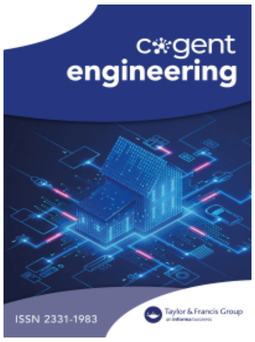

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A validation model to reduce non-contributory time based on Lean tools: Case of a construction company in Perú

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Abstract: The construction industry has long been suffering from high rates of non-contributory time. Construction processes are likely to include time, which is sometimes lost for non-value-adding operations resulting in time waste. Considering the large percentage of lost time in all operations, this study aims to reduce the high rate of non-contributory time (NCT) in construction services. To test the management model, a Peruvian company was selected as a study case. In this respect, a management model based on mostly implemented Lean tools such as Kanban, 5S, and TPM was utilized. It is of utmost importance to emphasize that this proposal aims to reduce the NCT by up to 25%, as well as reduce the number of orders generated with delay, and eventually reduce the loss or damage of materials and equipment stoppages.

Subjects: Engineering Management; Industrial Engineering & Manufacturing; Production Engineering

Keywords: construction industry; Kanban; lean tools; non-contributory time; 5S; TPM

1. Introduction

The construction sector is one of the most trending sectors in Peru because it has a large impact on the economy. In the fourth quarter of 2020, it generated a gross domestic product (GDP) of 19% (INEI, 2021). According to Pons and Rubio (2019), construction projects are generally executed with a compliance of 55% to 60% concerning planning, that is, the weekly goals are partly met. Similarly, the study implies that 57% of the time, effort, and materials are invested in activities that do not generate value (Rubio & Pons, 2021). This proves that construction projects are mostly executed with critical time delays and cost overruns (Martim et al., 2018).

Regarding non-contributory time (NCT), Hossain et al. (2019) implied that productive activities, which generate value, represent 33% of support activities that are involved in 41% of the civil works time and 26% of the time correspond to various activities such as waiting due to lack of requirements and rework. Likewise, in an analysis carried out when evaluating 10 construction projects, it was determined that the NCT could be equivalent to 24%, the productive time (TP) to 46%, and the contributory time (TC) to 30%, where the NCT has caused such as waiting time, transportation, reprocessing, displacement in the area (Uscategui et al., 2020).

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The main motivation of this research is to propose a solution proposal model to reduce the NCT in construction works, thus reducing the orders generated with delay, the loss or damage of materials, and machinery stops. At the same time, insights into process management in the construction sector are provided. Hence, the study intends to reduce the existing knowledge gap for the successful management of projects in the industry considering the complexity and uniqueness of each project. The proposal is based on mostly implemented Lean tools such as Kanban, 5S, and Total Productive Maintenance (TPM). The model, when effectively implemented, is expected to reduce the NCT by up to 25%, thus achieving international standards in corrective maintenance services for the buildings (Hossain et al., 2019).

This study involves four main stages: literature analysis, methodology, validation, and discussion. In the first stage, an extensive review was conducted to reflect on the success stories and solutions presented in the industry. In the next stage, a summary of the improvement model proposal is presented to reduce NCT. In the third stage, the data entered in the simulator was recorded with the help of the Arena Simulation software in a current scenario after the implementation of the Lean tools. Finally, in the discussion stage, the results are analyzed quantitatively and qualitatively through an in-depth discussion flow.

This article is the continuation and validation of previous research by Cabrera et al. (2022). In Cabrera et al. (2022), the authors focused on developing a conceptual model for avoiding non-contributory time but the authors neither tested nor validated the model developed. To test and validate the model developed, this study focuses on testing and validation using real data provided by a construction company in Peru. Therefore, this research is expected to show how a conceptual model can be implemented to devise effective strategies in terms of developing process efficiency and waste reduction.

2. Literature review

2.1. 5S methodology

Hossain et al. (2019) assert that experts in the construction sector stated that lean techniques do generate a positive impact on productivity and are effective. According to the ranking based on the importance index, the technique that would generate the greatest impact is 5S. Likewise, a group of recommended tools for the supply chain and materials management in construction is Just-in-time and 5S (Aslam et al., 2020).

5S is a workspace management method, which has positive impacts as it helps to control key locations on construction sites. This involves the management of workers, materials, machines, and others on the site. The phases of the methodology are (1) seiri-classify, (2) seiton-order, (3) seiso-clean, (4) Seiketsu-standardize, and (5) shitsuke-audit. Upon completion of all stages, it is expected to improve production efficiency and reduce waste (X. Wu et al., 2019) (Zeng et al., 2019).

On the other hand, recent research seeks to optimize production processes through the 6S methodology, where the sixth S refers to safety. This intends to increase the proper organization and signaling of the work area; however, due to its complexity, it is not recommended if there are no safety concerns or if the industry carries a higher risk (Jiménez et al., 2019)

The 5S methodology helps maintain a suitable site to perform the flow of activities optimally. As part of the 5S implementation, visual management plays a critical role in the workplace organization. Visual management makes the construction processes simpler for all stakeholders through various signs and boards. These tools allow to facilitate the construction processes and improve performance (Bajjou et al., 2017). Visual management uses visual devices to externalize information making information easy to understand and accessible, providing clarity in the face of complexity. The essential goal of visual management is to help detect problems and correct them at the source (Brady et al., 2018).

3. Just-in-time (JIT)

JIT is a Lean tool aiming to reduce inventory and overproduction by sequencing the procurement and work tasks. Lean construction with its pull-driven approach targets to minimize buffers and inventories, and work-related accidents resulting from improper use of construction tools and equipment (Enshassi et al., 2019; P. Wu & Low, 2012). Minimizing production flow times helps to reduce the response time of suppliers to the end-users. Hence, JIT is an effective means of eliminating waste in processes (Ansah et al., 2016). Krafcik (1998) stated that JIT requires less effort, investment, space, and time. The implementation of JIT generates great savings in the execution time of the workers since it increases the time with added value and decreases the time dedicated to the search for materials. Likewise, it generates an increase in the rate of use of the work area by 12%, reducing, in the same way, the percentage of losses of materials and equipment on-site (Tetik et al., 2020). For Moussaoui et al. (2021), this tool begins by ordering the required quantities of supplies and as the work progresses, partial deliveries are made that must be packed in kits before being stored. This allows for greater flexibility in planning as well as greater control of management practices on the site. This results in a smoother workflow as the operator begins working with material already on their job site, making progress easier and reducing the chance of missing materials. However, a disadvantage of the tool is that it requires early planning and a trained team is required to develop the kits (Moussaoui et al., 2021). In the logistics field, JIT allows real-time detection of the work and the flow of materials within the work (Zhao et al., 2021). In the construction sector, inventory problems such as damaged or stolen materials are common. The implementation of well-developed materials management techniques such as Just-in-Time can provide a solution to the existing problems in the sector (Dakhli & Lafhaj, 2018).

Kitting consists of packing different materials and delivering them as one package while JIT delivery consists of delivering materials to construction sites, to be installed immediately without being stored. Combining those two services will therefore allow for delivery of the right quantity, at the right time, and in the right condition (Moussaoui et al., 2021). For Tetik et al. (2020) material kitting is an effective solution to organize just-in-time (JIT) material deliveries around assembly tasks. In the case of the study, findings indicate that kitting can stabilize assembly work and increase workplace utilization and on-site labor.

3.1. E-kanban

The Kanban board is operated by workers, who put information on the Kanban about the quantity of the type of material, the place of delivery, and the name of the team. The personnel responsible for the flow of material manage this panel and the supply in all workstations (Valente et al., 2019). The Kanban concept can be characterized as a shifting inventory management system. Its main objective is to control the maximum level of inventories based on production through the Kanban cards (Pekarcikova et al., 2020).

When we combine Industry 4.0 technology with traditional tools of industrial practice, we can enhance tools such as Kanban and streamline control of the flow of materials and performance of operations through the lean manufacturing philosophy. According to Pekarcikova et al. (2021) with the e-kanban system downtimes are reduced and the flow of materials becomes more efficient. In addition, they mention that 40% of companies expect the digitization of Lean tools to generate lower inventories and higher purchase volumes. This causes greater transparency in the process, providing better support for decision-making in the supply chain.

3.2. Total productive maintenance

Total Productive Maintenance has eight pillars, which are based on quality, cost, delivery, flexibility, and overall equipment effectiveness (OEE) indicators, it can be said that the most relevant are autonomous maintenance, planned maintenance, quality maintenance, and training, due to the greater impact that they generate (Adesta et al., 2018). However, although these results cannot be standardized, since for each industry the priorities and the weight of each criterion may be different, the priorities could be categorized into maximum, medium, and low, belonging to category one autonomous maintenance, and the two planned maintenance (Shinde & Prasad, 2017). The success of the company is closely related to the maintenance management system used since this can allow greater efficiency, as well as a reduction in costs and an increase in the availability and useful life of the equipment. A partial implementation of the TPM, that is, only executing some pillars, can provide positive results which can be evaluated with indicators such as mean time to repair (MTTR), mean time between failures (MTBF), Availability, and OEE (Pinto et al., 2020). The approach based on the first pillars of the TPM can be completed with the failure mode and effect analysis (FMEA) analysis of the reliability centered maintenance (RCM), to carry out a preliminary study of the equipment (Palomino-Valles et al., 2020). Likewise, the implementation of the methodology provides an increase in availability between 2% and 5% (Mahraj et al., 2021; Palomino-Valles et al., 2020). Currently, due to the growth of the construction industry, it is wiser to implement relatively new techniques such as lean methods. The application of techniques such as value stream mapping (VSM), JIT, and TPM can generate a considerable increase in productivity and performance with proven evidence in the company's profits (Heravi et al., 2019).

3.3. Autonomous maintenance

The development of the practice of autonomous maintenance focuses on increasing the availability and reliability of the machines through the daily tasks performed by the operators, which include periodic reviews of the machines, and cleaning, among others. In the same way, it has the benefit of improving the performance of the team and the skills of the working staff (Palomino et al., 2022). Likewise, according to Semrau and Horzela (2021), autonomous maintenance means that a team of employees carries out maintenance as part of their work schedule activities, to prevent failures.

3.4. Preventive maintenance

Preventive maintenance is based on the conservation of the equipment through inspection and repair, thus guaranteeing the operation and reliability of the machines. Rizkya et al. (2021) state that this pillar must be carried out according to the rate of damage that occurred and/or expected since its objective is to reduce sudden damage and control the failure of machinery components. This same proposes to implement daily, weekly, and monthly maintenance to obtain favorable results. The first is to check the critical components of the equipment, the weekly reviews to verify the condition of the machine, and the monthly to verify the performance of the maintenance management (Rizkya et al., 2021). Likewise, according to (Pinto et al., 2020) planned maintenance must be structured about the type of machine, and the frequency of use and must be planned in a way that is compatible with production planning.

One other remedy for predictive maintenance can be the use of digital twin (DT) technology, which is a simulation-based planning and optimization concept (Tao et al., 2019). Grieves (2019) identifies DT as *"digital equivalent to a physical product"*. The digital twin can be used at different stages in the construction industry including the design stage. For example, Liu et al. (2021) implied that DT can be used to redesign existing physical object or to evaluate the performance of designed objects. They further indicated that it is used for real-time monitoring, production planning, and control at the manufacturing phase, where it is used for fault detection and state monitoring for predictive maintenance. Despite the broader use in the manufacturing industry, limited use in the construction industry has been realized in recent years. Sacks et al. (2020) mentioned that there is still no consensus among industry practitioners of how DT can support the design and construction of buildings. On the other hand, Kaewunruen and Xu (2018) used the DT concept for the sustainability evaluation of a railway station building including its maintenance. A considerable portion of DT research further focused on system design and system engineering. Gabor et al. (2016) developed a simulation-based architecture for smart cyber-physical systems. They conducted the simulation of the physical object to predict the future states of the system. Bajaj et al. (2016) proposed a unified system model, which enables the coordination of architecture, mechanical, electrical, software, verification and other models within the system lifecycle using DT. Kan and Anumba (2019) concluded that DT helps to achieve more efficient construction processes and enables to have more informed decisions leading to safer environments with reduced cost and improved efficiency.

3.5. Training

The purpose of training and education is to ensure that operators receive adequate training in skills that have been identified as critical for an efficient implementation of the TPM, based on the objectives of the organization (Emuze et al., 2017). Rizkya et al. (2021) affirm that a lack of knowledge of the tools or machines causes damage to the equipment and that with adequate training the operator could improve their knowledge and techniques to analyze damage to machinery or work equipment. Zhang and Jeng (2021) state that it is important to check the status of the education of the operator to decide on an adequate training module and schedule.

Some recent technologies have been in use for training purposes. For example, technologies such as machine learning (ML), knowledge-based systems, robotics, and optimizations, which are sub-fields of artificial intelligence (AI) are successfully applied in various industries for profitability, efficiency, and safety purposes (Abioye et al., 2021). AI can enhance safety in construction projects and automate the decision making in safety and risk assessment of construction projects (Bigham et al., 2018). Park and Kim (2013) mentioned that virtual reality (VR) and augmented reality (AR) can be used in different areas of planning, training, and supervision of construction safety. Bhoir and Esmaeili (2015) implied that VR proposes an effective learning environment, where workers can learn how to protect their safety information. Le et al. (2015) further implied that experiential construction safety training can be implemented through social and collaborative VR. Chen et al. (2014) indicated that AR can help to train workers protecting them being exposed to hazards and develop less fear of hazards. A considerable portion of the studies revealed that IoT can be an effective means of accident prevention and hazard identification with its use in construction projects (Yang et al., 2020; Yeo et al., 2020).

Given this background, it is observed that previous research focused on some Lean techniques for process efficiency and better productivity. On the other hand, there is a gap in the literature in terms of proposing a comprehensive model to eliminate non-contributory time, which is a major waste type in many construction firms. Moreover, the literature fails to provide a real case, where the use of Lean tools showed effectiveness to avoid non-contributory time. This study proposes a novel validation model to reduce non-contributory time, which is a major setback for construction projects. In this respect, the model involves the use of basic Lean tools and is tested with the data of a construction company operating in Peru. In this respect, the model presents important information to guide both industry practitioners and Lean implementors in terms of best managing non-value-adding activities and eliminating those with effective strategies.

4. Methodology

The Lean methodology in construction is a technique focused on minimizing waste, maximizing productivity, and final customer satisfaction (Demirkesen & Gokberk Bayhan, 2019). Lean aims to maximize value while minimizing waste. Hence, it is essential to use Lean tools and techniques for achieving higher value in construction projects (Demirkesen et al., 2020). The methodology provides a large number of tools; however, regarding the lean techniques that are recommended to be implemented, according to the ranking based on the importance index, some of the techniques that would generate the greatest impact are 5S, VSM, and Visual management (Hossain et al., 2019). On the other hand, according to Aslam et al. (2020), a group of recommended tools for the supply chain and materials management in construction is JIT and 5S. Heravi et al. (2019) tells us that the application of techniques such as VSM, JIT, and TPM can generate a considerable increase in productivity and performance, seeing this reflected in the company's profits. A partial implementation of the TPM, that is, only executing some pillars, can provide positive results which can be evaluated with indicators such as MTTR, MTBF, Availability, and OEE (Palomino et al., 2022).

Finally, Zegarra and Alarcón (2019) affirm that the use of the Lean methodology in construction project teams causes a variation of 10% to 54% in the reasons for failures, reliability, and progress.

Relying on the conceptual model by Palomino et al. (2022), the methodology consisted of two parts: simulation and pilot study. After analyzing the problem and developing the conceptual model, the model was simulated using Arena software, where the data provided by a construction company in Peru was used. Then, Output analyzer software was used to reach the optimal number of runs in the model. Finally, a pilot study was conducted to validate the simulated model in active work in a warehouse. The 5S was implemented to see how the proposed model can help in 5S implementation and experience less non-contributory time.

4.1. Analysis of the problem

The company L2S23 belongs to the construction sector and has eleven years of experience performing these services for the state. According to Palomino et al. (2022), the sample size to obtain a 95% confidence level must be 384 and the steps for the analysis of the problem are (1) Identify activities, (2) Classify the activities, (3) Time taking of activities on the site, (4) Analysis of three times: productive time (PT), contributory time (CT), and non-contributory time (NCT). In Palomino et al. (2022), the efficiency of each item was measured first, this was calculated by dividing the real income of the workers in L2S23 and the income exposed in the CAPECO magazine. Therefore, the efficiency of the TP is determined as 88% with 318.68 hours of lost time. The second time measured the efficiency of the activities of the category of transfer, cleaning, security, services, and verification. With this, the efficiency of the CT is calculated as 62% with 396.87 hours of lost time. Finally, the TNC analysis is carried out and it was observed that the lost time is 1198-man hours.

From what was previously specified, it can be concluded that the time focused on is the TNC since it generates more time waste. The company under evaluation has a high rate of non-contributory time that corresponds to an average of 25% of the total time. The main causes of this problem are orders generated late (28.6%), loss or damage to materials and tools (26.9%), machine breakdown stops (28.6%), supplier delays (4.1%), use of inappropriate material (5.5%), Badly executed work (5.9%) and design changes (3.7%). Of the causes mentioned, we find an uncontrollable cause, which represents 3.7%, which is the changes in the design made by the contracting entity.

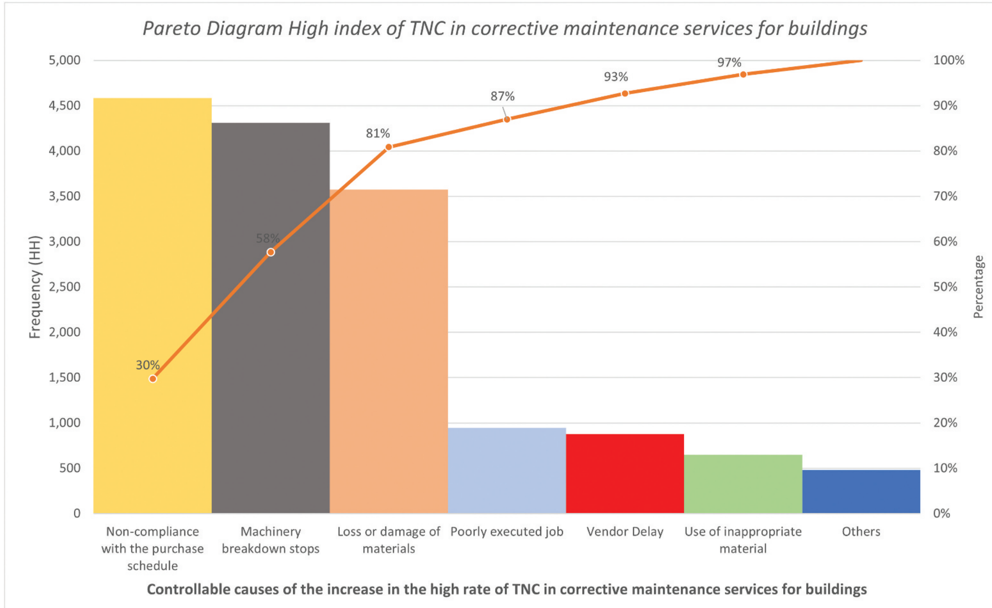
With the data collected, a Pareto diagram was made (Figure 1) in which it was determined that approximately 81% of controllable causes lead to non-contributory time in activities.

4.2. Lean methodology implementation

(a) E-Kanban: As can be seen in, the implementation begins with the Kanban, which is the identification of key materials, then classifying the products through the Kraljic matrix, and finally development of the Kanban cards. It is important to mention that the Kanban board will have three sections: (1) To order, (2) Order, and (3) Reception. T+he first section must be filled out by the site resident, whereas the last two are by the purchasing area.

(b) TPM: The model proposes the partial implementation of TPM. The pillars implemented are Autonomous Maintenance, Preventive Maintenance, and Training. With respect to the first pillar mentioned, a standard for cleaning and maintenance of the machines is expected to be proposed to keep control of autonomous maintenance activities. Likewise, a One Point Lesson (OPL) is developed, which includes the basic knowledge to carry out autonomous maintenance. For the training phase, a preliminary evaluation starts to identify the initial knowledge that the workers have. The assessment is about your operational knowledge and basic concept of lean tools. Then a training schedule is elaborated and at the end of this stage, a final evaluation is carried out.

Figure 1. Pareto Diagram NCT (Palomino et al., 2022).



(c) 5S methodology: The implementation of the 5s methodology has six steps. The first is the preliminary stage where awareness is raised, policies are established, and workers are trained. In the first S, the objects in the work warehouse are classified and the objects with a red card are discarded. For the second S, kitting is implemented to reduce the handling of materials. For Seiso, the warehouse is cleaned, and a cleaning schedule is developed. Finally, in Seiketsu, the activities to be standardized are defined, procedures are elaborated, and visual management is implemented. Finally, the results are evaluated with a 5S auditor.

Figure 2 shows the proposed implementation flow for reducing the non-contributory time by employing Component 1 based on the Kanban method (C1), Component 2 utilizing the 5S methodology (C2), and Component 3 applying TPM (C3). In this figure, the green circle represents the initiation of the flow, while the red circle represents the conclusion or endpoint. Additionally, the plus sign (+) indicates the parallel implementation of Component 1 and Component 2. The rectangles within the figure represent specific activities or steps undertaken during the implementation process. These rectangles outline the various tasks and actions required to accomplish the desired outcome.

4.3. Indicators

According to Palomino et al. (2022), the implementation of the model can reduce downtime by 51% due to la ack of materials and increase equipment availability by 10%. The model uses three tools Kanban, 5S, and TPM, as can be seen in Figure 3.

The indicators used for the control and monitoring of each of the tools are quality of generated orders, 5S evaluation, physical loss index, and OEE which can be seen in Figure 4. The Kanban has the quality indicator of generated orders, in which the orders have been ordered without setbacks or in an extraordinary way. Currently, there is 52% of orders generated on time and Pekarcikova et al. (2020) mentioned that an increase of approximately 14% is expected in terms of timely generated orders. In addition, according to Jiménez et al. (2019), the evaluation of compliance with the 5S criteria must reach 75% to be considered correct for the implementation of the tool. Also, with the elaboration of JIT in the “2nd S”, Zhao et al. (2021) affirmed that this generates an increase in the use of space, thus allowing to reduce in the handling of materials and equipment, and a decrease of 12% in the loss rate.

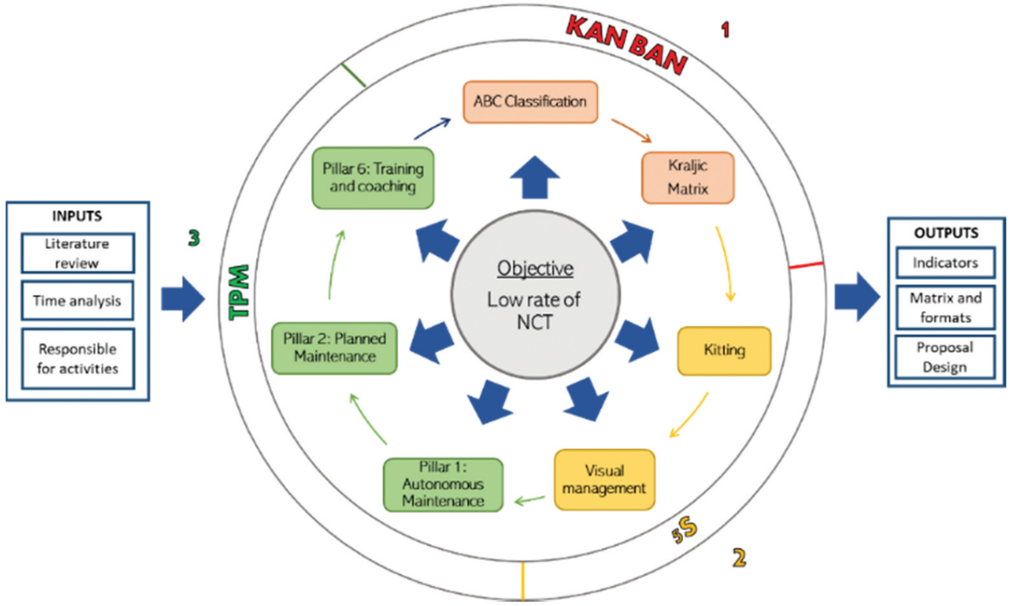


Figure 2. Model to reduce NCT Palomino et al. (2022).

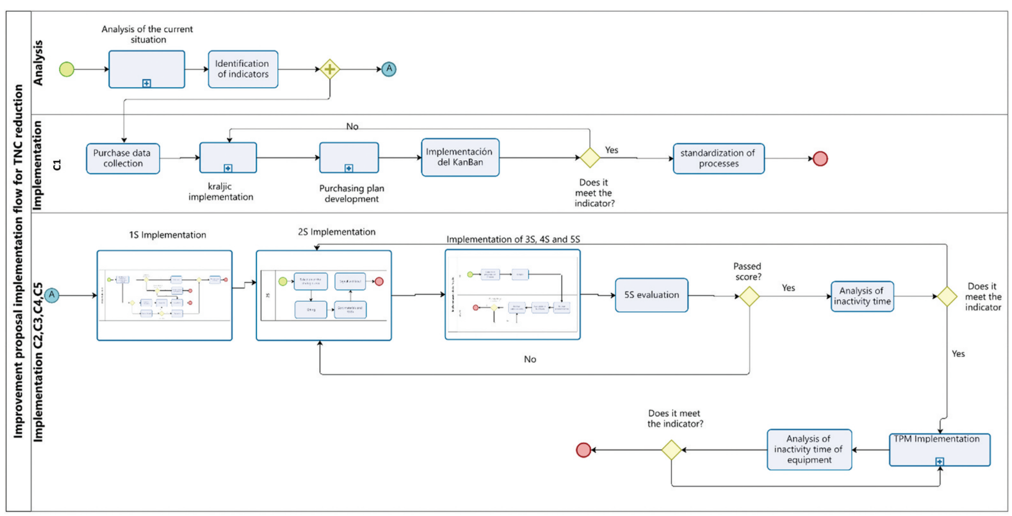


Figure 3. Proposal implementation flow to reduce non-contributory time.

Finally, Mahraj et al. (2021) stated that TPM is possible to increase the OEE by 10%, which is why it is expected to improve the effectiveness of equipment, obtaining 68%.

5. Validation

To validate the suitability of the proposed model, two methods are used for its validation: simulation, and a pilot study.

5.1. Simulation

In the case of the expected improvements to the Kanban for purchasing management and the TPM for maintenance management, the simulation of the current system and the system after the improvement proposal was implemented using the Arena simulation software.

Analyzing the data for the year 2021, it is known that it has 8,156 MH of non-contributory time caused by orders generated late and stops due to machinery breakdowns distributed in eight items: Walls and partitions, floors, columns, carpentry, electrical installations, roof, sanitary

Figure 4. Evaluation and control indicators.

ITEM	INDICATOR	AS IT	TO BE	FORMULA	AUTHOR
KANBAN	Quality of generated orders	52%	66%	(Orders generated on time)/(Total orders generated)	Pekarcikova et al (2020)
5S	5S evaluation	50%	>=75%	(Actual score)/(Ideal score)	Jimenez et at (2019)
	Index of physical losses	50%	38%	(Physical Input - Physical Outputs)/ Physical Input	Tetik et al. (2021)
TPM	OEE	58%	68%	*Availability x Performance x Quality*	Mahraj et al (2021)

installations, and paint. To carry out the simulation with the Arena software, the games that generate the greatest impact on the NCT are selected, for which a Pareto diagram was created. Figure 5 shows that 80% of the non-contributory time is focused on three items Walls and partitions (41%), floors (25%), and Columns (14%), so it was focused on the activities of these games for the elaboration of the simulator.

For the development of the simulation, it is necessary to enter the current data distribution of the purchasing, execution, and maintenance area of the construction project. See Figure 6.

The input data inserted in the software were evaluated by considering a confidence level of 95% and a margin of error of 5%. The Chi-Square test and the Kolmogorov-Smirnov test were performed, concluding that the data meet the satisfactory conditions, where the two tests provided results greater than 0.05, which is above the acceptable level.

Figure 5. Pareto diagram of corrective maintenance items for buildings.

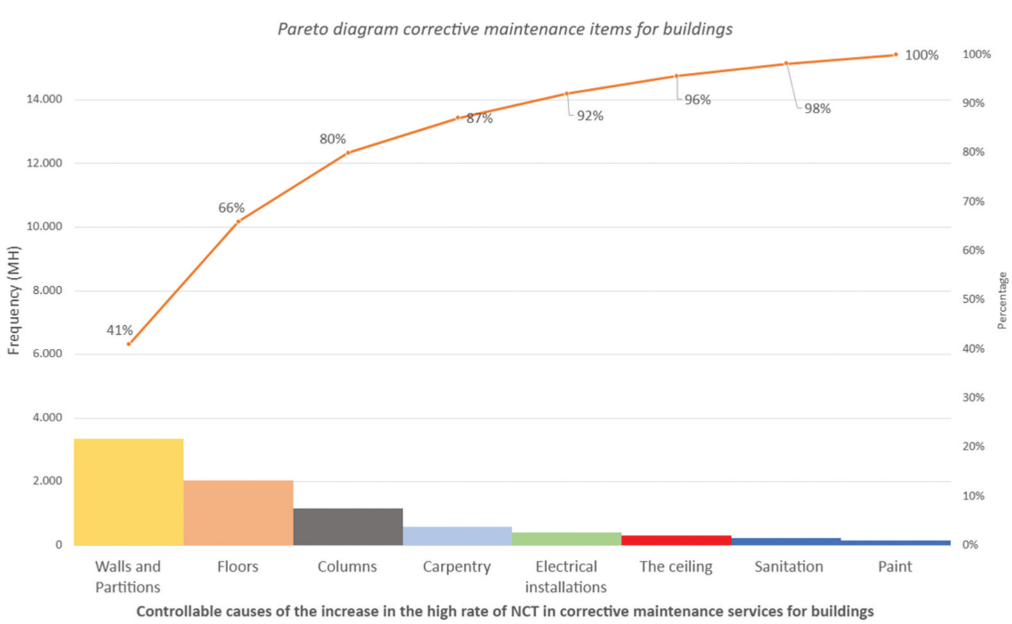
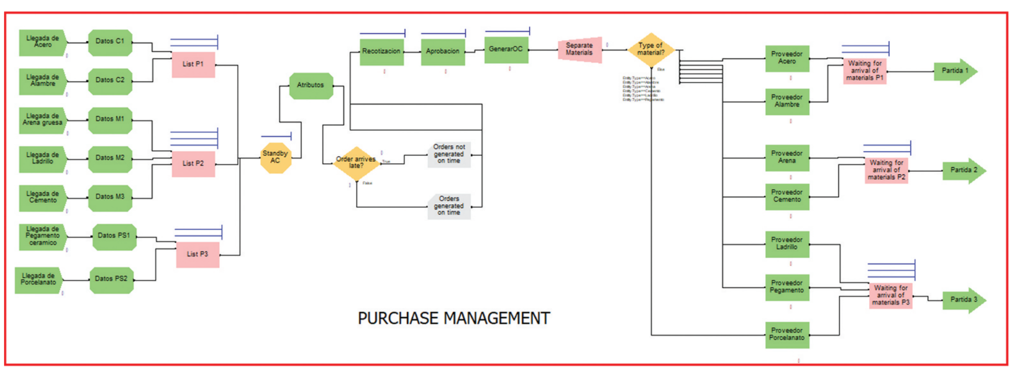


Figure 6. Input data distribution.

N°	Detail	Distribution
1	Ts concrete in columns	NORM(23.5,4.79)
2	Ts formwork and stripping of columns	UNIF(95.1,4.92)
3	Ts corrugated steel	NORM(95.1,4.92)
4	Ts head clay brick walls	TRIA(118,122,126)
5	Ts rope clay brick walls	84+5*BETA(0.921,0.984)
6	LT wire	NORM(12.9,3.82)
7	LT corrugated steel	TRIA(48,56.5,64)
8	LT gross sand	NORM(11.9,4.08)
9	Lt clay brick	NORM(18.2,3.89)
10	LT cement	UNIF(10,17)
11	TLL floor materials	713+107*BETA(1.09,1.11)
12	TLL column materials	20+25*BETA(1.09,1.11)
13	TLL materials walls and partitions	459+107*BETA(2.17,1.91)
14	TLL price quote	NORM(7,1.81)
15	TLL budget approval	TRIA(8.19,12.2,15.7)
16	TLL OC generation	NORM(11.2,2.14)

Figure 7. Current simulation system part I.



Figures 7 and 8 show the current simulation model made under the assumption of 360 days a year, 8 hours of work per day, and 6 workers per activity. To determine the optimal number of runs, the software called OutputAnalyzer was used, which generated an optimal number of runs of 236.

The results of this run were the total system time (TSystem), the time lost due to waiting for materials, and the use of machines for each of the three simulated batches. Regarding the machinery used in the simulation, Table 1 shows the utilization of 65.42% for the concrete mixer and 63.38% for the plate compactor. In addition, in Table 1 the non-contributory time (NCT) of the first item is 33%, of the second item it is 29%, and the third item is 34%. That is why it is concluded that the average NCT is 32% as shown in Table 2.

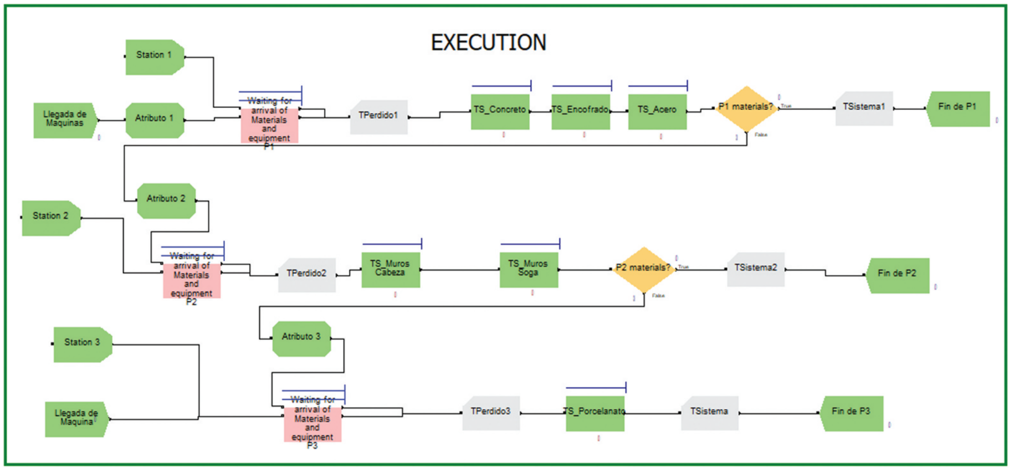


Figure 8. Current simulation system part II.

Table 1. Result of using the current situation

Output	Result simulation
Concrete Mixer	65.42%
Plate compactor	63.38%

Table 2. NCT result of simulation of the current situation

Output	Percentage
NCT1	33%
NCT2	29%
NCT3	34%
Average NCT	32%

Table 3. Results of using the proposal simulation

Output	Result simulation
Concrete Mixer	78%
Plate compactor	75%

Table 4. NCT result of simulation of the proposal situation

Output	Percentage
NCT1	30%
NCT2	26%
NCT3	31%
Average NCT	29%

Note: From the analysis, one can conclude that the implementation of these two short-term tools reduces non-contributory time (NCT) by 3%.

Figures 9 and 10 show how the proposed simulation model was carried out under the same assumptions as the current simulation. In this scenario, the implementation of the Kanban tool is simulated with the purpose of indicating the beginning of the next activity so that the purchasing manager proceeds to quote and make the orders of the required materials at the appropriate time,

Table 5. Income and costs of the solution proposal

YEAR	PROJECT INCOME	VARIABLE COST
2023	$ 9 522	$ 2 937
2024	$ 9 363	$ 2 889
2025	$ 9 204	$ 2 840
2026	$ 9 281	$ 2 863
2027	$ 9 358	$ 2 887

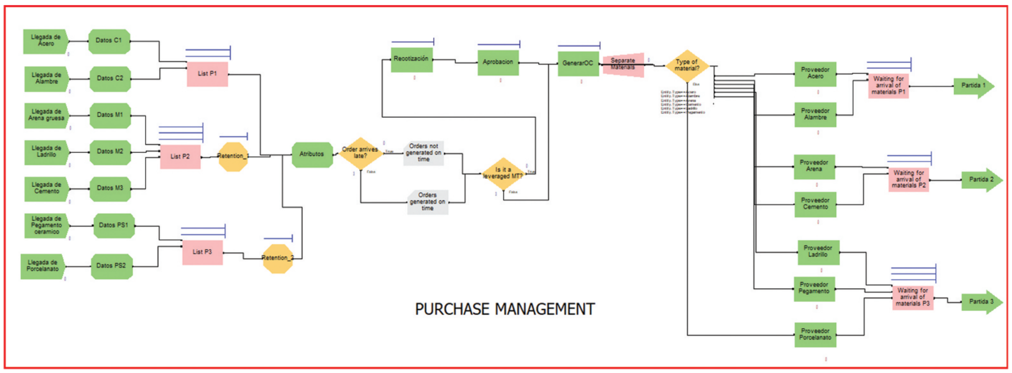


Figure 9. Simulation of the Proposal part I.

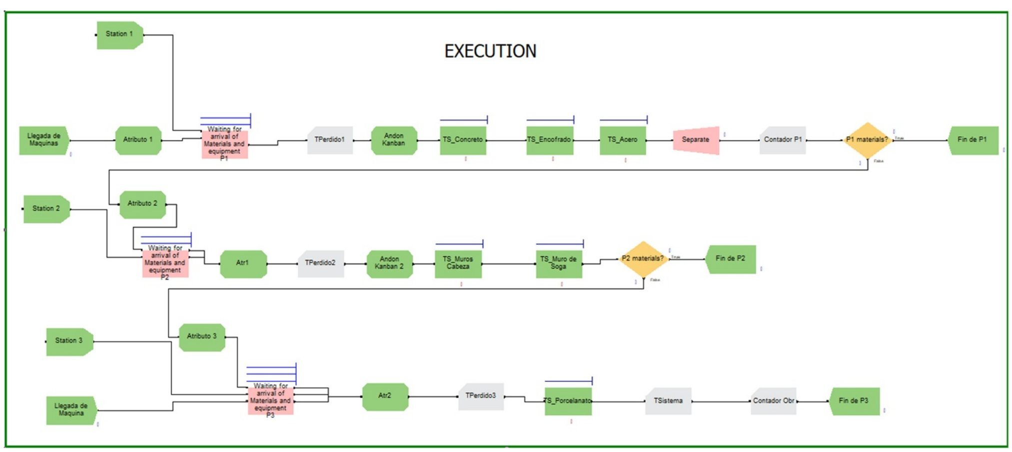


Figure 10. Simulation of the Proposal part II.

thus avoiding delays or excess of inventory. In addition, the implementation of the TPM tool is simulated to reduce equipment downtime in relation to three pillars that are autonomous maintenance, planned maintenance, and training. In Figure 10, the elements called "Kanban Signals" indicating the right time to make purchase orders, considering the Lead time of each required input are shown. In this case, the optimal number of runs is 1512 and the results in relation to the machinery used in the activities have a usage rate of 78% for the top and 75% for the steamroller, as shown in Table 3. Table 4 shows the NCT obtained by batch, in the first 30%, in the second 26%, and in the third 31%, so that on average the implementation of these two tools manages to reduce the NCT to 29%.

6. Pilot study

To validate the results expected from the development of the 5S methodology, its implementation began in one of the warehouses of the active works in March 2022. The first step is to carry out the process in coordination with senior management since their commitment to the development of the methodology is important for the success of the pilot project. Then the current situation of the warehouse was analyzed, and a record of its inspection was made. The 5S evaluation of the current situation shows that the warehouse is in poor condition fulfilling only 50% of the test items. Figure 11 shows the evaluation results that can appreciate that self-discipline is the higher problem because of the lower score. Also, in the current situation, the category of the result is regular.

In the first S, the objects stored with red, orange, and green cards were classified as shown in Figure 12.

The second S orders the warehouse, as shown in Figure 13, the 5S signaling tapes are placed in the areas that the materials or tools will occupy according to their classification. In addition, the preparation of kits by activity and the importance of the kitting tool in the proposal was taught.

In the third S, it was cleaned following the cleaning procedure and schedule. In the fourth S, visual controls were implemented, such as the ideal condition cards, the tool profile, and the use cards when a tool is removed, thus obtaining data such as the person in charge and the area in which it is being used in real-time. Figure 14 shows the current situation of the tools in the

Figure 11. 5S evaluation summary before implementation.

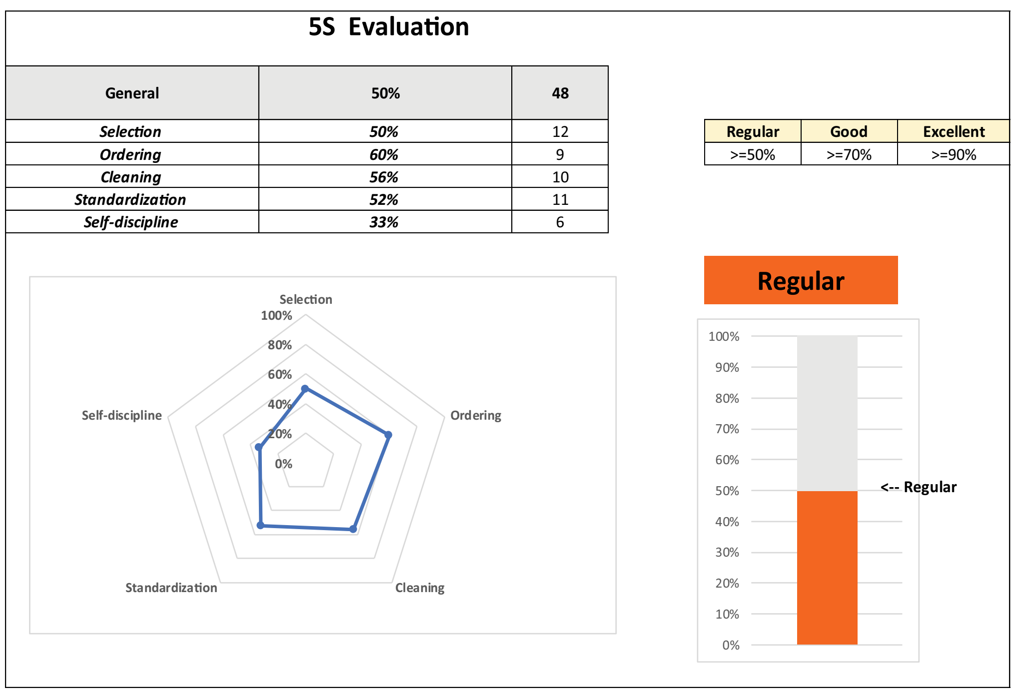


Figure 12. Classification objects.

Figure 13. Implementation of marking tapes.

Figure 14. Tools: Current situation.

warehouse, messy and without easy access; however, Figure 15 shows the order of the same tools but with the use of the tool profile.

In the last S, each ordered section is labeled, the learning in the training is evaluated and the 5S evaluation is carried out. As can see in Figure 16, after the implementation of 5S the score increased by 28% and the category changed to “Good”.

In conclusion, the simulator allows us to affirm that the proposal based on the implementation of Kanban and TPM generates the expected impact as can be seen in Figure 17. The quality of generated orders increased by 22% with Kanban implementation. Likewise, with the implementation of the TPM, equipment shutdowns will be reduced, which can be seen in the increase in

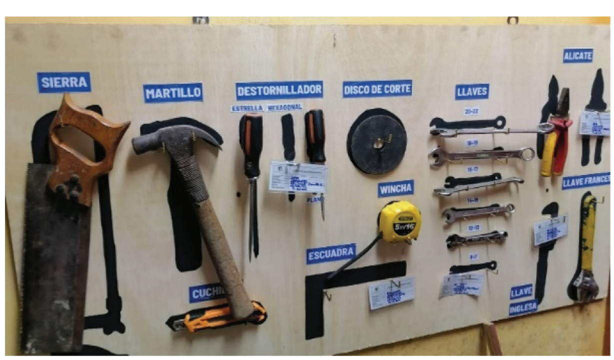


Figure 15. Tool profile.

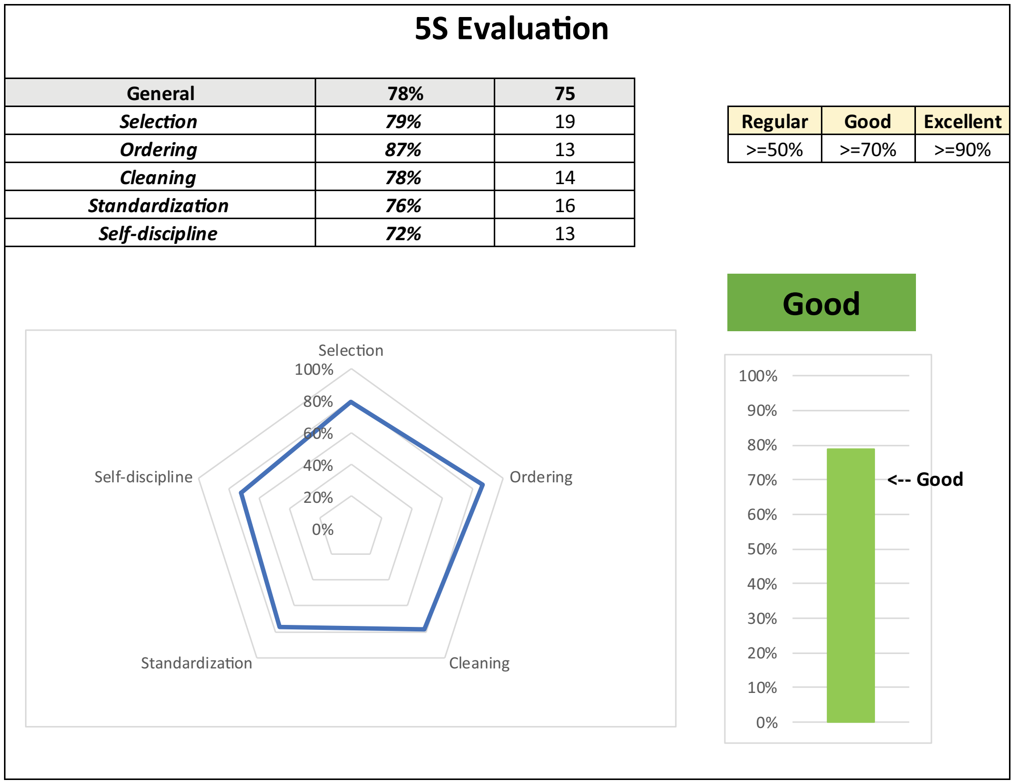


Figure 16. 5S evaluation summary after implementation.

Figure 17. Evaluation and control indicators validation.

ITEM	INDICATOR	AS IT	TO BE	DIFFERENCE	FORMULA
KANBAN	Quality of generated orders	48%	70%	22%	(Orders generated on time)/(Total orders generated)
5S	5S evaluation	50%	78%	28%	(Actual score)/(Ideal score)
	Index of physical losses	50%	35%	15%	(Physical Input - Physical Outputs)/ Physical Input
TPM	OEE	56%	67%	11%	*Availability x Performance x Quality*

availability by 13% and OEE by 10%. That is why, with the results obtained, it is possible to affirm its viability.

Finally, it is important to evaluate the economic viability of the project in the company under study. Table 5 shows the variable income and costs for the next five years when implementing the proposal, in addition to the development of the cash flow, a capital investment of $4,229 and a fixed cost of $714 must be considered. With this, the result obtained from the economic cash flow is an NPV of $10,131 and an IRR of 85%, from which we affirm that the project is viable and profitable since it has an IRR > COK (13%) and a positive NPV.

7. Discussion

On the one hand, with the context aforementioned, it is indicated that the reduction of the NCT according to the literature is 5% with the implementation of the proposed model. Thus, it is initially expected to reduce non-contributory times from 29% (current) to 24%, obtaining a total reduction of 2,591 MH per year.

On the other hand, as shown in Figure 17, the results of the validation by the Arena software and the pilot implementation indicate that the Kanban tool increases the quality of generated orders from 48% to 70%, reducing the first year 51 MH the time waiting for orders generated late. In addition, the 5s methodology increases the rate in the evaluation of 5s criteria by 28% and decreases the rate of loss of materials and tools by 15%, resulting in a reduction of 1,851 MH per year in waiting time due to loss or damage to materials. Finally, the TPM tool improves the OEE indicator by 11%, obtaining a reduction in the first year of 469.7 MH due to machinery breakdown stops. All this generates a decrease of up to 6% of the NCT, adjusting the current value obtained during the simulation from 32% of the non-contributory time to 26%, in other words, it decreases by 3,262 MH per year. This exceeds the expected values according to the literature by 1%, allowing us to validate the impact of the proposed proposal. The contribution of the proposed model is evidenced since the goal set by the technical gap is exceeded, where Hossain et.al states that the international average of NCT is 25%. However, with the proposed proposal, it will be possible to reduce the NCT from 29% to 23%.

According to Aslam et al. (2020), the Last Planner System is recommended to reduce the NCT in construction projects. Also, some tools that allow construction companies to understand their status and the necessity for production improvement and production waste identification are the Gemba Walks (Martim et al., 2018). Bearing in mind, one might say that if these two tools are included, it can reduce the NCT more. However, conforming to Gjerde et al. (2019), although the Last Planner System (LPS) has been proven to deliver target performance in construction projects, to date, most engineering contractors have struggled to implement it in practice. Another tool that can improve the model according to X. Wu et al. (2019) is JIT because it can shorten the waiting times of workers and the equipment required. It has also been applied to the timely treatment of equipment failures and hidden safety hazards, the establishment of appropriate construction safety plans, and the elimination of periods of idleness. For the inefficient construction management plan, workers must spend more time waiting. This study implemented these tools through a case study, but one cannot fully discard the impact of digitization in production improvement and waste identification. Therefore, the proposal model could be enriched to reflect a more representative model involving recent technologies' use.

Moreover, it's important to consider the economic impact of the proposal because it shows that the company would go from having a profit margin of 10% to 14% per service which is equivalent to $10,124.09 per year. Also, Cortez and Alan Ittyeipe (2021) study mentioned that the construction industry is a sector that has a high potential for employment. El Peruano (2021) stated that the performance of the construction sector generates a greater demand for labor at the national level. According to the INEI (2020), in 2020 approximately 1079 thousand jobs were generated. According to the INEI (2020), in 2020 approximately 1079 thousand jobs were generated. Therefore, one can affirm that by increasing the profitability the sector will generate more employment. The proposal presented aims to reduce the amount of non-productive time, generating a greater amount of profit for the sector. Another benefit of the proposal is to avoid the demotivation of the workers when doing the tasks. According to Rojas and Gisbert (2017), the 5S methodology improves the work area and maintains an environment under safe conditions, increasing the motivation of workers. Considering the use of technology helping to enhance construction safety and foster training, one can benefit from several state-of-the-art (SOTA) models such as AI, ML, and DT but it is also essential that workers physically practice and simulate process improvement through experimental implementations such as 5S and LPS. In this respect, the use of 5S, Kanban, and TPM have considerable potential to reduce waste in construction projects. In addition, the TPM and Kanban tools, it was managed to improve the control of operators and production. All of this helps to execute the philosophy of continuous improvement in the company under study since motivation and training are necessary to develop self-discipline when executing activities with a good level of work.

According to Pekarcikova et al. (2021), Industry 4.0 has been taking ground recently to streamline the process with the digitization of the supply chain. Likewise, procurement planning also makes use of technology to avoid excessive or insufficient deliveries of materials. The DT is another initiative for the digitization of operations and for more effective processes. Schluse and Rossmann (2016) implied that DTs are virtual substitutes of real-world objects involving smart objects appearing as intelligent nodes within the internet of things (IoT) and services. In this respect, they act as highly effective tools for simulation-based development and operation of complex systems. Teisserenc and Sepasgozar (2021) proposed a technological framework that used blockchain technology to enhance the effectiveness of DT through trust, security, decentralization, efficiency, traceability, and transparency of information through the project lifecycle. Mateev (2020) indicated that state-of-the-art technologies such as IoT, cloud computing (CC), big data analytics (BDA), and artificial intelligence (AI) have largely impacted the building industry as part of the Industry 4.0 transformation. He further added that DT is also a key enabler for Industry 4.0 and helps to create energy models for optimization, investigation of complex structures, structural health monitoring, and enhancing human safety. Furthermore, Piew (2020) mentioned that lack of trust is a major problem in procurement and current practices are not sufficient to track the provenance of faults, make contract alterations, and drawing revisions in a timely manner. The study by Isikdag (2019) implied that e-procurement only comes with a few benefits compared to its non-electronic counterpart for the fact that there is a lack of trust, inadequate cyber security, and unsatisfactory legal structure. In this respect, he proposed that blockchain technology can be a good solution to address these challenges through decentralized information, information privacy, and standardization of regulatory bodies. Özdemir and Hekim (2018) highlighted that Industry 5.0 is rising from the need of democratizing knowledge coproduction from Big Data. They further indicated that Industry 5.0 is positioned to use extreme automation and Big Data through safe and innovative technology policy driven by 3D symmetry in innovation ecosystem design.

For Goh and Goh (2019), one of the most effective tools for digitizing procurement systems is an E-Kanban system, which uses electronic signals through codes allowing real-time communication between the upstream area of the process and increasing the visibility of the system. The incorporation of this tool is expected to have a technological impact on the company since the bases are laid for the design of an interactive digital Kanban between the warehouse area, the construction site resident, and the purchasing area, with the use of a card with a color traffic light. When this tool is designed, it is expected to change the traditional system for better communication in real time between individual subsystems of the company for correct purchasing management. In addition, the visibility of the E-Kanban system is improved with the variation of the cards to ones with a color traffic light indicating the flow status of the order placed. However, improvements are recommended to be applied over time considering the company's growth and the staff's cultural change for lean production. As is the intensification of the digitization of the tool with Industry 4.0 technology, expanding its use by creating individual subsystems between the areas of the company, and strengthening quality communication in the production and logistics processes.

Cortez and Alan Ittyeipe (2021) affirm that construction and demolition waste represent the largest flow compared to other industries. The construction industry is considered one of the largest sectors in terms of environmental impact and resource exploitation as it faces major problems due to non-compliance with resource management principles. The solution for waste minimization is to design correct management that allows us to reduce the number of materials used and thus prevent the creation of excesses. Likewise, Luangcharoenrat et al. (2019) state that some of the causes of the generation of construction waste are poor planning of activities, as well as inadequate management of purchasers and suggest that the characteristics of an efficient logistics and procurement process should focus on the participation of suppliers, effective material management and efficient bill of quantities.

Currently, the sector has a great environmental impact, due to its high rate of waste generation from construction waste. According to Janani and Kaveri (2020), the materials that are usually wasted are cement (10.5%), bricks (5%), concrete (1%), and steel (3%). They emphasize that the main reasons are the misuse of the material, inadequate handling, and transport, as well as poor storage, due to the lack of a good location system. It is intended to reduce the probability of waste due to handling and poor storage, with the implementation of the 5S methodology, due to the development of Kitting and the organization of the warehouse taking into account the specifications of each material.

Given this background, it is shown that the construction industry still suffers from high rates of construction, demolition, and environmental waste. On the other hand, the industry has not yet developed effective working solutions to avoid this big amount of waste and low productivity. The results of this study provided that with a proper organization of 5S and other tools such as Kanban, and TPM, companies can develop proper means of managing waste and considerably reducing the non-contributory time, which is a major setback for effective production. Therefore, the results and validation provided in this study can lead industry practitioners in terms of observing the effectiveness of Lean tools and how a construction company can beat non-contributory time. The provision of real data can further thrill production specialists and employees to make use of Lean tools in a wider frame.

8. Conclusions

The construction industry is one of the most waste generating industries leading to low productivity. Especially, the non-contributory time rate in construction is alarming. Considering this, the study proposes a validation model to reduce non-contributory time with respect to some basic Lean tools such as Kanban, 5S, and TPM. The model was tested with a construction company operating in Peru. The model proposed managed to reduce the TNC by 6%, which satisfied the proposed objective of reaching an international standard for the sector. Furthermore, the proposed model helped to increase the equipment availability by 10%, reduced the downtime due to delayed orders by 14%, and material loss and damage by 28%. It was shown that the Lean methods implemented made a considerable contribution to the improvement in various areas such as time, cost, and quality. Finally, for the development of the project, a budget of 20,493.09 US dollars was necessary and it was observed how the proposed model brings up economic viability, obtaining an NPV (Net Present Value) of 38,674.04 US dollars and an IRR (Internal Rate of Return) of 85%, which is greater than the established COE (cost of equity).

Given this background, one can conclude that the validation model proposed in this study might be a preliminary guide to experiencing less waste in construction projects. On the other hand, the efficiency of the model can be enhanced by integrating more Lean tools of which their effectiveness has already been proven. In this respect, the model had some limitations for the fact that it relies on certain subjective measures regarding the implementation of specific Lean tools, and it has only been tested with one company's data. In case of more data, the model might generate different results. Despite the limitations, the results that the study proposes can be generalizable for the construction industry practitioners and industry practitioners might benefit from the findings to revise and revisit their strategies to overcome challenges related to time, cost, and quality.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

Data availability statement

All results of the simulation that was included in the paper can be found here: https://drive.google.com/drive/folders/1uQGHLkIBI9wUW3Cfw2enjFDjdRP3fsD9?usp=sharing

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