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RESEARCH ARTICLE

Lean TRIZ method to prevent safety related problems in the construction industry

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Abstract

The construction industry needs safer practices due to its complex and fragmented nature. Therefore, making errors visible is essential to the process of error proofing. With the Lean concept, it becomes possible to design out errors and develop ways to prevent errors before they turn into defects. Lean also creates a more productive and effective process when implementing innovative methods such as TRIZ, a problem solving, analysis and forecasting tool. Lean TRIZ is a new approach to improve construction processes while reducing the likelihood of defects. It strongly coincides with the elimination or possible prevention of errors originating from unsafe actions and conditions. Considering the high number of accidents in the construction industry, it is of utmost importance to implement tools and techniques to prevent the probability of such occurrences. Therefore, this study proposes a new method for error prevention with the implementation of the Lean TRIZ method to minimize safety-related problems in construction. Then, real construction problems caused by unsafe practices and conditions are analyzed with the Lean TRIZ method. The main contribution of the study is to introduce the Lean TRIZ concept and analyze the feasibility of applying this method to solve safety problems. In addition, the study provides a guide and encourages construction practitioners to benefit from the solutions provided by this research in the context of Lean TRIZ methodology.

Keywords

Construction, Lean, Safety, TRIZ, Error proofing, Construction safety

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1. Introduction

The dynamic nature of the construction industry brings the need for more efficient methods of managing construction projects. Majority of construction companies today are struggling with uncertainty, complexity, low performance and efficiency in construction projects. Therefore, finding efficient solutions to areas that need improvement is of utmost importance. Moreover, there must be strategies that show an innovative way to improve performance and promote practices on construction sites. At this point, Lean management offers a unique solution to the problems created by the increasing complexity of projects, as Lean aims to maximize value while minimizing waste. "Simply put, lean is about creating more value for the customer with fewer resources" (https://www.lean.org/whatslean/). Although Lean has its roots in the manufacturing industry, it has recently been adopted as an excellent method for improving construction processes.

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With the application of Lean principles, it is possible to complete construction projects with higher success. The use of lean tools and techniques also helps to avoid errors. Considering the error-prone nature of construction projects, the use of Lean methods becomes even more important to eliminate waste and increase value. The benefits of using Lean tools and techniques in construction projects have been mentioned in several studies [1-5]. This has led to the construction industry practicing Lean on a large scale and looking for similar strategies to improve performance.

It is obvious that the industry needs inventive solutions to problems in construction projects. Therefore, the industry is adapting to an environment, where errors are either avoided or detected. This is possible through the adoption of innovative strategies and the use of outstanding techniques. At this point, the Theory of Inventive Problem Solving (TRIZ) is an excellent method to provide inventive solutions to problems thanks to the promotion of innovative ideas. TRIZ has already been applied in various construction related researches, which highlights its power in promoting innovation and advancing construction technology [6-8]. TRIZ is a more powerful technique when integrated with other problem solving tools such as SWOT, brainstorming and 6σ [9]. In particular , sound techniques must be used to improve performance in fault design. Therefore, this study investigates Lean TRIZ, which is a process improvement methodology structured with Lean and TRIZ principles. In this regard, the study first presents the background of Lean design in relation to TRIZ. Then, the Lean TRIZ methodology is introduced. To illustrate the method, examples of safety-related problems in the construction industry are analyzed using the Lean TRIZ method.

2. Lean construction

Lean was first introduced in 1998 by John Krafcik as 'Lean production'." It had its roots in the manufacturing industry. Krafcik [10] described a Lean plant as a production system in which inventory levels are minimal so that stoppages and quality problems that occur can be easily identified and dealt with. Although lean was initially offered as a term in the manufacturing industry, it later found wide application in other industries such as healthcare, engineering, and construction. The adoption of Lean in the construction industry began in the 1990s. Gregory Howell and Glenn Ballard, two researchers from Lean Construction Institute, gained a broader experience on construction sites. They discovered that a large proportion of construction projects share similar problems, such as inefficient planning, budget overruns, and low worker efficiency and productivity. By recognizing these common problems, they developed the Last Planner System (LPS), a collaborative planning process for lean project execution with the goal of increasing worker productivity [1]. Then, Koskela [11] also mentioned that a new production philosophy must be introduced for the construction industry, which will act as a fundamental paradigm shift. In this way, the construction industry could better benefit from the production principles of manufacturing under lean.

Lean thinking introduces five main principles: (i) identify the value and eliminate all non-value adding activities, (ii) identify the value stream from the customer perspective, (iii) continuously maintain the value stream, (iv) let the customer pull, and (v) strive for perfection through continuous improvement [12, 13]. These principles are designed to help organizations create and sustain value in the most efficient manner [14]. Lean construction provides various benefits such as customer satisfaction and profitability, improved productivity and safety, and reduced project duration [15, 16]. It also indicates that the phases of work must be considered to optimize the project rather than just dealing with the phases [17].

Lean is a must for the defective processes in mass and craft production. Therefore, Lean has already proven to be an effective approach for both customer satisfaction and improved project performance [18, 19]. Several studies to date have investigated the use of lean in construction, focusing mainly on the benefits to construction projects. For example, Sacks and Goldin [20] developed a Lean management model for high-rise residential buildings by applying Lean principles (i.e., pull scheduling, reduced lot sizes, and some degree of multiskilling). The model aimed to provide bespoke housing, improved cash flow and reduced cycle times for housing delivery. Aziz and Hafez [3] concluded that Lean projects are safer, easier to manage, faster to complete, cost effective and of better quality by pointing out the impact of Lean in minimizing waste in construction. Boyce et al [21] studied the aspects of Lean thinking and concluded that it helps to improve the design phase of complex projects by highlighting the essential function of collaborative design process in highway design. Similarly, El-Reifi [22] suggested the positive impact of lean thinking on the design team to achieve higher customer satisfaction. Khan and Kim [23] emphasized the importance of identifying waste types in mid/high rise construction. However, the literature still lacks a comprehensive description of approaches or models to show the relationship between lean components. In particular, the integration of Lean with other failure detection methods is worth exploring to reveal their benefits.

This study discusses TRIZ in the context of lean construction. In this context, the Lean TRIZ approach is presented to promote its application in the construction industry to experience less waste and higher value. Examples are provided and analyzed using TRIZ principles and Lean aspects.

3. TRIZ

TRIZ is the Russian acronym for the "Theory of Inventive Problem Solving" [24]. TRIZ was first invented by Soviet inventor and science fiction writer Genrich Altshuller and his colleagues starting in 1946. TRIZ is the "theory of solving invention-related tasks" and it is "a problem-solving, analysis, and forecasting tool derived from the study of invention patterns in the world patent literature" [25, 26]. The theory reveals the patterns of evolution, and TRIZ practitioners developed an algorithmic approach for inventing new systems and refining existing ones.

TRIZ offers repeatability, predictability and reliability with its structure and algorithmic approach. It is an international science of creativity developed based on patterns of problems and solutions rather than relying on the spontaneous and intuitive creativity of individuals and groups. TRIZ is the result of evaluating more than three million patents to discover the patterns that predict breakthrough solutions to problems. Fig. 1 illustrates the TRIZ method, which aims to develop innovative solutions to problems while removing the barriers that traditional methods entail. Problems are solved thanks to the 40 principles of invention based on a complete technical evaluation.

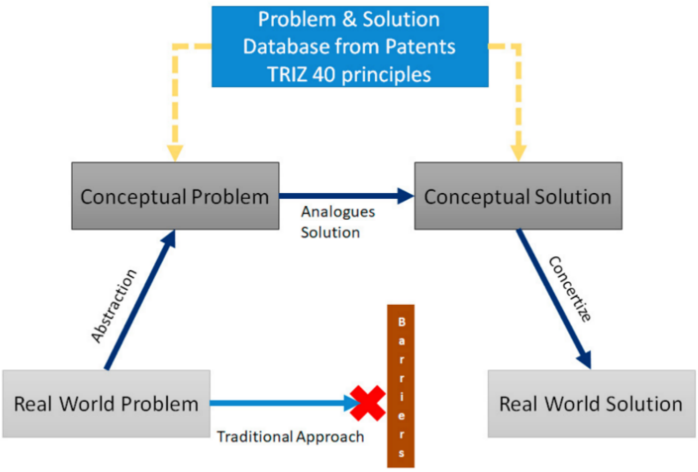

Fig. 1. TRIZ essentials (Sukharamwalaa and Parmar, 2020)

TRIZ consists of a practical methodology, tool sets, and model-based technology for generating innovative solutions to solve problems. The previous research on TRIZ has brought that problems, solutions and patterns of technical evolution are repeated across industries and sciences. Prior research also showed that innovations leverage scientific effects outside the field in which they were developed. TRIZ practitioners apply these insights to create and improve products, services, and systems [24]. TRIZ is more powerful when integrated with other methods [9]. The methods are strengthened when integrated with TRIZ, and the integrated methods are applied to the design phases of the new product development process. Therefore, TRIZ has a proven benefit in improving processes when integrated with other problem solving techniques.

To improve processes and find solutions to problems, especially in engineering applications, TRIZ uses the 40 principles of invention discovered by Genrich Altshuller [27]. These 40 principles were provided for creating inventive solutions through a careful study of engineering patents. The 40 principles can be applied not only in technical fields such as architecture, computer software, microelectronics, food production, but also in non-technical fields such as biology, agriculture, economics, management, marketing, social relations, education, and so on. The inventive 40 principles represent basic, universal and powerful tools of human creativity.

TRIZ intervenes in the field of quality management. Therefore, it is common to find several examples in the field of quality management, such as quality standards, control, assurance, reliability, customer orientation, supplier selection, project management, and improvement teams, in which TRIZ is used [27]. Mistake Proofing, a useful lean tool, is therefore closely related to TRIZ in that it exemplifies several principles of TRIZ. For example, asymmetry, a TRIZ principle, is explained in two ways; "A: Change the shape of an object or system from symmetric to asymmetric. B: If an object or system is asymmetric, change the degree of its asymmetry" [27]. Similarly, the principle of "mutual exclusivity" is also used for debugging. Another TRIZ principle is "provisional anti-action", which is explained as follows; "A. If it will be necessary to perform an action with both harmful and useful effects, this action should be replaced by anti-actions to control harmful effects." [27]. This principle is used to error-proof the design for foreseeable unintended use. Below is an example of how error-proofing has been used in inventing solutions by applying the principles of "prelim action" and "self-service".

TRIZ brings new insights to problem solving by using resources to reach the ideal solution. To have good solutions, contradictions are solved, unused resources are used, and solving contradictions by using resources makes the system more ideal [28].

4. Lean TRIZ

The Lean TRIZ Method (LTM) is a modified and simplified version of TRIZ enriched with the aspects of Lean for problem solving. This method also arises from a broader modification of the TRIZ contraction matrix, which aims to reveal principles of solving product-related problems depending on their characteristics. The main goal of the implementation of LTM is to experience a reduction in cost, cycle time and error rates in a process up to 15% in a period of 30 days. Its implementation has already proven its benefits in various applications. For example, when applied to a product or service, it has the ability to improve product design thanks to a two-day LTM design improvement workshop LTM is more of a simple form of the traditional TRIZ method because it offers short-term improvement initiatives. It also enables faster process redesign, process reengineering, benchmarking and Six Sigma [29].

LTM includes five phases, namely identifying improvement opportunities, preparing for the workshop, conducting the workshop, implementing the change, and measuring the results and reward or recognition. Figure 2 shows the LTM cycle based on these phases. As shown in Fig. 2, LTM is an effective means of providing improvement opportunities for product and process design.

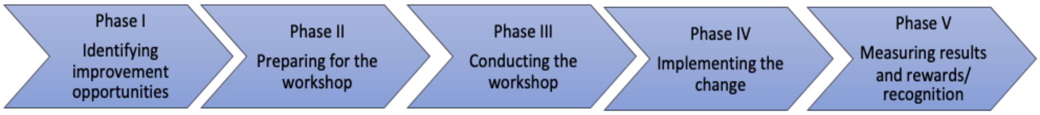

Fig. 2. Lean TRIZ method cycle (Adapted from [29])

Given the critical nature of process efficiency in construction projects, it can be argued that LTM can be successfully applied to construction processes to improve process efficiency. In addition, the method also enables the creation of a safer working environment by revealing the areas that need improvement.

TRIZ principles complement Lean in terms of project performance improvement because the principles help organizations develop innovative solutions to problems. Considering this complementary structure, Lean implementation before or during innovations leads to reduced flow waste and better collaboration between project teams [30]. Using the synergy between TRIZ and axiomatic design is a powerful approach to solve the problems associated with lean design and increase productivity, quality and efficiency [31].

The use cases of TRIZ and Lean together have been provided in previous studies. In the study by Muruganantham et al. [31], the use case was defined as reducing cycle time and operator fatigue during part removal after the machining process. This was defined as a common problem in most of the workshops while removing the components after machining. TRIZ was applied to this case along with Kaizen (continuous improvement) - a lean technique - to reduce time with less effort. The contradiction matrix of TRIZ was used to determine the improving and deteriorating factors which were defined as equipment complexity and automation level respectively. Principle number 24, which is "intermediate", was used as a solution to this contradiction, meaning that an intermediate carrier or process should be used or one object should merge with another on a temporary basis. As a result, attaching ejectors in bush shape was applied so that the processing helps to lift the component, which allows the work to be completed in 3 seconds. With such an implementation, the removal of the component took 3 seconds, which is a time saving of 17 seconds. In this way, time is reduced and productivity is minimized.

TRIZ and Lean have many aspects in common as both methods aim to improve system operations. TRIZ focuses more on optimizing individual elements, while Lean aims to discover potential efficiencies throughout the system. In the TRIZ method, the problem solver is required to make the current problem definition and understand the assumptions of the jargon. In the Lean method, it is important for the problem solver to "see" the problem at the source, which is different from TRIZ, which theorizes rather than understand what is wrong in the system at the source. In this way, an ideal state for a particular problem solution is achieved. In the last case, both TRIZ and Lean aim to optimize resources [32]. As a major source of inefficiencies in the construction industry, safety-related problems can also be solved using innovative methods such as LTM. Therefore, this study discusses the method and its potential to reduce or eliminate errors for safety-related examples in the construction industry.

4.1. Safety specific examples from the industry

Construction safety is of paramount importance for contractors to successfully complete construction projects. However, there are still some concerns about the prevention of safety-related hazards and accidents. For example, Mhando [33] mentions that inefficient use of personal protective equipment (PPE) is one of the major causes of work-related accidents. In addition, Çelik et al. [34] emphasize that the use of safety nets is an effective protective measure for high-rise construction, but there are still problems in testing and labeling safety nets in developing countries such as Turkey and Iran. Kazaz et al. [35] further mention that occupational health and safety measures need to be initiated through academic studies and field work in view of the increasing number of work-related accidents. In view of this, this study approaches safety in construction from an innovative approach. In this context, examples of safety-related problems that interfere with TRIZ principles are presented below. In order to provide systemic solutions for safety-relevant problems in civil engineering, the examples provided are analyzed and discussed in the context of LTM.

Example 1- Mechanical overload switch

Mechanical switches are used to provide overload protection in conjunction with the hoist. Specifically, when excessive force is applied to the hoist anchorage, these devices cause a spring to flip the switch and shut down the hoist. They are important in detecting overloads and preventing dangerous overloads. For this example, the problem, the countermeasure and the associated TRIZ principle are explained below.

Problem: The load that a hoist or crane can carry depends on its suspension as well as the lifting radius and thus the boom length. The crane capacity is lower if the lever arm is larger.

Countermeasure: An overload switch indicates the load that a hoist or crane can carry. This enables the user to detect overloads and loads.

TRIZ principle: This example refers to the "feedback" principle of TRIZ. Introducing feedback (feedback, cross-checking) is essential to improving a process or action. Examples of this principle include automatic quantity control in circuits, statistical process control, or measurements to modify a process as needed.

Fig. 3. Mechanical overload switch (https://vetec.dk/product/overload-switch/)

When feedback is already introduced into the system, the principle points to changing either the magnitude or the influence, such as supravision instead of supervision or using half-life as an improvement measure [36]. In this example, then, the function of cross-checking or referring back is augmented by user detection of excess capacity.

Example 2-Prestressed rebar before concrete pouring

Prestressed concrete is substantially compacted during production, which provides better strength against tensile stresses. Prestressed concrete is mostly preferred in a variety of structures, such as civil engineering and infrastructure, where the improved performance results in reduced structural thicknesses and material savings, and allows longer spans [37]. Therefore, the main problem in casting concrete is dealing with undesirable working stresses. The following is a summary of the problem, the countermeasure the prestressed rebar provides, and the associated TRIZ principle.

Problem: Undesirable working stresses in concrete casting.

Countermeasure: Concrete beams are typically prestressed, meaning the steel reinforcement in the concrete is placed in tension before the concrete is poured into the fixture. This strengthens the ability of the concrete to resist stresses through the reinforcing bar, which in turn reduces construction costs.

Fig. 4. Prestressed rebar before concrete pouring (http://www.southampton.ac.uk/~jps7/Lecture%20notes/TRIZ%2040%20Principles.pdf)

TRIZ principle: This example speaks to TRIZ's "preliminary anti-action principle." This principle states that action should be replaced by anti-action to control harmful effects when it is necessary to perform an action with harmful and beneficial effects. Moreover, the principle is further articulated as creating beforehand stresses in an object that counteract known undesirable work stresses [38]. Therefore, it is possible to deal with undesirable working stresses with the prestressed rebars before concreting in terms of the preliminary anti-action principle of TRIZ.

Example 3-Drilling into rebar

Improper drilling can cause damage to structural elements and structural safety. Therefore, it is important to avoid such damage. One of the most common examples of improper drilling is drilling into rebar, which can lead to undesirable situations. Fig. 5 shows the case of drilling into rebar. With simple devices or prevention mechanisms, it is easy to avoid such defects. To avoid such defects, the PROTEK company has developed drilling interrupters that automatically stop when they hit rebar. Below is the problem, the countermeasure, and the associated TRIZ principle.

Problem: Prevent errors before they turn into defects.

Countermeasure: Drilling can damage metal pipes, conduits, rebar. PROTEK drill interrupters provide protection against drilling into grounded metal pipes, empty conduits, post-tension cabling, and reinforcing steel when drilling concrete walls and slabs.

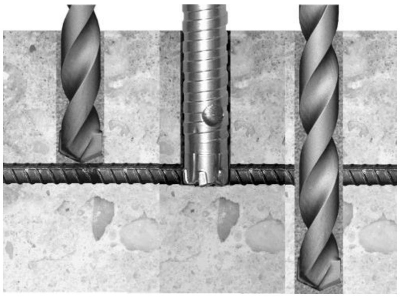

Fig. 5. Drilled into rebar (http://championcuttingtool.com/cm79-sds-rebar-cutter.html)

TRIZ principle: This example addressed TRIZ's principle of "beforehand cushioning" meaning that preparing contingency resources in advance compensates for the relatively low reliability of an object or system. In this example, a device called the PROTEK drill interrupter for detecting metal in concrete is presented. The device works by stopping the current when the drill comes into contact with either grounded metal pipes, empty pipes, or rebar. In this way, the operator is no longer able to drill through the metal object [38]. The use of such error preventing tools, equipment and practices in the processes increases the reliability of the system.

Example 4-Worker fall protection

Falls from height are among the fatal four of all construction accidents [39]. Therefore, preventive measures must be taken for people working at height. However, there are still problems with the proper use of PPE for fall hazards or low safety awareness is still a cause of accidents on construction sites. Therefore, the g-link dual retractable system is mentioned here as an example of PPE to prevent accidents at work.

Problem: Workers can fall from heights because the majority of workers still do not wear PPE or are not trained to work at heights.

Countermeasure: The g-link dual retractable system allows 100% rigging, where you can move from one anchor point to the next without releasing the retractable. The majority of the unit attaches to the back of a person's harness. The system is made of lightweight aluminium components, which reduces worker fatigue.

TRIZ principle: This example refers to the TRIZ principle of "Beforehand Cushioning", principle of TRIZ, which directs preparing emergency means beforehand to compensate for the relatively low reliability of an object. 100% protection in this way can save many lives and make workers feel safe to work. The use of such devices offers significant benefits in terms of improved productivity, reliability and safety, leading to improved project performance. Risks are mitigated and mistakes are avoided by using such devices.

Fig. 6. G-link dual retractable system (https://www.guardianfall.com/performance-safety-products/self-retracting-lifelines/product/g-link-dual-retractable-srl)

Example 5- Andon display

The use of visual aids facilitates safety in construction [40]. Since visualizations make errors clearer, it is easy to see which processes lead to errors. Andon display is an effective way of showing processes that require early intervention. In this way, operators and workers are alerted to problems and immediate action is taken to prevent errors.

"Andon" is a principle and is also a typical tool for applying the Jidoka principle in Lean Manufacturing - Jidoka is also referred to as 'autonomation', which means that as soon as a problem occurs, it is highlighted so that immediate countermeasures can be taken to prevent its recurrence." (http://www.shmula.com/about-peter-abilla/what-is-andon-in-the-toyota-production-system/ visited 12/03/2017).

Problem: To remove errors by visual aids.

Countermeasure: Andon is a visual aid that warns and highlights where action is required. For example, it may be a flashing light in a manufacturing line indicating that the line has been stopped by one of the operators due to an irregularity. Figure 7 shows an example of the Andon display showing takt time, daily target, downtine and actual time. This allows for better planning and organization so that quick actions lead to positive results.

Fig. 7. Andon Display (http://toa-se.com/wp-content/uploads/andon-screenshot-web.png)

TRIZ principle: This example speaks to the "feedback" principle of TRIZ, which means that feedback (referencing back, cross-checking) is introduced to improve a process or action. Feedback is introduced into the system through the Andon display, and operators receiving this feedback make quick decisions to correct errors before they become defects. While the Andon display is not a completely preventative mechanism, it does have the potential to eliminate defects through increased awareness and warning.

Examle 6- Cordless clutch

Equipment used on construction sites must be ergonomic to avoid causing fatigue and exhaustion. In addition, ergonomic equipment provides a safer environment where the worker's attention is focused on the job at hand. In particular, equipment with heavy cables leads to unsafe acts where people can break the cables or are exposed to electric shocks due to improper use. To avoid such cases, the cordless coupler offers the possibility to avoid physical reactions and exertion (Figure 8). It also creates a safer workplace thanks to improved ergonomics.

Problem: To avoid bodily reaction and exertion.

Countermeasure: Cordless assembly tools provide a safer environment because they have virtually no operator backlash and improved ergonomics. They also eliminate tripping hazards, remove dangerous air hoses and provide a clear work area (ftp://ftp.panasonic.com/assemblytool/catalog/asse mblytools_%202015_full_%20catalog.pdf visited July 5, 2017).

Fig. 8. Cordless clutch (ftp://ftp.panasonic.com/assemblytool/catalog/panasonic_assembly_tools_catalog.pdf)

TRIZ principle: This example refers to the principles Local Quality and Beforehand cushioning of TRIZ, which states that the product with its built-in quality helps to eliminate errors and defects. This principle of TRIZ is used to produce items with built-in quality so that defects are eliminated at the source. Even though cordless clutch do not 100% effective in preventing hazards, it does help to eliminate the majority of dangerous instances where damage can occur. This is important to focus attention on the job and help workers work in a safer environment.

Example 7- Wheel movable lift

Moving objects can be troublesome and dangerous for people who work at heights. To prevent dangerous situations from occurring in such occupations, movable lifts provide comfort and safety for their users. The ease of use and time savings that it offers to benefit from wheel movable lifts is definitely one way to deal with problems when working at height.

Problem: Unsafe conditions arise when working at heights.

Countermeasure: The movable 4-wheel lift is a specially designed lift that has a high working capacity so that several people can work on it. It can be moved easily and raised and lowered smoothly.

Fig. 9. 4 Wheel movable lift (http://www.scissorslifttable.com/sale-8130986-500kgs-10m-mobile-scissor-lift-4-wheels-mobile-aerial-work-lift-platform-with-ce.html visited Oct 19th, 2017)

It is an ideal device for safe operation and easy working. It has explosion-proof valves that protect the hydraulic line and anti-hydraulic pipe rupture. It also has an emergency decline valve that can go down in case of an emergency (http://www.scissorslifttable.com/sale-8130986-500kgs-10m-mobile-scissor-lift-4-wheels-mobile-aerial-work-lift-platform-with-ce.html visited October 19, 2017).

TRIZ principle: This example addresses TRIZ'preliminary anti-action" and "nested doll" principles, which imply that safer actions are preferred over unsafe conditions by doing the work with less or no error. The movable lift is designed to prevent unsafe conditions with its parts such as explosion-proof valves and emergency decline walve. In addition, the movable lift is designed to nest parts to save space, take advantage of unused volume, and contain one thing within another. This creates a safer work zone and more comfort for the operator. Even though the moving lift is not a preventative tool to avoid mistakes, it does have a certain amount of control to avoid mistakes.

5. Conclusions

Safety is a major concern in construction projects. The increasing number of safety-related accidents is causing construction companies to rethink and revise their strategies. Therefore, companies are looking for innovative tools and techniques to manage projects optimally and achieve higher safety performance. In order to eliminate or possibly prevent errors in the processes, it is important to prevent errors and redesign the processes. There are several tools and techniques to prevent errors and make workplaces safer. Among these, lean practices deserve special attention. As one of them, LTM is an excellent way to approach safety-related problems, revealing the root cause of the problem and analyzing it with inference to TRIZ principles. Therefore, LTM is discussed in this study along with the examples from industry. The method is also applicable to construction processes in terms of performance improvement, mainly related to safety. In this regard, examples related to safety in construction are presented accordingly. The study aims to demonstrate safety awareness and promote safety performance through the use of inventive techniques such as LTM. It is expected that the study will also guide practitioners in the construction industry in using effective tools and techniques to successfully execute projects. The study also has some limitations such as the lack of examples related to construction safety and data sharing concerns of companies. Therefore, a short list of examples is included. As future work, a database can be developed that includes a detailed list of examples. In addition, the TRIZ method with its advantages and limitations could be discussed to improve the method to better meet the expectations of construction practitioners.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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