsible for each other's performance. As a result, some of the obstacles to implementing PtD, such as the knowledge gap between designers and contractors on the design and construction of safe sites and workplaces and lack of motivation in designers for getting involved in safety management process can be solved. In addition, the use of LPDS enables the project participants to facilitate the creation of a positive safety climate in the project by creating a collaborative environment between stakeholders and creating a long-term vision based on the life cycle analysis of the project, including all stages of design, construction, operation and recycling. Given the rapid growth of industries and the growing importance of resources, today, increasing productivity of projects is more than ever necessary. With regard to the ability to influence the lean principles and techniques in improving project performance, it is expected that using the approach presented in this paper to combine the underlying principles of lean construction with safety principles can be a positive step towards improving safety and, consequently, improve the productivity of construction projects. It is also expected that the proposed model provides new insights in the field of lean construction and safety. Future research may investigate the details of this model and its practical implementation through empirical study.

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