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Original Article

A Proposed Lean Approach Model to Increase the Operational Efficiency of Natural Gas Connection Installations in Metropolitan Lima

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Abstract - *The construction sector is significant, contributing approximately 10% of industrialised countries' Gross Domestic Product (GDP). However, it is complex and associated with a high level of risk that leads to failures in terms of time, cost and quality. Thus, problems are evidenced in the execution of infrastructure projects, such as delays, cost overruns, poor quality of work and increased musculoskeletal disorders in workers. The present study seeks to increase operational efficiency by addressing the fundamental reasons and causes identified in the study, delays in the work plan, unproductive work time, and work stoppage time. Consequently, these causes have generated an economic impact of 8.62%. Given the above, a pilot validation was carried out where it was proposed to implement Lean tools (Standardized Work), an ergonomic analysis (Economy of Movements) and a Behavior Based Safety System (BBS) to the positions with the highest incidence of occupational hazards in order to solve the sub-causes that generate low efficiency. Finally, the proposal allowed for increasing the operating efficiency of the gas installations to 88.00%, reducing the cycle time by 45.00%, increasing the safe behaviour index by 45.16% and reducing the average dysergonomic risks by 54.84%.*

Keywords - *Efficiency, Standardized work, Lean construction, Ergonomics assessment, Behavior based safety.*

1. Introduction

Like all economic activities in the country, the construction sector was affected by the covid-19 outbreak. From March 2020 to February 2021, the national production decreased by 11.97% [1]. However, based on the Construction Economic Report No. 44 carried out by the Peruvian Chamber of Construction (CAPECO), the GDP of the construction sector has presented a positive variation of 38% in the period July 2020 - June 2021, about the previous year, which shows growth in this area [2]. In addition, within the sector at the national level, there are types of construction with greater participation, including formal and informal housing, as well as public-private infrastructure, with a percentage of 40%, 10.6%, and 4%, respectively [2]. Consequently, from these types of projects, other infrastructures related to the need of natural persons to develop and improve their quality of life are also involved. The tasks of natural gas installation services stand out, which are in more significant growth, occupying the first place for the projects most likely to be developed in the sector, with an average total of 6.00 in the construction sector. In addition, the growth of natural gas connection services has shown an increase of more than 20% each year since 2017 concerning the accumulated number of residential natural gas connections in Lima and Callao. For 2022, a goal of 1,523,300 internal links is estimated, 15.7% more than in 2021 [3, 4]. It should be noted that, at the end of the second quarter of 2022, 68 have been carried out.

Although natural gas consumption in Peru is accurate, it is constantly growing; there are problems in natural gas installation and connection services that affect construction processes and result in low efficiency, which have partly increased due to the recent financing impulse carried out by the government through the Bono Gas program since 2016, supporting a total of approximately 2 million gas connections by the end of 2020. One of the problems is the hours needed to complete a project, which only sometimes meets the delivery deadline, exceeding the projected schedule. Also, there are variations in the execution times of the projects, in which it is observed that, since the first semester of 2021, it has been increasing compared to the previous year [5]. Likewise, another problem that affects the efficiency of the natural gas connection service is the need for work experience, delays in payments, rework due to labour errors, lack of supervisor experience, and shortage of materials. Also, there are reworks in construction projects that are generally caused by a lack of labour skills, non-compliance with specifications, frequent change orders, inadequate work planning, and inadequate coordination and integration [6]. As a result, construction services continually suffer from rework attributable to poor project management practices, inherent dangerous characteristics, roughness, uncleanliness, and inadequate staff competence and knowledge [7].

In the search to improve and increase the efficiency of the construction processes, there are cases in which ergonomic evaluations were applied, achieving an improvement in efficiency in 35% of the workers by adopting new postures and activities with less ergonomic risk in the positions work [8]. In another case study, researchers increased productivity by an average of 6% and reduced rest days required due to occupational diseases by 9% through participatory ergonomics [9].

On the other hand, there is evidence of the management of Lean tools for the reduction of waste that affects efficiency and productivity in construction projects, resulting in a 41% increase in productivity and a 17% reduction in cycle times. [10]. In the same way, In the case of construction and installation of finishes, the implementation of the 5S method and the time study managed to identify that 78% of the activities carried out by the operators did not add value to subsequently reduce them and reduce the average time by 50%. Search and delivery of items and equipment. [11].

Although it was possible to increase the efficiency of construction activities in the previously mentioned investigations, the tools used were addressed independently. However, based on the results, the feasibility of implementing the movement economy can be determined, as part of a work-study, in conjunction with the standardized work and behaviour-based safety tools, to optimize the evidenced results, applying it in a case study belonging to the construction sector.

2. State of the Art

2.1. Efficiency Situation in the Construction Sector

The construction sector is one of the most complex and is associated with a high level of risk that leads to failures in terms of time, cost, and quality. According to the sources consulted, labour productivity is an essential element influencing most construction projects' profitability. According to the literature consulted in the construction sector, there are key productivity constraints such as technology, labour, legal compliance, and project management that have led to various problems in the execution of infrastructure projects, such as delays, cost overruns, and poor quality of work, which has generated concern and the need to seek improvement alternatives to create value and competitiveness [12-15].

2.2. Problems of the Construction Sector

Secondly, it is stated that delays or delays in the work plan are one of the main problems affecting construction projects because they impact non-compliance with activity schedules. It is emphasized that this problem can require up to 26% additional time to complete the project. The authors agree that there is also evidence that these delays in construction projects increase costs, reduce project quality, reduce the performance of activities, and harm companies by being unable to start new projects [16, 17]. The costs associated with rework range between 10% and 15% of the project's total cost.

2.3. Lean Construction Tools to Increase the Efficiency of Natural Gas Facilities

In the same way, the standardization of work applied in construction activities can reduce the rate of rework and rejections by 73%, reduce the time spent on activities that do not add value, reduce cycle time by 23% and reduce variability up to 84%. in construction procedures. In addition, another tool that is applied in the construction industry is the construction study, which is responsible for increasing efficiency through a systematic evaluation of activities to optimize resources and performance. This tool covers two critical points: the study of methods (the analysis of operations, planning, and movements) and the measurement of work (the time dedicated to a specific task) [18].

2.4. Techniques to Reduce Accidents and Non-Ergonomic Risks in Construction Activities

In the same way, the musculoskeletal disorders frequently observed in the construction sector stand out due to the high number of manual handling jobs. Likewise, they affirm that the use of different ergonomic risk analysis methods, such as Rapid Entire Body Assessment (REBA), Ovako Working Analysis System (OWAS), and Quick Exposure Check (QEC), allow us to identify the most affected parts of the body in construction works are the waist, with 73% of activity; the shoulder, with 69%; the back, with 66%; and the foot together with the ankle, with 26%. In addition, the authors state that by analyzing different tasks that can cause damage to the musculoskeletal system, a risk map of the body could be made from the results obtained for each case study [19].

2.5. Application of Other Alternative Tools to Improve Efficiency

Finally, the authors address different tools to improve the efficiency of processes in the construction sector through methodologies, such as lean manufacturing, Value Stream Mapping (VSM) tools and standardization of work and Building Information Modeling (BIM) methodology, which allow for reducing the delivery time of projects between 30% and 4.6%, respectively[20]. The situation is due to reducing and eliminating activities that do not generate value and the elimination of rework, achieving the standardization of procedures and improving human resources through their training [21-23].

3. Proposed Model

In Figure 1, the proposed model is presented, based on the PDCA cycle and the literature review carried out for this research which has an estimated time of 03 months of implementation.

First, in the planning stage, a visual analysis of the workspace is carried out, determining the main problems that generate inefficiency, a literature search for solution tools, and the proposal of indicators to measure the model's success [24-26]. Then, in the Do stage, various lean construction artifacts will be used and applied in the following components: Safety Based on Behavior (SBC), in which the actions and work methods of field operators will be observed to implement proposals for improvement and a change in their behaviors and processes, ergonomics, in which the REBA, NIOSH, SNOOK, and CIRIELLO evaluations will be carried out to propose changes and improvements and, finally, the standardized work for the analysis and elimination of activities that do not generate value. Then, in the verification stage, the data will be stored, and the indicators will be calculated to measure the model's success during its validation in the case study to mitigate the problems of low operational efficiency.

Finally, in acting, the continuous improvement cycle is applied, considering the results obtained and the opportunities for improvement identified in the observations [27]. The data will be stored, and the indicators will be calculated to measure the model's success during its validation in the case study to mitigate the problems of low operational efficiency [28].

The main contribution of the proposed model is the unification of the tools Safety System Based on Behavior, Standardized Work (SW), and Economy of Movements, which have yet to be applied jointly in a company in the construction sector, to increase the efficiency of domestic natural gas installations.

3.1. Model Components

3.1.1. Behavior-Based Safety

The SBC methodology significantly reduces the rate of accidents in the construction sector, increases the rate of safe behaviour in workers without excessive use of resources, and can be measured reliably. Performance improvement is due to the importance of setting objectives and giving feedback to workers as observations are recorded in the case study. Likewise, the SBC promotes the commitment of the collaborators of the different areas to increase performance as there is a review of the study's objectives [29, 30].

3.1.2. Ergonomics

The REBA postural analysis method reduced high-risk factors and injuries by 17.55% and increased working conditions and worker performance [31]. Likewise, musculoskeletal disorders are frequently observed in the construction sector due to the high number of manual handling jobs.

In addition, they state that the use of different ergonomic risk analysis methods, such as REBA, OWAS, and QEC, allow the identification of the parts of the body with the most significant risk in the construction industry, such as the waist, with 73% of activity; the shoulder, with 69%; the back, with 66%; and the foot together with the ankle, with 26% [32].

3.1.3. Implementation of Standardized Work

The standardization of work, applied in construction activities, can reduce the rate of rework and rejections and reduce the time spent on activities that do not add value. Likewise, work standardization in construction activities reduced cycle time by 23% and variability by up to 84% in construction procedures. These results can be obtained by implementing standard work sequences or operating systems, establishing daily work packages, eliminating lean waste in processes, and inspecting and testing plans for quality verification. Considering this evidence, the decision is made to opt for this tool to seek to reduce the rate of non-compliance with construction procedures, rework,

The model allows for demonstrating a sequence of procedures, which complement each tool with each component, improving installation efficiency and reducing times due to high risks, and improving working conditions and methods during the project's duration. Also, workers will not have to rework or be interrupted during the inspection[33]. Additionally, during the implementation, there will be a low opportunity cost since the activities to be carried out by each tool are typical of their daily activities. A team has been defined for the implementation and monitoring of the proposal.

3.2. Indicators of the Proposed Model

3.2.1. Indicator 1 (I1): Efficiency

A study has concluded that the proposed Lean Construction model can increase efficiency by up to 69.00% [27].

$$I1 = \frac{A}{B} \times \frac{C}{D} \times 100$$

A: Number of facilities reached
B: Planned facilities
C: Time invested
D: Expected time

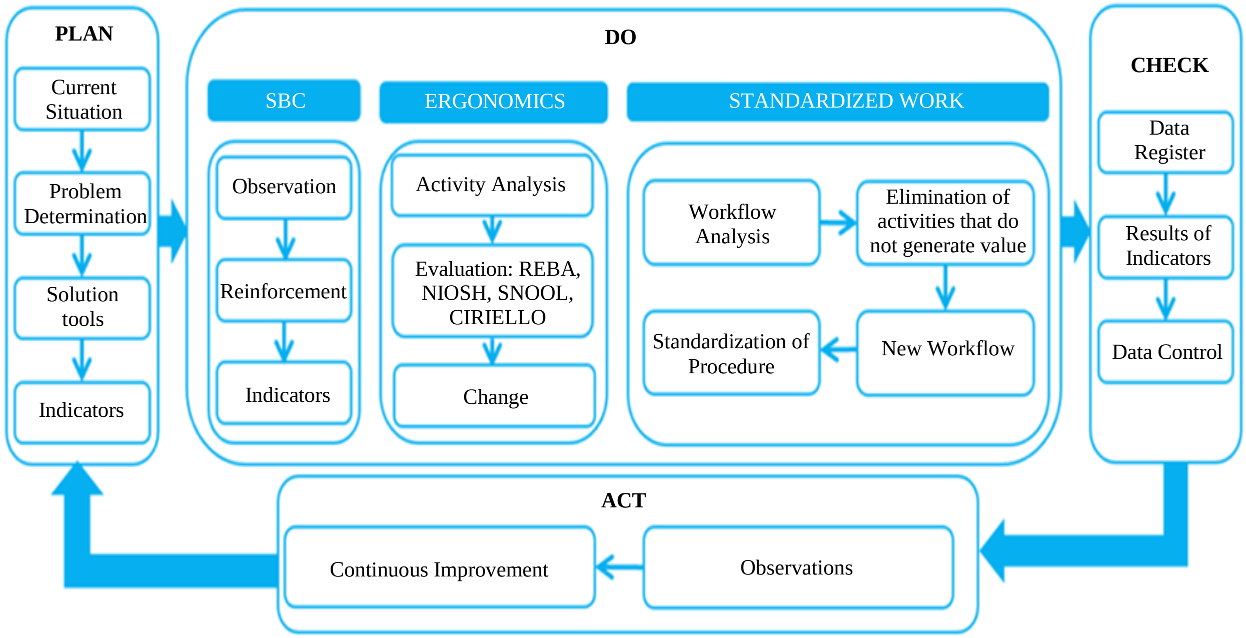

Fig. 1 Proposed model

3.2.2. Indicator 2 (I2): Reduction of Cycle Times

The study has concluded that the proposed Lean Construction model can reduce cycle times by up to 57% [28].

$$I2 = E - F$$

E: End date
F: Start date

3.2.3. Indicator 3 (I3): Index of Safe Behaviors

A study has concluded that the proposed Behavior Based Safety model can increase the rate of safe behaviors by up to 90% [34].

$$I4 = \frac{I}{J} \times 100$$

I: Safe behaviors
J: Behaviors observed in primer

3.2.4. Indicator 4 (I4): Level of Disergonomic Risk Reduction

A study has concluded that the proposed Lean Construction model can reduce disergonomic risks by up to 50.00% [28].

$$I5 = \left(\frac{\frac{K - L}{K}}{\# \, Evaluations} \right) \times 100$$

K: Σ Baseline Assessment Score
L: Σ Final evaluation score

3.3. Validation Model

3.3.1. Initial Diagnostic

The case study where the pilot test will be implemented is a company in the construction sector dedicated to installing gas in homes. It is because it is a company that provides this service to one of the most recognized companies in Peru. The company was founded in 2012 in Peru. The most critical process in the case study is the internal facilities since it has been determined that there is low efficiency, with a value of 62%, below the sector. It is due to the delays in the work plan (35.89%) generated by delays in the work progress report and the lack of standardization of construction procedures due to unproductive work times (27.31%) caused by the disorder of the workspace and the lack of debris cleaning procedures. Likewise, due to the work stoppage time (22.32%) generated by the inadequate safety procedure and the hours lost due to a musculoskeletal disorder. Of the problems registered, it was in the internal installation of natural gas, for which the model's improvements in said activities have been proposed. Consequently, this low-efficiency problem has generated a negative economic impact of 8.62% during the period from September 2020 and August 2021 due to penalties and the use of overtime.

3.3.2. Validation Design

For the proposal validation, it was determined to carry out the pilot test alternative in the study company since the tools we will apply in the project can be verified according to the observation and continuous improvement on site. Therefore, this method is suitable for model validation. Finally, this validation will collect all the necessary information to determine if the model solves the problem significantly, positively impacting all interested parties. Then, the results will be verified with the indicators proposed for the investigation.

SBC Component Validation

The Behavior-Based Security System was defined to carry out the training and formation of teams of observers. Six observers were defined. In the case of exceeding the permitted load limit of 25 kg, it was reduced to 32 incidents before it was 200 per month. In the case of postures with dysergonomic risks, the incidences were reduced to 40 before it was 140 per month. In the case of not using PPE, it was reduced to 12 incidents, which was 120 per month. When not turning off the equipment during the break, it decreased to 20 incidents per month before it was 60.

Ergonomic Component Validation

The validation was structured in principle according to the four stages, as evidenced below: Training, instructions, proposal implementation, and observational evaluation. Initially, it was scheduled to conduct training sessions for all company members, educating the recent procedures, systems, and work methods through support material (Pictures, audiovisual media, and group talks). The preparation of the instructions fulfils the objective of illustrating the procedures, techniques, and processes.

The new positions were implemented in the main internal installation activities. Through the observational appreciations for each of the proposals constituted and carried out; in this case, the evaluation with the NIOSH and SNOOK and CIRIELLO methods used in the material storage process; likewise, the REBA method evaluated the proposals for the activities of cutting the wall, cutting the pipe network and cutting the pipe network. By the results of the observational systems specified in the previous section, a percentage reduction in risks can be verified for each proposal established as follows:

- Wall chipping: The REBA method was used, reaching a percentage decrease of 69.75%
- Pipe network cut: The REBA method was used, getting a percentage decrease of 12.38%
- Pipe network chopping: The REBA method was used, getting a percentage decrease of 60.37%.
- An average REBA index reduction of 48% was obtained.

Material Storage

The NIOSH method was used for material loading and unloading tasks, obtaining a reduction of 72.88%. Likewise, the SNOOK and CIRIELLO method was used for the material transfer activity, reducing 58.68%. According to Fig. 2, the REBA evaluation results after the model's implementation for each activity were 3 for Pipe Network Chopping, 7 for Pipe Network Cutting, and 2 for Wall Chopping. Therefore, it is determined that there was a notable improvement in the wall-chipping activity after the implementation. As per Fig. 3, the NIOSH assessment after implementation decreased significantly to 0.83. According to Fig. 4, the value of SNOOK and CIRIELLO was reduced to 1 after the implementation.

Validation Standardized Work:

With the help of the two components previously carried out, all activities that do not generate value or present a risk to the worker will be eliminated on-site. In this way, it will reduce the cycle time for each installation to improve the efficiency of the process. The company supervisors are informed of the activities that will be changed for a better workflow. The number of observations is determined with the help of the statistical method International Labour Organization (ILO) for each activity. We proceed to train the 20 crews participating in the project; since one team performs the entire home gas installation procedure, this training will indicate the new workflow and the activities that will be eliminated to reduce time.

The new workflow demonstrates the time reduction in all the activities carried out. Since changing the loading method, there has been a reduction in the material unloading activity of 50%. The timing of the model shows a reduction of 17.00 min in the debris cleaning activity at the facility since the model replaces the activities that generate waits with classification and removal of debris. Finally, the timing will be determined to evaluate the new cycle time and analyze the results. A 45% cycle time reduction was obtained as a result.

4. Discussion

This proposed model, as shown in the validation, was carried out over four months to achieve the reliability of the indicators and their results. In this way, to generate a discussion of the importance of the results, a comparison is Figure 4 SNOOK and CIRIELLO evaluation results made with the results of other investigations, allowing us to determine the model as successful for the following studies concerning the construction sector.

4.1. New Scenarios vs. Results

In the first place, on the primary indicator after the implementation of the model, an efficiency of 88% was obtained, which exceeded the level expected by other investigations, which maintained an optimal efficiency of 69.00%. On the other hand, regarding the indicator of cycle times for the Work Study component, a value of 267 min/installation was obtained, representing a 45% reduction of the initial diagnosis, considering it an improvement item for other investigations. In contrast, the goal proposed by other studies was up to 57% [35].

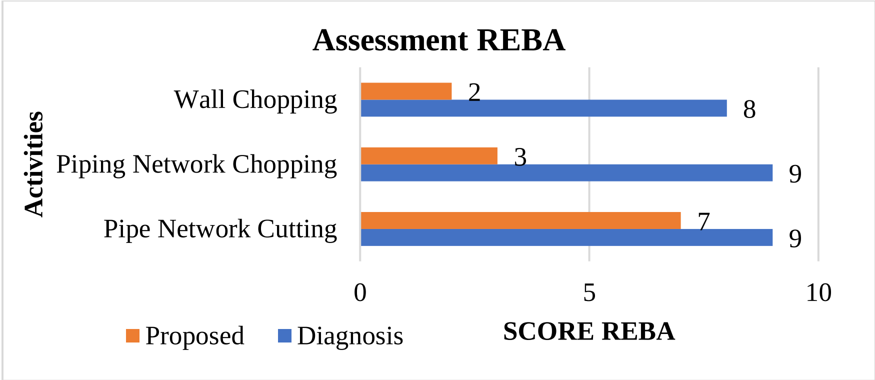

Fig. 2 REBA evaluation results

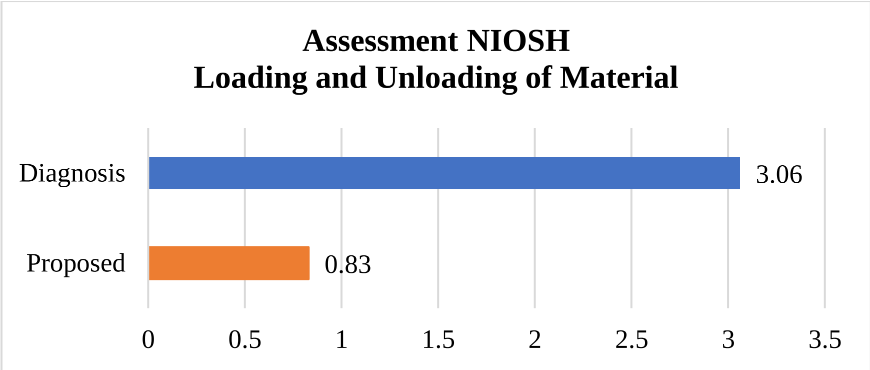

Fig. 3 Niosh evaluation results

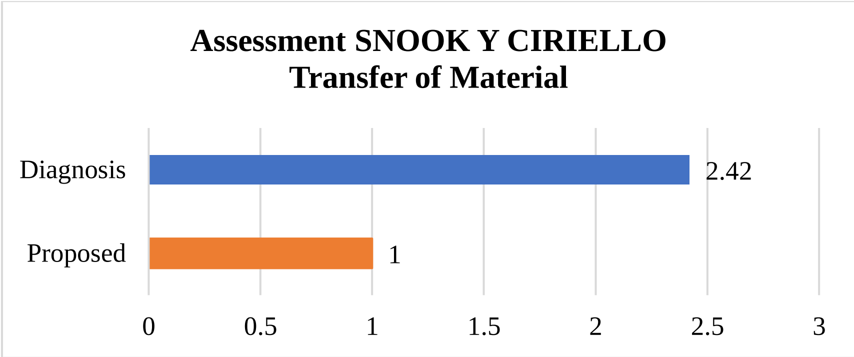

Fig. 4 SNOOK and CIRIELLO evaluation results

Also, on the Behavior-Based index indicator, an average index of 90% was obtained, achieving the objective of other investigations that had proposed an index of at least 90%[36, 37]. In addition, for dysergonomic risks, 48% was obtained, being almost at the level proposed by other investigations for this indicator since they consider that at least a risk level of 50% must be found.

5. Conclusion

The new work methods and workflow for installing natural gas home networks have increased efficiency from 62% to 88% and reduced cycle time by 45% compared to the initial diagnosis. In addition, on-site work progress and administrative reports have reduced average times from 128.0 minutes to 55.0 minutes. Standard work diagrams were established for internal natural gas installation, and on-site work progress reports were visual management tools so the company's operators followed the tasks. In addition, four non-sequential moments were established for cleaning debris in the facility: classification, elimination, and cleaning of the work area, in which the timing of the model shows a reduction of 17 min. Likewise, a standard distribution was determined for the work components for the installations of one-story houses that require a cabinet. On the other hand, the SBC tool made it possible to increase safe behaviors from 62% to 90%.

In contrast, with the REBA application, a percentage reduction of 69.75%, 12.38%, and 60.37% was achieved for wall chopping, cutting of pipe network, and crushed pipe network, obtaining an average reduction rate of 48%. Likewise, the NIOSH index decreased from 3.06 to 0.83. There is a considerable NIOSH decrease of 72.88% in percentage terms, and the SNOOK and CIERIELLO index fell from 2.42 to 1.

With the results obtained, it can be determined that the model was developed successfully and satisfactorily, leaving the present investigation of the effectiveness of Lean Construction in a novel scenario for the construction sector. Likewise, according to the literature review, the model presented can be applied to other industries with optimistic results, thus justifying the quality of the model. Finally, the study presented allows expanding the literature referring to efficiency in the construction sector, mitigating problems such as delays in the work plan, unproductive work time, work stoppage time, and delay in the transport of materials, thanks to the implementation of tools such as SBC, ergonomics, and standardized work. In addition, for future research, it is recommended to implement the model in a process that involves all activities to evaluate the impact of the tools, allowing a better scope and optimal results.

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