Safety Management Model Based on Lean Construction and Behaviour-Based Safety to Reduce Accidents in SMEs in the Construction Sector

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***Abstract*—The construction industry has experienced a worrisome problem, increasing work accidents over the years. These have caused many workers to have an organic injury, functional or psychiatric disturbance, a disability, or, in the worst case, death. In Peru, more than 20,000 occupational accidents occur every year. These accidents generate monetary losses and inefficiencies in the final delivery of the work, affecting the profitability of the companies. Based on the problem posed, a safety model based on Lean Construction and Behaviour-Based Safety was developed to reduce the number of accidents and implement a safety culture within a Peruvian company in the construction sector through the analysis of indicators. The implementation was set through a pilot test, which reduced the accident rate by 35.37% per 200 thousand person-hours worked. Furthermore, this innovative model demonstrates that it can considerably reduce the number of casualties after its application.**

***Index Terms*—Applied improvement, lean tools, pilot test, training management, occupational safety and health**

I. Introduction

Globally, the construction sector is rated as one of the most dangerous sectors because it has experienced a high rate of occupational accidents. The death rate in construction is three times the death rate in manufacturing (Bajjou *et al.*, 2017) and is the highest compared to other industries in the world (Enshassi *et al.*, 2019). In Peru, within the year 2020, about 19,857 notifications of occupational accidents occurred. Of which 10.64% belong to the construction sector, totalling 2,112 accidents. This result shows that it is essential to prioritize the safety of workers in this sector to reduce this rate.

The industry faces many problems, including the lack of safety, which causes more than 150 people to die and thousands of people to be injured. Most accidents are caused by the lack of protection, awareness, and modern construction methods such as Lean tools in the workplace (Ahmed *et al.*, 2020). This cause shows that safety in the construction industry is an issue of concern, and it is crucial to implement the tools of the model.

Some research highlights that inadequate safety conditions, lack of organization in the workplace, and dangerous actions increase the accident rate. Improving safety conditions, supervision, planning, and organization, using Lean Construction tools can reduce the number of accidents on the construction site as it decreases the indicators related to the problem (Demirkesen *et al.*, 2020). Likewise, the behaviour-based safety tool reduces unsafe behaviours and raises workers' awareness to avoid accidents (Dinagaran *et al.*, 2020).

In this research, an improvement model highlights the importance of applying Lean tools in construction companies to reduce the accident rate. The model is composed of Lean Construction tools (5S, Visual Management and Last Planner System) and Behaviour-Based Safety. Practical cases are extracted by applying these tools that positively impact the company, so it is necessary to adopt these tools to address safety problems by improving and developing a safety culture within the organization to obtain good management.

II. State of the Art

A. Occupational Health and Safety Management in the Construction Sector

Occupational health and safety management is essential to improving organizations' quality of life within the construction sector. It generates excellent benefits by developing a culture of self-care, quality processes, and better working conditions. It also increases productivity, reduces absenteeism and compensation costs due to accidents (Serrano *et al.*, 2018). Based on the above, it is essential to strictly comply with safety laws to avoid workplace injuries and increase job satisfaction (Shaawat *et al.*, 2020).

B. Occupational Accidents in the Construction Sector

There are always high-risk activities in construction sites that can cause injuries, accidents, and possible fatalities (García *et al.*, 2021). In addition, projects are often plagued with significant risks due to their large size, dispersed execution, and technical difficulties that trigger the need to monitor them (Li *et al.*, 2018).

Additionally, accidents generate monetary, time, and labour losses, which decrease the productivity of organizations (Enshassi *et al.*, 2019). Because the new construction management processes maximize value and minimize waste on projects, several companies are interested in implementing them (Awada *et al.*, 2016).

C. Lean Tools in the Construction Sector

Lean Construction changes traditional work thinking through innovative management systems based on loss analysis, eliminating activities that do not add value to reduce waste, improve productivity and occupational health at the construction site (López *et al.*, 2017).

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Its application is based on implementing planning techniques and systems that improve construction projects' quality, safety, and delivery times (Ramos *et al.*, 2021). The most used Lean tools in the studied industry are Last Planner System (LPS), Visual Management, and 5S.

D. Last Planner System

It is the most reliable planning and control system of all Lean techniques and tools for safety promotion. The purpose is to introduce information into a construction process for further process planning (Jiang *et al.*, 2019), minimizing the sources of waste by developing a monitoring schedule to avoid accidents caused by poor control in the works. A study confirmed that this tool increases the participants' understanding and power over the project tasks (Lühr *et al.*, 2021). This statement is also consistent with another study, which identified that projects with a PPC (Percentage of Plan Completed) equal to or higher than 77% perform significantly better than projects with a lower PPC (Lagos *et al.*, 2019).

E. Visual Management

It is a communication method that enhances efficiency and clarity through visual signals (Ahmed *et al.*, 2020). Furthermore, it allows the process to be carried out in a transparent, simple, and, above all, safe way. It should be highlighted that the significant accidents on construction sites are due to poor process visualization. Therefore, correct visual management significantly reduces the risk of performing dangerous activities and movements on the construction site.

F. 5S

5S management comprises five Japanese words: Seiri, Seiton, Seiso, Seiketsu, and Shitsuke (i.e., sort, order, clean, standardize, and discipline). This tool eliminates unnecessary objects that threaten the safety of employees, maintains a clean and orderly workspace, and facilitates circulation by promoting safety. In this way, 5S optimizes work and assurance, resulting in an organizational culture adapting to safe conditions (Cordeiro *et al.*, 2020).

The above is consistent with the results of a study of 141 construction organizations where the study found that applying Lean tools reduced the accident rate by 6.95% (Wu *et al.*, 2019).

G. Behaviour-Based Safety

One of the best-known behavioural intervention methods, behaviour-based safety, has played an essential role in effectively modifying unsafe behaviours. It focuses specifically on individual safety-related behaviours of workers, reinforcing safe behaviours, and eliminating the dangerous (Zhang *et al.*, 2017).

As mentioned above, one of the main factors contributing to the high accident rate is the unsafe behaviour of workers (Fang *et al.*, 2020). Guo *et al.* (2016) reported that approximately 88% of these accidents are caused by mistakes, forgetfulness, inattention, incompetence, and lazy attitude.

Also, Dinagaran *et al.* (2019) showed that efficiency improves due to applying a well-planned Behaviour-Based Safety (BBS) approach and that it is possible to avoid accidents on construction sites. Li *et al.* (2015) is consistent with the experimental results showing that the tool prevents accidents and increases the SI (safety index) in 36.07% of workers. Finally, Zhang *et al.* (2017) conducted in Hong Kong, the results showed that with its application, the percentage of safe behaviours increased from 63.77% to 82.84% during the weeks of the intervention period and continued to increase to 89.90% in the following three weeks without any intervention.

From this information, this method of improving worker safety through self-awareness, motivation, and feedback is vital because it helps to ensure an environment that fosters personal responsibility for protection (Chen *et al.*, 2021).

III. Contribution

A. Model Basis

Different models, tools, and methodologies have emerged over time to reduce, mitigate, and eliminate the various operational problems in a company. Lean Construction was one of the most influential and essential work philosophies studied within the literature review. It has different tools for its implementation in the improvement proposal. Additionally, a proactive methodology of continuous improvement applied to safety called Behaviour-Based Safety (BBS) was found.

Combining these tools covers the different problems related to the main issue. Together, it is possible to reduce the accident, frequency, and severity rate, improving its productivity (see Table I).

TABLE I: Matrix of Comparison of Objective vs. State of the Art

Objectives / **Scientific Articles**	**Supervision/ Training Management**	**Management for a Suitable Working Environment**	**Employee Behaviour Management**
Bajjou *et al.* (2017)	LPS	5S	-
Zhang *et al.* (2017)	BBS	-	-
Li *et al.* (2015)	-	-	BBS
Wu *et al.* (2019)	BBS	5S / Visual Management	-
Proposal	**LPS / BBS**	**5S / Visual Management**	**BBS**

B. Proposed Model

The proposed model shows in Fig. 1 involves implementing the Behaviour-Based Safety (BBS) methodology and the Lean Construction philosophy, which features different tools such as Last Planner System (LPS), 5S, and Visual Management.

The inputs are recognized as historical data on the number of occupational accidents in the construction project. The outputs are the improvement of the indicators of the proposed model and a considerable reduction of the problem. The implementation of the proposed solution consists of five phases: initially, the first phase consists of preparing the work team to be aware of the improvement project.

The proposal continues with the second phase, which is the design and implementation of the BBS methodology. This phase will allow the organization's workers to become aware of the importance of performing safety standards, eliminating unsafe behaviours, and acquiring safety habits to function effectively. In addition, the third phase is composed of the Last Planner System (LPS) tool, which will help us create a weekly work plan to identify the tasks, steps, and sequences to be followed throughout the execution time of the work.

After this, we will proceed to the fourth phase, where we will implement the 5S tool, which will help us improve the work environment conditions and establish the basic guidelines to be applied in the last phase.

Finally, the signalling phase of the process is performed. We will implement posters, signs, boards, graphics, among others, that support workers and supervisors in the construction process to avoid accidents.

This model aims to increase awareness, safe behaviours of workers, the proper use of Personal Protective Equipment (PPE), increase signage and improve the work environment to reduce accident indicators in the company.

C. Components of the Model

a) Component 1: Introduction to tools

The supervisor will prepare the work team to understand the scope of the project and the objectives to be achieved. Then, it explains the Behaviour-Based Safety methodology and Lean Construction philosophy with its tools. This phase aims to generate commitment in the workers to solve the current troubles. Then, the workers' knowledge will be evaluated utilizing a survey about the topics explained to know the percentage of workers that acquired knowledge about the tools to be implemented.

b) Component 2: Behaviour-based safety

It refers to implementing the Behaviour Based Safety (BBS) methodology to raise awareness among workers of the importance of safety at work and improve behaviour through motivation and feedback. It allows them to respond proactively in emergencies and promotes safe habits to perform the entire process efficiently. It will be demonstrated that targeting workers' unsafe behaviours can improve productivity and reduce accidents on construction sites. Likewise, workers will give training talks to ensure proper compliance with the methodology, explaining the benefits of its correct use and promoting a safety culture within the organization.

c) Component 3: Last planner system

It consists of implementing the Last Planner System (LPS) tool, which aims to control and plan the projects, thus reducing the various deviations. Meetings will be held weekly and will last 30 minutes. The advantage is that it encourages the participation of base and management personnel to be familiar with the hazards within the work environment.

d) Component 4: 5s

The objective of this phase is to maintain a clean and orderly work environment where the employee's daily activities are carried out. In addition, this component will allow us to quickly access the needed materials and tools, reducing dangerous trips and increasing worker satisfaction.

e) Component 5: Visual management

Finally, the Visual Management tool will influence construction management systems, focusing on placing safety warnings for workers concerning machinery or equipment used in the activities. Additionally, it improves the visualization of unsafe situations.

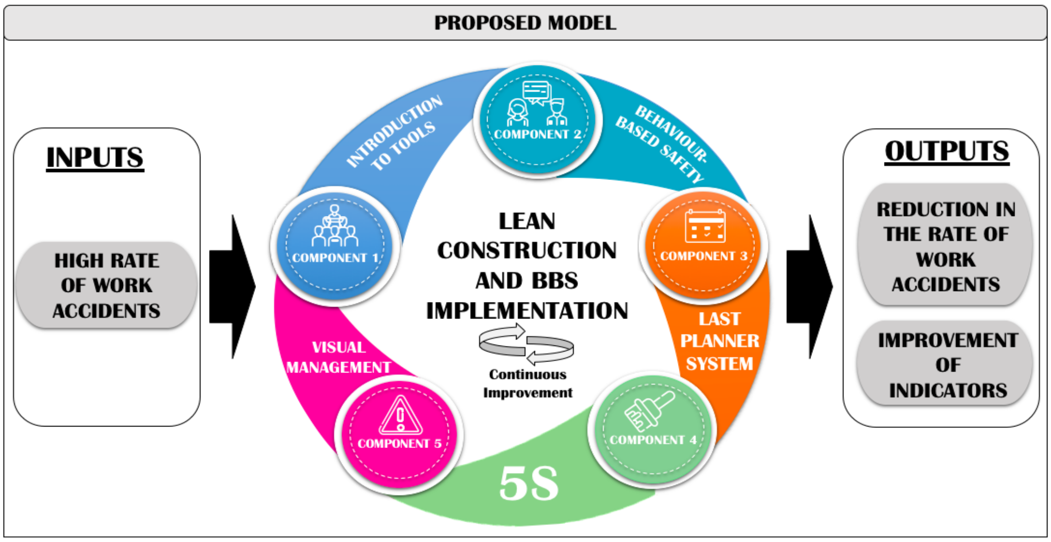

Fig. 1. Proposal model.

D. Indicators

The effectiveness of the improvement proposal will be evaluated through the following indicators:

- *Training indicator:* This indicator allows calculating the percentage of training completed out of the total number of training planned to verify compliance. Objective: To ensure that the rate of the training sessions is more significant than 85%.

$$\%TI = \frac{Number\ of\ training\ sessions\ completed}{Number\ of\ training\ sessions\ planned} \times 100$$

- *Safe behaviours indicator:* Measures the rate of safe behaviors over observed behaviors. Objective: To achieve a rate of 80% of safe behaviors.

$$\%SB = \frac{Number\ of\ safe\ behaviours}{Number\ of\ observations\ in\ the\ month} \times 100$$

- *Indicator of correct use of PPE:* Allows reduces the accident rate and frequency rate through the proper use of PPE in the workplace. Objective: The percentage of the appropriate use of PPE is greater than 90%.

$$\%Ippe = \frac{Number\ of\ parameters\ fulfilled}{Nnumber\ of\ established\ parameters} \times 100$$

The improvement of the indicators presented will allow us to reduce the accident, frequency, and severity rate directly related to the problem.

IV. Validation

After going through the five components of the proposed model, its validation is presented. A pilot test was implemented for three months, which allowed the collection of the necessary data to analyse the improvement proposal.

A. Initial Diagnosis

Upon analysing the data provided by the company under study, it was found that the main problem detected is the increase in the number of accidents caused in the works during 2020. It is directly related to unsafe behaviour on the workers, lack of constant training, incorrect use of PPE, and an inadequate workplace.

The main consequence of a high accident rate is an increase in workers' compensation and replacement hiring costs, which amount to 22 thousand soles per year and represent 2% of the company's profitability.

B. Validation Design and Comparison with the Initial Diagnosis

It was possible to conduct a pilot test for three months, from September 2021 to December 2021, to evaluate the impact of the recommended tools on the main problem. The implementation was carried out in the department of Ancash, Peru, and for its development, the collected data from the current situation of the construction company.

With the information obtained, we proceeded to start the implementation. First, two weeks of training on the proposed tools were developed. Then, to implement BBS, a preliminary analysis of risks and hazards at the site was required. Likewise, through exhaustive observation with the help of an observation booklet, we were able to quantify safe behaviours and identify unsafe behaviours performed by workers to mitigate them in the training sessions subsequently. Finally, in implementing LPS, weekly meetings were held to establish the weekly plan, and the PPC (Percentage of Plan Completed) was calculated.

Regarding 5S, the objects were classified according to the established criteria, and the place where the personnel kept the protection equipment was ordered. Then, the work area was cleaned according to the daily and weekly cleaning plan. As a final and complementary stage, a 3D method was made to simulate the signs placed at the worksite.

The company's current versus expected indicators are presented in Table II.

TABLE II: Indicators

Indicators	Present Value	Expected Value
Accident rate	4.05	3
Frequency rate	20.14	15
Severity rate	172.61	120
Percentage of training compliance	25%	85%
5S audit	30%	95%
Percentage of safe behaviours	56.94%	75%
Percentage of correct use of PPE	72.84%	90%

C. Improvement—Pilot Test Implementation Proposal

The first component gathered information about the workers' knowledge of the model's tools; after two weeks of training and introduction, a survey was conducted. The survey showed that approximately 50% of the workers obtained between 50% and 80% correct answers regarding implementing the tools. The implementation of the second component analysed unsafe behaviours to increase safe behaviours through constant training. The third component measured the percentage of training carried out to increase them. In the fourth component, an initial audit of 5S was conducted to evaluate the work environment's current conditions and take actions for improvement. Finally, missing signs were implemented in the workplace.

TABLE III: Actual vs. Improved Implementation

Indicators	Current Value	Improved Value
Accident rate	4.05	2.62
Frequency rate	20.14	14.38
Severity rate	172.61	110.28
Percentage of training compliance	25%	90.63%
5S audit	30%	96%
Percentage of safe behaviours	56.94%	76.39%
Percentage of correct use of PPE	72.84%	91.23%

As can be seen in the results of Table III, the main objective was accomplished, improving the initial situation of the problem.

V. Conclusions

Thanks to implementing the model proposed with the Lean Construction and Behaviour-Based Safety tools, the expected results were obtained during the three months of the pilot test. As a result, the accident rate was reduced from 4.05 accidents per 200 thousand person-hours worked to 2.62, which gives us a reduction percentage of 35.37%, exceeding the initial expectation. Furthermore, it was shown that the severity and frequency rates were reduced by 36.11% and 28.57%, respectively. The index decrease was significant in the analysis since it was the basis for knowing that the model works correctly.

In addition, we confirmed that the percentage of training compliance increased to 90.63%, exceeding expectations by more than 5%. Furthermore, the rate obtained from the audit qualification showed an increase of 66%, which indicates that the workplace is adequate and complies with the standards of the proposed tool. Finally, the increase in the percentage of correct use of PPE, safe behaviours, compliance with training, and the 5s audit confirms that the indicators presented in the model are directly related to the reduction in the accident rate.

For future research, it is necessary to start implementing tools with the awareness of workers about what is required to be achieved with the model and why it is essential to implement it during daily work. Also, it is necessary to highlight the implementation of a lasting safety culture for future projects within the organization to increase profitability.

Conflict of Interest

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Virginia Gonzales-Pejerrey developed the models and analyzed the data. Fressia MoCrocho-Caballero conducted the research and wrote the manuscript. Juan Carlos Quiroz, Alberto Flores, and Martin Collao supervised this project and contributed ideas for the document's drafting. They provided support throughout the construction of the research. All authors have approved the final version.

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