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Artículos científicos

Mejora de procesos de laboratorio de mecánica de suelos aplicando herramientas de manufactura esbelta

Improvement of soil mechanics laboratory processes applying Lean Manufacturing tools

Melhoria dos processos laboratoriais de mecânica dos solos através da aplicação de ferramentas de manufatura enxuta

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Resumen

En la actualidad, la productividad es una herramienta esencial en las organizaciones, la cual se logra con la mejora de procesos mediante el uso de diversas herramientas, filosofías y metodologías de la ingeniería disponibles de manera abierta. La falta de productividad trae como consecuencia pérdidas que repercuten en altos costos, escasos ingresos y, por ende, pocas o nulas utilidades. Existen técnicas que pueden ser empleadas por micro y pequeñas empresas para aprovechar mejor los recursos con los que se cuenta. Por eso, en este trabajo se propone el uso de herramientas de manufactura esbelta o *lean manufacturing* tales como 5'S, diagrama de *spaghetti*, tableros *kanban*, entre otras, para optimizar los procesos en un laboratorio de mecánica de suelos, donde se analiza la calidad de diversos materiales utilizados en la construcción. Durante la implementación de las herramientas se realizó la redistribución de elementos de trabajo y se mejoró el control de los procesos. Como resultado se obtuvo una reducción del 44.88 % en los movimientos requeridos por el personal para ejecutar diversas actividades y se liberó el 32.37 % del área de trabajo que se encontraba desaprovechada, lo que permitió realizar trabajos de forma paralela, mejor el flujo laboral y disminuir la cantidad de muestras en espera. Al implementar tableros *kanban* se consiguió un control y organización que facilitan el seguimiento de los procesos por parte del jefe de laboratorio y el personal, lo que sirve para realizar las actividades de forma ordenada.

Palabras claves: manufactura esbelta, mejora continua, redistribución.

Abstract

Currently, productivity is an essential tool in organizations, this is achieved with the improvement of processes through the use of various tools, philosophies and engineering methodologies available in an open manner. The lack of productivity results in losses that have an impact on high costs and low income and therefore few or no profits. There are techniques that can be used by small and micro enterprises (SMES) to make better use of available resources. This paper proposes the use of Lean Manufacturing tools such as 5'S, spaghetti diagram, Kanban boards among others to optimize processes in a soil mechanics laboratory, where the quality of various materials used in construction is analyzed. During the implementation of the tools, work items were redistributed, and control processes was improved. As a result, a 44.88% reduction was obtained in the movements required by the personnel to carry out various activities, 32.37% of the work area that was wasted was released, which allowed execute activities in parallel, improving the workflow and reduced waiting. By implementing Kanban boards, control and organization was achieved, making easier the management of the laboratory staff to follow up on the processes, carrying out the activities in an orderly manner.

Keywords: Lean manufacturing, continuous improvement, redistribution.

Resumo

Atualmente, a produtividade é uma ferramenta essencial nas organizações, que é alcançada com a melhoria de processos através da utilização de diversas ferramentas, filosofias e metodologias de engenharia disponíveis abertamente. A falta de produtividade resulta em perdas que resultam em custos elevados, baixos rendimentos e, portanto, pouco ou nenhum lucro. Existem técnicas que podem ser utilizadas pelas micro e pequenas empresas para aproveitar melhor os recursos de que dispõem. Portanto, este trabalho propõe a utilização de ferramentas de manufatura enxuta como 5'S, diagrama espaguete, quadros kanban, entre outras, para otimizar processos em um laboratório de mecânica de solos, onde se avalia a qualidade de diversos materiais utilizados na construção civil. Durante a implementação das ferramentas, foi realizada a redistribuição dos elementos de trabalho e melhorado o controle dos processos. Como resultado, obteve-se uma redução de 44,88% nos movimentos exigidos pelo pessoal para a realização de diversas atividades e foi liberada 32,37% da área de trabalho desperdiçada, o que permitiu a realização de trabalhos em paralelo, melhorando o fluxo de trabalho e reduzindo o número de amostras em espera. Com a implementação de quadros kanban, foram alcançados controles e organização que facilitam o monitoramento dos processos pelo gestor e equipe do laboratório, o que auxilia na realização das atividades de forma ordenada.

Palavras-chave: manufatura enxuta, melhoria contínua, redistribuição.

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Introduction

Every company, regardless of its area of specialization, is seeking to improve its processes and productivity to contribute to the optimization of resources, improve its working conditions and be more competitive (Vargas-Hernández *et al*., 2016). To achieve this, there are currently a series of tools, philosophies and agile methodologies focused on obtaining the greatest benefit from the available resources. Among the most used, lean manufacturing methodology (Vilana Arto, 2011), kanban methodology (Gómez *et al*., 2020*)*, 5'S (Quiroz-Flores and Vega-Alvites, 2022), spaghetti diagram (Torres Rodríguez, 2019), and kanban boards (Carrera Cabezas, 2019) can be mentioned, among other.

For example, Gisbert Soler (2015) mentions that the lean manufacturing is aimed at the elimination or reduction of waste in production processes, which allows its adaptability to different areas. On the other hand, in the soil mechanics laboratory, analysis tests are carried out on construction materials, which include the construction and maintenance of land roads and the construction of concrete structures. This type of laboratory handles variable volumes of samples daily, hence the delivery times for results are considered, which varies between five and ten days, depending on the type of client.

In the specific case of this study, it has been observed that the analyzed company faces different organizational problems in the area of execution of laboratory tests, which causes the flow of activities to be not constant and generate delays in the delivery of results. Another situation detected is that the company has work areas and commonly used tools where constant clashes or interruptions occur when carrying out activities. All of this has an impact on a difficult work environment, mainly in the months of September to November, when the workload is greater.

On the other hand, in general, it can be indicated, that the construction sector has not been studied in depth and the percentage that considers the implementation of aspects of lean manufacturing is only 2.73% (Tapia Coronado *et al*., 2017). Some examples of this have led to the creation of the term *lean construction,* although this manufacturing is still under development (Albalkhy and Sweis, 2021). This seeks to maintain productivity and quality processes at significant levels, minimize downtime, changes or waste, as well as other indicators of a company's performance.

This process described was adapted from the Toyota production system (Ahmed *et al* . 2021), which allows a reduction in costs, process duration, safety risks, accidents, errors, rework, waste, among others, as well as improvements in sustainability, inventory management, work predictability, productivity and customer satisfaction (Albalkhy and Sweis, 2021). For Shuquan *et* *al*. (2020), the *lean construction technique* is mainly dedicated to eliminating everything that does not contribute or add value to the final product, regardless of what it is and having a total business vision.

Taking the above into account, a multidisciplinary approach can be generated that applies the principles of industrial engineering to a different area, such as health (Martin *et al*., 2014), education (Montes Dorantes *et al*., 2020), metal mechanics (Montes Dorantes *et al*., 2018), manufacturing (Montes Dorantes and Méndez, 2023; Mexicano *et al*., 2022) or construction. In particular, this approach can be applied to the soil mechanics laboratory, which plays a crucial role in research aimed at assisting engineers and architects in selecting the most appropriate type of construction based on soil conditions.

Therefore, it is necessary to implement strategies that optimize processes within the laboratory, which will not only improve existing procedures, but will also make the most of available resources, such as personnel, equipment and time.

Background

This section presents examples of multidisciplinary approaches that represent successful cases of the application of industrial engineering tools in various areas, with different industrial characteristics. For example, Martin *et al*. (2014) applied tools such as 5'S, A3 (generates a simple problem report with its current outcome and a suggestion), value chain maps, and rapid improvement events to OR processes at Seattle Children's Hospital to optimize the patient care and the staff teamwork.

On the other hand, Torres Rodríguez (2019) used DMAIC tools (define, measure, analyze, improve, and control), 6S, spaghetti diagrams and kanban to improve manufacturing lines in the Stryker company by 12.5%; with this work, significant improvements were achieved in efficiency and in the reduction of material transportation distances. Bosnjak and Bosnjak (2020) presented a method based on lean management to improve healthcare, for which they implemented tools such as 5'S, kanban, Kaizen events and spaghetti diagrams.

Huerta Estévez (2021) applied lean manufacturing, including process mapping and route diagrams, to reduce line stoppages in an automobile assembly plant. Lista *et al*. (2021) carried out a plant redistribution based on lean manufacturing principles in a textile company, which allowed them to reduce costs and unnecessary movements. Rapale (2018) implemented DMAIC, six sigma, 5'S, and color cards methodologies to optimize the search for materials and tools in a cleaning products company, which optimized efficiency and organization.

For their part, Pedraza *et al*. (2021) used lean manufacturing tools as value flow maps to increase productivity and quality in a microenterprise of peanut products. Likewise, Escudero (2020) applied tools such as the balance chart, 5S, and cellular manufacturing to eliminate waste in a pizza assembly company, which decreased processing time and increased productivity. In the area of construction, Carrera Cabezas (2019) used lean six sigma, total productive maintenance (TPM), just-in-time (JIT) and kanban methodologies in a hollow-core concrete slab company, which reduced concrete overproduction and non-conformities in products.

However, Latorre (2017) and Pons Achell (2014) explain that *lean* philosophy *Construction* is a growing methodology in construction that focuses on global projects, considering costs and duration of the project as a whole, rather than individual activities. Table 1 summarizes the methodologies and tools used by the previously analyzed authors.

Table 1. Methodologies and tools used by different authors

AUTHORS	JOB	METHODOLOGY	RESULTS
Marmolejo *et al*. (2016)	Improvement through lean manufacturing tools in a clothing company.	5'S and visual control.	Reduction of lost time due to activities that did not generate value (transportation times) to the process.
Bošnjak and Bošnjak (2020, p. 127)	LEAN System Management in Hospitals.	Lean, 5'S, kanban, kaizen events, spaghetti diagrams, Heijunka, among others.	Use of lean tools to improve and increase standards in medical care.
Martínez *et al*. (2016)	Improvement in patient care time in an emergency unit through lean manufacturing.	Lean manufacturing tools such as value stream mapping and spaghetti diagram.	Reduction in patient waiting time of up to 67%.
Martin *et al*. (2014, p. 6)	Improvement of processes in the operating room through the application of the Toyota lean methodology	Lean, such as 5S, A3, value chain maps, rapid improvement events.	Improved processes in an operating room and the quality of patient care and staff work.
Fuertes and Sepúlveda (2016)	Scrum, kanban and canvas in the commercial, industrial and educational sector. A review of the literature.	Scrum, kanban and canvas methodology.	Commercial sector, Scrum tool, kanban and canvas: 38% Industrial Sector, Scrum and kanban: 33.33% Education sector: Scrum: 28.57%
Pérez and Quintero (2017, p. 411)	Dynamic methodology for the implementation of 5'S in the	5'S, JIT (Just in Time), kanban and kaizen.	Proposal for dynamic methodology in the production area of organizations.

	production area of organizations.		
Peláez Saladriga (2014)	Identification of the bottleneck in the production chain of 100 W luminaires of the electromechanical production company.	Data Envelopment Analysis DEA (Data Envelopment Analysis).	DAE Implementation to obtain bottlenecks.
Pons Achell (2014)	Introduction to lean construction.	Lean Production, Just in time (JIT), jidoka and kaizen or continuous improvement, PDCA action plan (Plan-Do-Check - Act) or Deming cycle.	Use of Lean Production philosophy, and aspects of the Toyota production system in construction.
Torres Rodríguez (2019, p. 5)	Process improvements in a production line.	DMAIC, 6S, spaghetti diagram, kanban.	Increase in efficiency of 16%. Space reduction by 12.5%. Reduction of material transportation distance up to 40% in a medical technology company.
Rapale González (2018)	Optimization design in organizational logistics.	DMAIC, six sigma, 5'S, *spaghetti* diagram and color cards.	Optimized the time spent searching and obtaining materials and tools in a company dedicated to the manufacturing of cleaning products. Increased workflow.
Sánchez Quiroz (2021)	Proposal to improve the maintenance process of measuring instruments and tools to reduce service times.	Lean manufacturing Value Stream Mapping (VSM), 5'S, Poka yoke (error proof), kaizen (continuous improvement).	Reduction of operating costs, attention times for the maintenance process of measuring instruments and tools. Expansion of calibration laboratory capacity from 72% to 95%.
Huerta Estévez (2021, p. 52)	Reduction of in-line material handling in a car assembly plant through the application of lean manufacturing.	Lean manufacturing as process mapping and journey diagram.	Achieved a 50% saving on the production line and an 85% reduction in work cycles in a car assembly plant.
Lista et al. (2021, p. 5)	Lean layout design: a case study applied to the textile industry	Lean manufacturing VSM, spaghetti diagram.	They carried out a plant redistribution in a company in the textile industry, reducing handling costs, unnecessary movements and adjustments to arrangements.
Pedraza et al. (2021, p. 151)	Application of the lean manufacturing methodology to reduce the production time of peanut balls.	Lean manufacturing Value Stream Mapping (VSM).	Identify bottlenecks, improve productivity and quality in a microenterprise dedicated to producing and distributing peanut products. Process times

			decreased and production increased by 35%.
Escudero (2020, p. 51)	Improvement of lead time and productivity in the pizza assembly process by applying lean manufacturing tools.	Balance graph, 5S and cellular manufacturing.	Detected and eliminated waste in a medium-sized company, reducing lead time by 99% and increasing productivity by 20%.
Carrera Cabezas (2019)	Improvement of the production process of hollow core slabs under lean six sigma methodology in the public cement company EPCE.	Lean Six Sigma. Total productive maintenance (TPM). Just in time (JIT). Kanban.	By applying the TPM, JIT and kanban tools, the process time was reduced from 29.75 to 22.58 hours. An adaptation was made to the portable reels, reducing the laying time from 75 minutes to 30 minutes per track. By implementing TPM, the machine conditioning process was eliminated, saving 60 minutes, and by implementing JIT and kanban only the necessary concrete is produced. Thus, downtime is avoided, and casting time is reduced by 30 minutes.

Source: own elaboration

Based on the information presented in Table 1, the use of lean manufacturing principles was proposed to optimize the company's processes.

Materials and methods

The methodology used in this project was carried out over five months in the soil mechanics laboratory and was based on observation and familiarization with the organization of the laboratory and its needs. Once the initial analysis was completed, it was decided to apply the principles of lean manufacturing, whose purpose is to improve processes by eliminating waste, that is, all those activities that do not add value to the product (Vargas-Hernández *et al.*, 2016). This was achieved through the use of tools designed to improve efficiency and organization in the work environment.

Lean tools selected for implementation in the soil mechanics laboratory are characterized by their adaptability to different work contexts. To do this, we began with a focus on the 5'S and visual control, which are based on five principles: *Seiri* (eliminate), *Seiton* (order), *Seiso* (cleaning and inspection), *Seiketsu* (standardization), and *Shitsuke* (discipline) (Pérez and Quintero, 2017). These principles were applied in all work areas, facilitating the organization and classification of tools used by staff, the elimination of tools in poor condition, and the promotion of discipline regarding order.

Total productive maintenance (TPM) was another tool used to maximize equipment performance, which allowed operators to carry out basic maintenance tasks (Carrera Cabezas, 2019). Since laboratory equipment requires periodic certified calibrations, staff were authorized to perform maintenance and cleaning on presses and tools. In this way, we try to prolong the useful life of the equipment until the next certified calibration.

The kanban system, which is based on the use of cards to control and schedule production and materials (Gómez *et al*., 2020), was implemented to keep track of the materials used in the laboratory. Each of them was identified by cards that clearly specify the areas and laboratory tests they must undergo, making it easier for staff and the laboratory manager to locate samples and collect results.

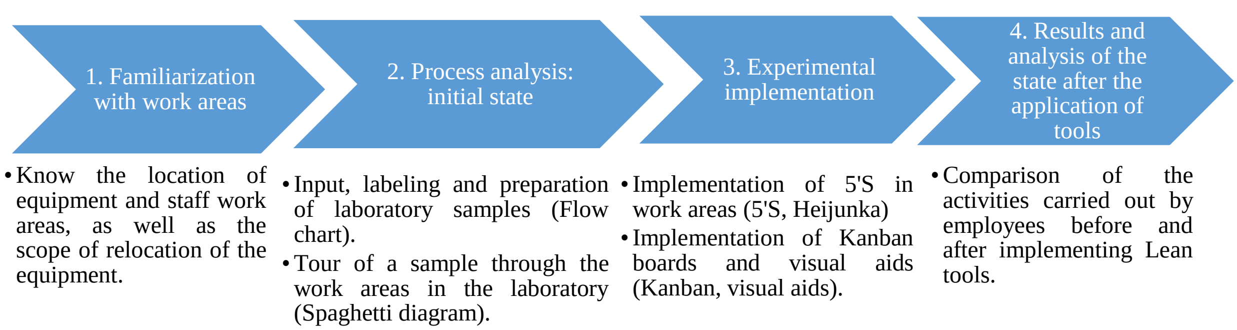
Additionally, tools such as Heijunka, which is based on the synchronization of operations to minimize unnecessary movements (Bošnjak and Bošnjak, 2020), and spaghetti diagrams were used to visualize workflows in the laboratory and areas for improvement. It is important to note that the laboratory managers intend to implement the Kaizen philosophy in the future. Kaizen is a culture of improvement that involves all company personnel and trains leaders to achieve long-term improvements (Dinas Garay *et al*., 2019).

These tools were used to carry out activities in parallel, reduce turnovers, bottlenecks, give order to activities and take advantage of the resources available to the laboratory following the methodology described below.

Methodology

The implemented methodology consists of four main stages: 1) familiarization with the work areas, 2) analysis of the processes: initial state, 3) experimental implementation and 4) results and analysis of the state after the application of tools. These stages are shown in figure 1.

Figure 1. Methodology used to optimize activities in the soil mechanics laboratory



Source: own elaboration

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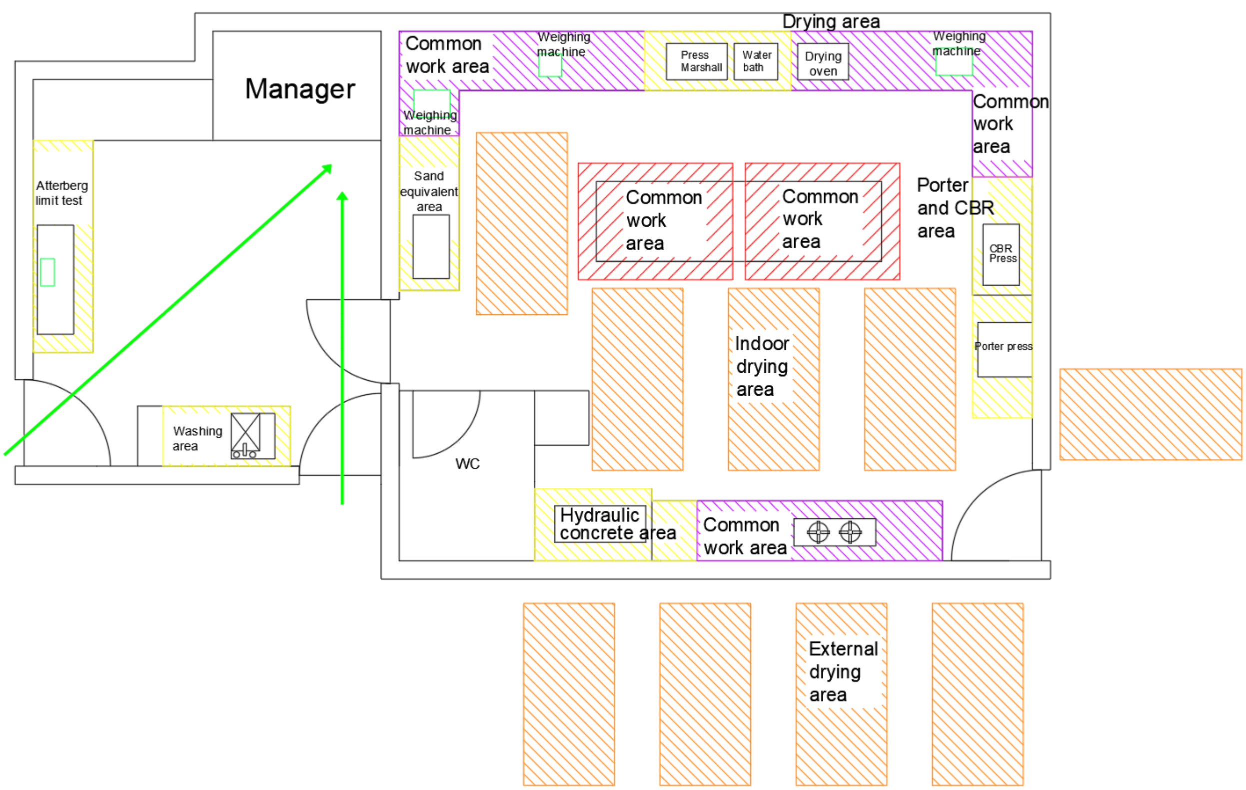
Familiarization with work areas

Taking into account the fundamental of acquiring complete knowledge and a detailed understanding of the work areas available in the laboratory, as well as the activities that are routinely carried out and the exceptional situations that may arise in these areas, in stage 1, called "Familiarization of work areas", a careful observation was carried out. This allowed us to identify that the soil mechanics laboratory is divided into two types of different work areas. First of all, there are the "Specialized Areas", intended for carrying out various laboratory tests. These are not flexible in their layout, as they house specialized equipment that remains in their fixed location (shaded yellow). Secondly, we find the "Common Work Areas", where staff have access to shared and general-purpose tools that are necessary to perform different types of tests or work stages (shaded in purple). Additionally, on the plan (figure 2) the two entrances through which the materials enter the work area are indicated with green arrows. Material drying areas, both interior and exterior, are highlighted in orange in the scheme. Importantly, this lab plan was designed using AutoCAD and is presented visually in Figure 2 for clearer understanding.

Figure 2. Company work areas



Source: own elaboration

Process analysis: initial state

At this stage it was possible to verify that the soil mechanics laboratory organizes its operations around three main areas: “dirt and stone materials”, “asphalt”, and “concrete”. After an exhaustive analysis of these work areas, it was determined that this project would focus on the broadest line of work, that is, the area of “dirt and stone materials”.

Figure 3 presents in detail the diagram corresponding to the line of work related to “dirt and stone materials”. This diagram illustrates how this line breaks down as it progresses through its various phases, which comprise materials entry, preparation, first distribution, second distribution, and culminates with the compilation of all the information in a single production report quality.

Entry, labeling and preparation of laboratory samples

At this stage, the laboratory manager receives the materials and enters them into the system (figure 3, activities highlighted in light green). Then, the material is labeled, which involves recording them in the log and assigning them a work number. Next, it assigns the specific tests that must be carried out and distributes the materials according to the different lines of work, as dirt and stone materials, concrete or asphalt. Finally, start the corresponding processes.

It is important to note that since the laboratory head carries out all these operations, a bottleneck is observed in the company from the moment the materials are received. This is due to the accumulation of waiting samples before they can begin their process, resulting in delays in the execution of tests.

Once the materials obtain their job numbers, they are moved to the drying area, which can be indoors or outdoors, depending on the weather conditions of the day. On sunny days, the outdoor drying area is used, while on rainy days the indoor area is used (figure 2). However, this variability in the drying location considerably complicates the activities of employees.

Figure 3 presents a flow diagram that illustrates the line of work in the laboratory, marking with different colors the different tests to which the samples are subjected. For a more complete detail of the flows, see Figures 4 and 5.

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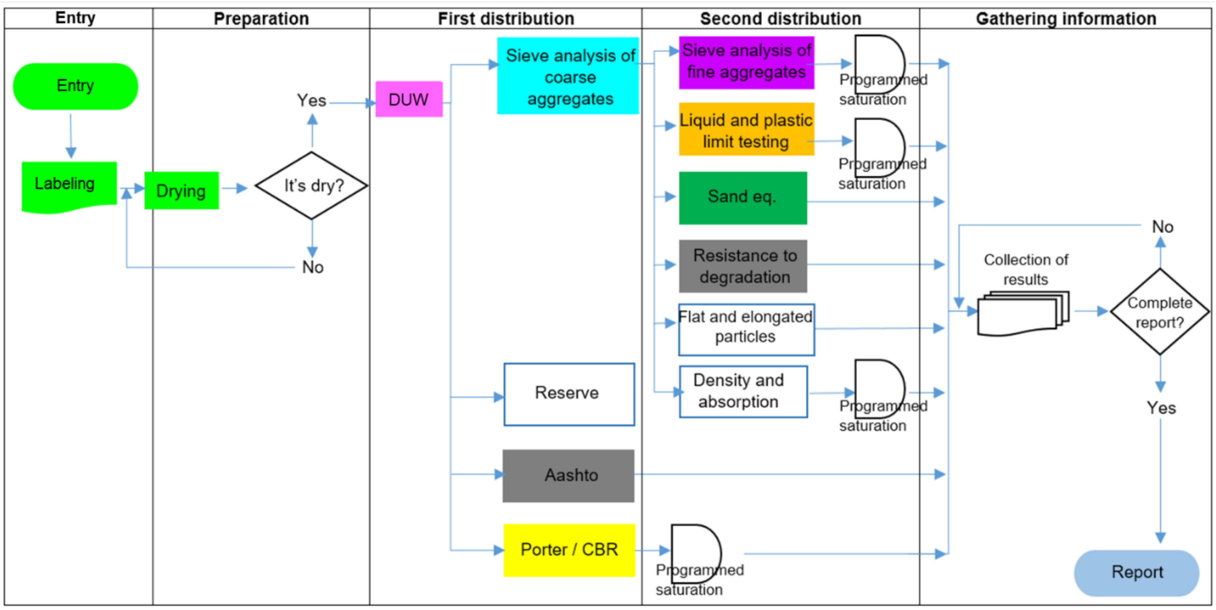
Figure 3. Flow diagram of the earthworks and stone materials work line



Source: own elaboration

Tour of a sample through the work areas in the laboratory (processes)

After the material has dried, the Dry Unit Weight test (DUW) is performed (figure 3, pink box) and the first distribution of the material is carried out, which is divided into four portions. The first is moved to the common worktable, the second is used in the Porter test area (figure 3, yellow box), the third is for the Aashto test (figure 3, gray box) and the fourth is stored.

The material that is sent to the common worktable is subjected to the sieve analysis of coarse aggregate (figure 3, box in light blue) and the fine material obtained is distributed again between the work areas to carry out the liquid and plastic limit tests (as noted in orange in Figure 3). This includes the sand equivalent test, represented in dark green in figure 3, as well as sending to the washing area to continue with the sieve analysis of fine aggregate, marked in purple in figure 3.

It is important to note that during this second distribution of the material a second bottleneck is created. This occurs because the number of samples to be processed can be significant, and some may have a higher priority than others depending on the client's needs and the work season. The sample analysis stage is concluded when the corresponding results from each work area are compiled and incorporated into a quality control report, which is delivered first to management and then to the client, as illustrated in the last stage of figure 3.

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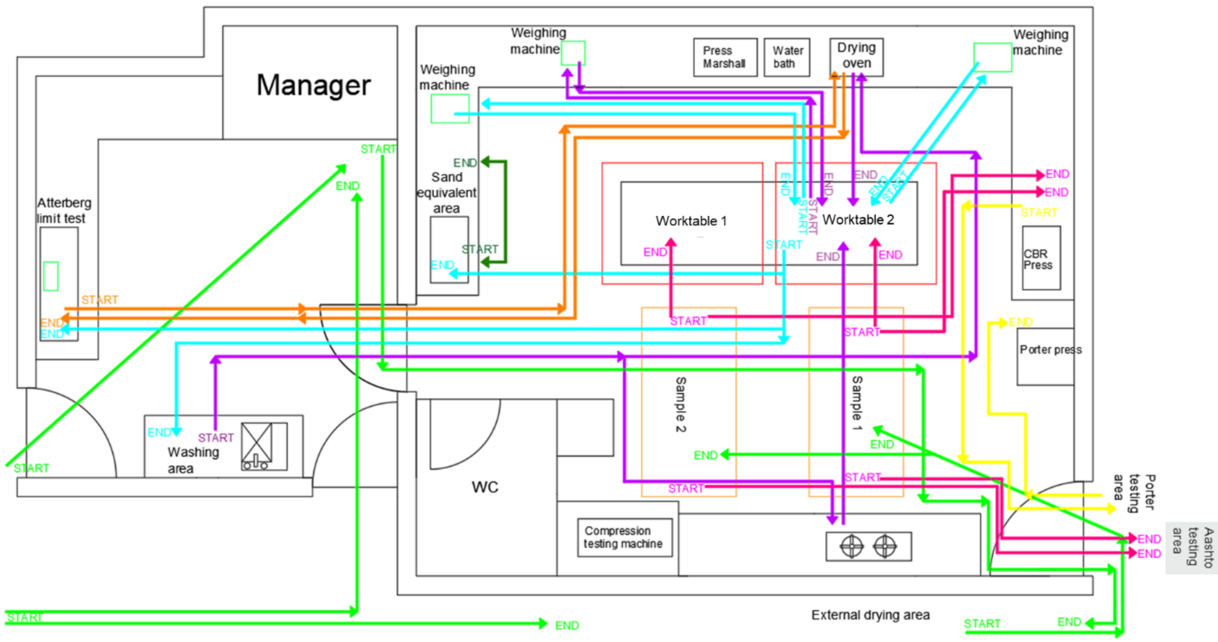
On the other hand, Figure 4 shows a spaghetti diagram (Bošnjak and Bošnjak, 2020) of the complete path of a sample through each of the work areas. This diagram is prepared considering staff movements and measures the number of steps taken to carry out each activity. It is important to note that this route occurs on both table number 1 and table number 2 when the workload is high, which allows work to be carried out simultaneously.

Figure 4. Spaghetti diagram of the complete route of a worktable, original organization



Source: own elaboration

Each color represents a different laboratory test and its journey through the work areas (figure 5). It should be noted that the Aashto test is carried out in a specific area outside the map, so it does not affect the taking of results.

Figure 5. Color code of the paths of the spaghetti diagram in figure 4

	Test	Color		Test	Color
1	Labeling		5	Liquid and plastic limit testing	
2	Dividing and distribution of samples		6	Sand aquivalent	
3	Sieve analysis of coarse aggregates		7	AASHTO	
4	Sieve analysis of fine aggregates		8	Porter / CBR	

Source: own elaboration

The commonly used table has the ability to carry out two tests simultaneously, but in practice it is usually used for a single sample at a time. In addition, it is observed that personnel constantly collide while providing commonly used materials for specialized tests. This problem is especially accentuated in the case of the common worktable and scales, since they are elements that staff frequently need.

Additionally, a significant accumulation of tools and material waste has been observed in common work areas, which makes staff operations difficult. In Figure 6, you can clearly see the accumulation of tools outside the designated areas, resulting in loss of tools and time searching for the necessary equipment.

Figure 6. Commonly used tool invading workspaces

Source: Own elaboration (soil mechanics laboratory)

Figures 6 and 7 show the accumulation of waste material and tools, both under the common work areas and in the drying areas. This created confusion among employees, as they did not know if the materials were registered or processed.

Figure 7. Drying area invaded by waste material, commonly used tools, and disused specialized equipment

Source: Own elaboration (soil mechanics laboratory)

Experimental implementation

During stage 3 (Experimental implementation), the 5'S tool (Pérez and Quintero, 2017) was used to address organizational problems. This made it possible to determine the conditions in which the tools, machines, and workspaces are located and then order and organize them following the recommendations of Manzano Ramírez and Gisbert Soler (2016). In addition, kanban boards were used to record the progress of the workflow.

Implementation of 5'S in work areas

Seiri (remove): We began by classifying and eliminating unnecessary elements in the work areas. To achieve this, commonly used tools were carefully reviewed to ensure that they met the specifications of the procedure manuals and were classified into three categories: in good condition, for repair, and waste. Tools and equipment that would not be used for more than a week were stored in the warehouse to avoid unnecessary accumulation.

Seiton (sort): With the commonly used tools in good condition, two complete sets were created and placed on either side of the main worktable. Scales were also relocated to allow employees to work without colliding with each other, which reduced unnecessary movements (Vilana Arto, 2011). The opinions and suggestions of the staff were taken into account, as long as the laboratory head authorized it, and they did not interfere with the operations of the other work areas.

Seiso (cleaning and inspection): An exhaustive cleaning of the work areas was carried out, removing everything that was considered waste and assigning a specific place for each tool (figure 8). The area originally designated for trash and unwanted materials was overrun with materials that could not be disposed of until a minimum of three months had passed since they entered the laboratory. To avoid disposing of materials that should not be disposed, two separated areas were established one for trash and one for stored materials. In addition, one Friday a month was scheduled to discard materials that had met the minimum time to be discarded. This activity was supervised by the laboratory head. Staff were also trained and allowed to perform preventive maintenance on the equipment to extend the useful life of the machinery while awaiting certified calibration (Pillado Portillo *et al*., 2022).

Seiketsu (standardization): Visual aids were placed in the work areas to guide staff in the processes, following the manuals corresponding to each test. It was also decided to hold informal meetings on Fridays before the end of the workday to raise questions and suggestions that would be analyzed by the team.

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Shitsuke (discipline): The laboratory head assumed the responsibility of verifying weekly that employees kept their work areas clean and orderly, with the necessary equipment and in good condition, in accordance with the relevant standards and manuals. This verification was carried out using a checklist exclusive to the laboratory manager, which detailed the equipment necessary for each work area. The goal was that over time these activities would become habits for the staff.

Figure 8. Comparison of the boundary area before (left) and after (right) the implementation of 5'S

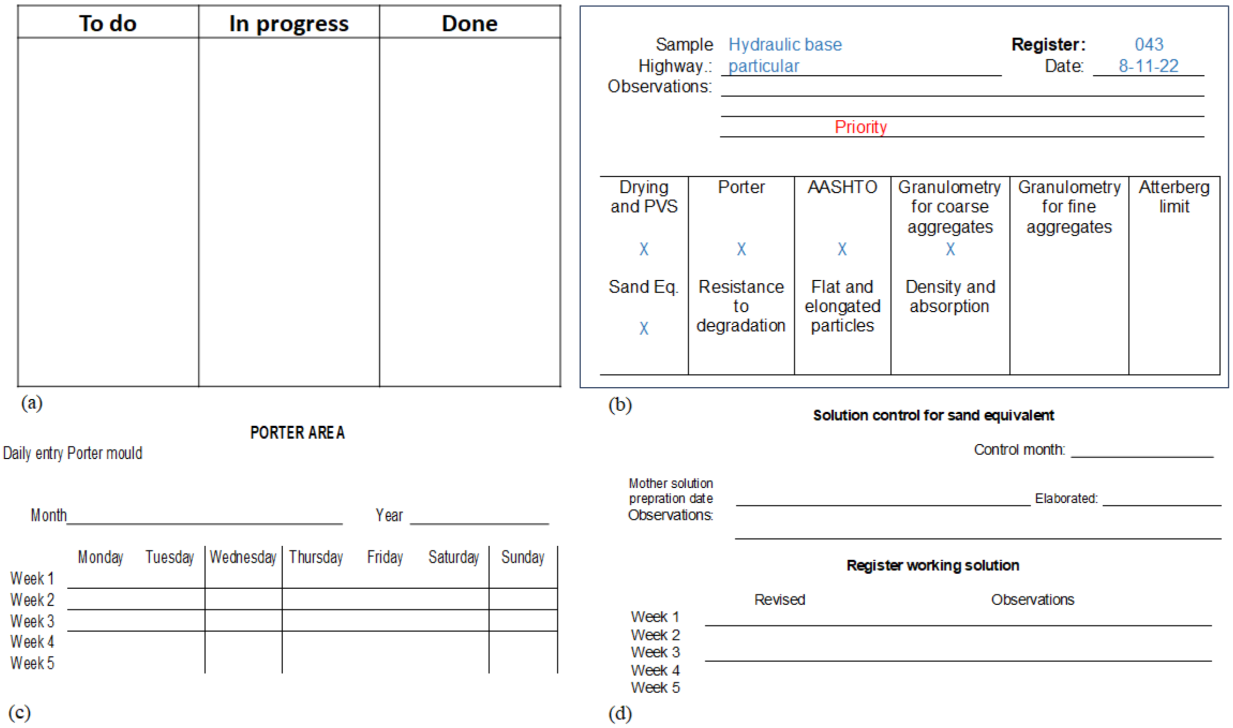
Source: Own elaboration (soil mechanics laboratory)

Implementation of kanban boards and visual aids

Kanban tool was implemented, which consists of a series of boards (Gómez *et al*., 2020) that allowed the laboratory head and operational staff to quickly and easily identify Clear work progress, priorities, and backlog of tests. This methodology has been successfully used by other researchers such as Torres Angel (2019) and Bošnjak and Bošnjak (2020) in their respective projects.

Figure 9(a) presents the kanban board that was under the responsibility of the laboratory head. In this, the samples are divided into columns labeled “To do”, “in progress”, and “done”, which allowed efficient location of the progress status of the work. Figure 9(b) shows an example of the job card that was used to label the samples. This details which analyzes should be carried out, according to an included checklist. In this way, the laboratory manager can mark the priority samples with red at the top.

Figure 9. Kanban board and visual aids



Source: own elaboration

For the Porter test area, a checklist type board was generated, which allowed daily control of the work carried out. In this the person in charge places his name (figure 9c) in order to quickly identify those who carried out an activity.

To meet the needs of the sand equivalent area, a recording format was designed (figure 9d) that allows quality control of the elements used in each test. This supervision is carried out weekly by the personnel in charge of the area to avoid using items in poor condition or expired, as well as to have a record of the distribution of supplies to field personnel.

Results

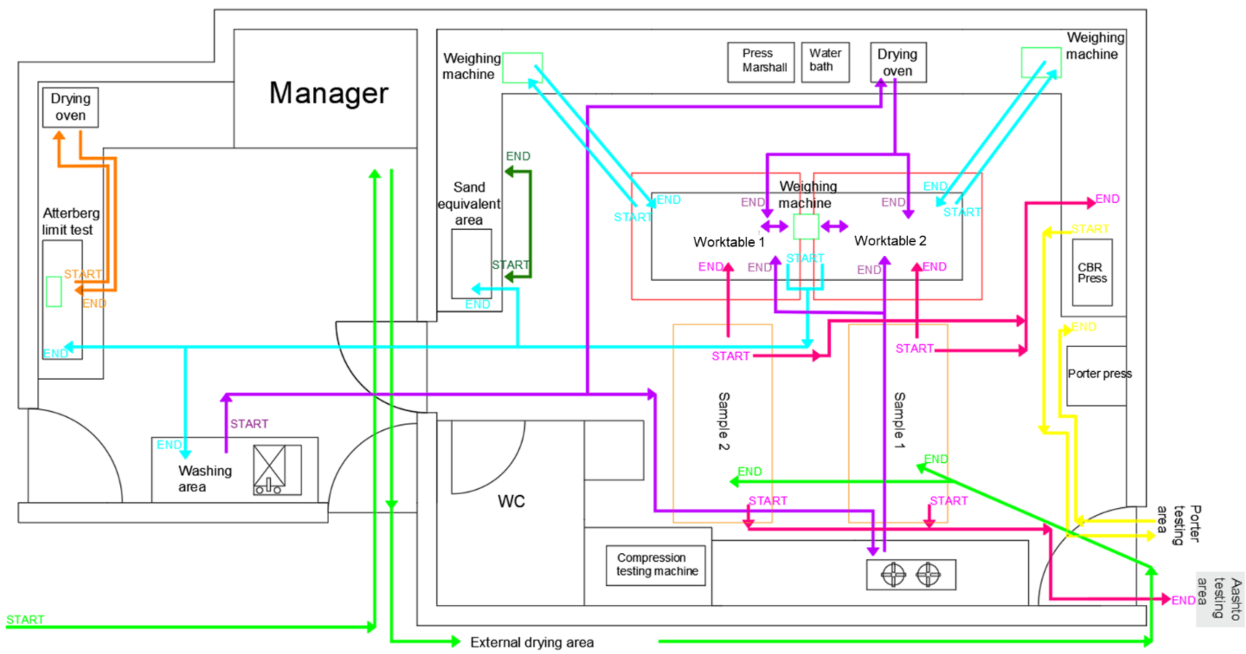
During stage 4 ("Results and analysis of the state after the application of tools"), it was observed that the lean tools used were adapted to the specific needs of the company. In this sense, it is important to note that many of these tools are originally designed for chain work lines. However, since part of the company's process follows this approach, it is essential to remember that, depending on the types of materials and variations in the process, some tasks may take longer or involve more steps.

This adaptation of the tools becomes more evident when comparing their implementation with that of other authors, such as Torres Angel (2019), Rapale Gonzalez (2018) and Escudero

(2020), which allows us to obtain a more complete vision of the various ways in which that these tools can be applied in different contexts.

In the specific case of the "dirt and stone materials" work line, the implementation of the 5'S tool resulted in an effective reorganization of the workflow. This made it possible to address various problems and allowed both work areas on the table to be used consecutively without interfering with personnel carrying out other activities. Figure 10 shows the spaghetti diagram of the proposed workflow, which optimizes personnel movements through areas, minimizing the number of steps required for each task and reducing possible collisions between employees.

Figure 10. Spaghetti diagram of the proposed workflow using the two workbench areas



Source: own elaboration

On the other hand, the sample handling process, which includes the labeling of each sample (indicated by the green arrows), is carried out exclusively through the side door. This allows the laboratory manager to keep a detailed record of all samples entering the work area, which prevents entry without their knowledge or loss of materials and contributes significantly to reducing the first bottleneck that the company faces.

During the sample run, the laboratory manager labels materials using the kanban system and assigns priorities when necessary. Once this process is completed, the materials are moved to the outdoor drying area (weather permitting) without the need to interrupt staff activities. Unlike the kanban systems used in large industries (Huerta Estévez, 2021), this adaptation of boards and labels on a smaller scale allows the laboratory manager to resolve his need to control sample input and daily progress.

Regarding the comparison of the number of steps and the time required by personnel before and after the redistribution of the tools, a clear improvement in efficiency is observed. Specifically, both the number of steps required, and the time spent by staff moving around work areas, for obtaining tools or distributing materials were reduced, resulting in a more efficient workflow. Additionally, the rehabilitation of the drying oven in the Attenberg area eliminated the need for personnel to travel to the common area drying oven, reducing travel from 44 steps to 14.

An increase in the company's capacity to handle waiting jobs was also achieved by parallelizing the main worktable area (worktable 1 and worktable 2), allowing up to ten samples to be processed daily, instead of the previous six, without neglecting the work assigned to the specialized areas.

Table 2 shows a detailed comparison of the number of steps and the time required by staff to carry out each distribution through the work areas before and after the implementation of lean philosophies. These data were collected for each sample processed in the soil mechanics laboratory, allowing for accurate assessment of changes in process efficiency. For example, before redistribution, in the spaghetti diagram of the path (Figure 4), the sample distribution and quartering line was highlighted in pink. On worktable 1, 30 steps were required, while on worktable 2, 38 steps were needed, for a total of 68 steps and a time of 46.2 seconds to complete the entire path before redistribution.

Table 2. Number of steps and time required by staff in each work area

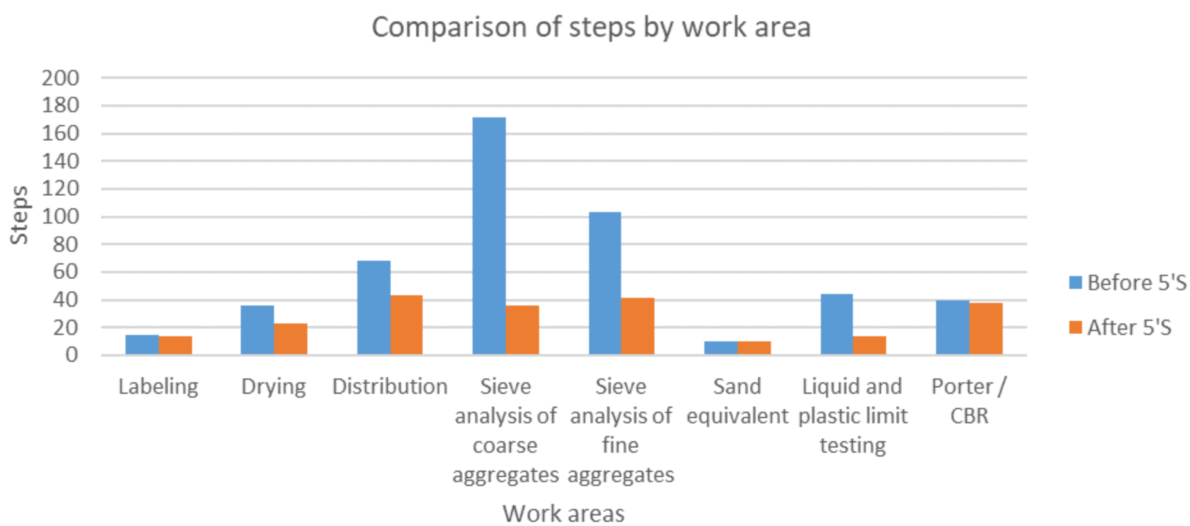
Before implementing 5'S		After implementing 5'S	
Time sec.	Number of steps	Number of steps	Time sec.
9.1	Labelling fifteen	Labelling 14	8.5
25.8	Drying 36	Drying 23	17.9
46.2	Distribution worktable 1: 30 Distribution worktable 2: 38 Total distribution 30+38= 68	Distribution worktable 1: 5 Distribution worktable 2: 5 33 Total distribution 5+5+33= 43	38
115.2	Sieve analysis of coarse aggregate worktable 1: 24 Sieve analysis of coarse aggregate worktable 2: 26 Distribution to work areas 72 | fifty Total coarse sieve analysis 24+72+26+50= 172	Sieve analysis of coarse aggregate worktable 1: 8 Sieve analysis of coarse aggregate worktable 2: 10 Distribution to work areas 18 Total coarse sieve analysis 8+10+18= 36	32.8
69.4	Sieve analysis of fine aggregate worktable 1: 53 Sieve analysis of fine aggregate worktable 2: 50 Total fine sieve analysis 53+50= 103	Total fine sieve analysis 41	27.8
8.0	Sand equivalent 10	Sand equivalent 10	6.5
26.6	Liquid and plastic limit testing 44	Liquid and plastic limit testing 14	8.5
24.3	Porter/CBR 40	Porter/CBR 38	23.7
324.6 sec. 5.41 min	TOTAL SUM OF STEPS PER SAMPLE 15+36+68+172+103+10+44+40 = 488	TOTAL SUM OF STEPS PER SAMPLE 14+23+43+36+41+10+14+38= 219	163.7 sec. 2.72 min

Source: own elaboration

When applying the new workflow (figure 10), the same quartering and sample distribution line marks five steps from quartering to worktable 1, and five steps from quartering to worktable 2. When performing the distribution of the total materials to work with instead of distributing them one at a time, it is allowed to make a single route of 33 steps, so the sum gives a total of 43 steps and a travel time of 38 seconds.

Figure 11 shows the comparative graphs of the number of steps required by personnel to move around the laboratory areas (upper graph), as well as the comparative graph of the time in seconds of personnel movements (lower graph) for each area of work before and after the proposed redistribution and the implementation of 5'S. With the new distribution, it is observed that by dividing the tool into separate sets and placing them in the common work areas, the two worktables can be used simultaneously, without interrupting the specialized work areas, which reduces the movement of employees in 44.88% with the new workflow. This allows us to solve the second bottleneck that the company presents.

Figure 11. Number of steps and time required by personnel in each work area



Source: own elaboration

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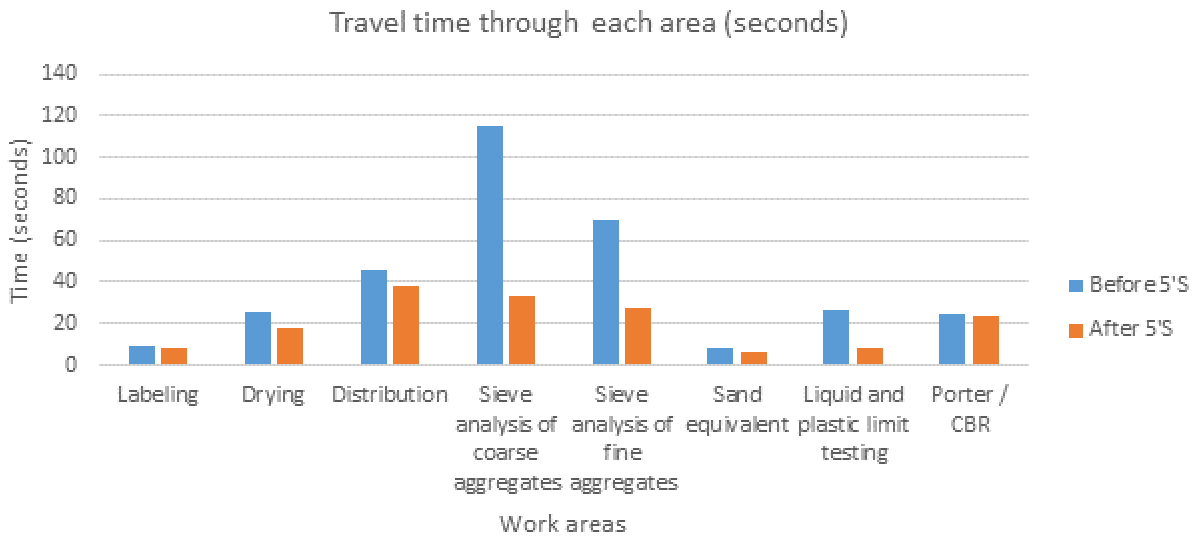

Source: own elaboration

Figure 12 shows examples of the common work areas once the 5'S methodology has been implemented. Work areas were cleaned, reorganized and identified through signs visible to all personnel. These actions made it possible to accommodate the tools necessary to perform each test and everyday equipment as close as possible. This shortened the distances needed by staff to carry out their activities.

Figure 12. Common work area after implementing 5'S

Source: own elaboration (soil mechanics laboratory)

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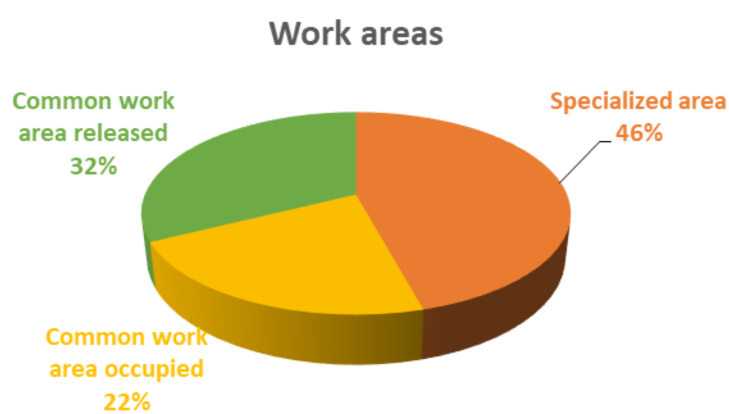
To 32.37% of the area destined for specialized and commonly used work was freed with the implementation of 5'S and the redistribution of tools (table 3 and figure 13). This allows these areas to be used to carry out specific tests, that is, it is not necessary to wait for the common worktable to be freed in order to work.

Table 3. Released common work area

Work area		m^2 per area	% By area
Specialized area		5.26	45.78%
Common work area	Occupied	2.51	21.85%
	Released	3.72	32.37%
Total		11.49 m^2	100%

Source: own elaboration

Figure 13. Distribution of work areas



Source: own elaboration

In short, as Bosnjak and Bosnjak (2020) comment, quality management can avoid part of the errors made by a company's staff. In the case of the construction sector, in addition to detecting needs and improving management, the aim is to minimize errors, reduce work times, minimize accidents and double the work capacity of personnel, which translates into profits for the organization.

Discussion

When comparing the activities carried out in this research with the work developed by Martin *et al*. (2014), the usefulness of lean tools can be seen to identify areas with potential for improvement in various work environments, regardless of their nature. This possibility allows these tools to be applied in both small companies and large corporations, according to the specific needs of each one.

On the other hand, it is important to note that throughout the execution of this project some limitations were identified. One of them lies in the lack of information on optimization techniques in areas that do not belong to the industrial field, which became evident during conversations with operating personnel. Another limitation is the variability in workload, which is linked to seasonal fluctuations. Predicting the needs of the company's customers becomes difficult in this context, resulting in long periods of high demand followed by periods of reduced activity.

Conclusions

Lean principles and tools (5'S, Kanban, spaghetti diagrams, Heijunka, and visual aids) allowed an improvement in the processes of the work line in the area of “dirt and stone materials” in a soil mechanics laboratory, which had delays in its results delivery times. When studying the case, various problems were found such as lack of order in the work areas, bottlenecks, accumulation of disused tools and equipment.

After implementing 5'S, 44.88% of the movements that personnel required in the work areas were reduced and 32.37% of the common work areas that were invaded by tools and waste materials were freed. Likewise, it was possible to parallelize jobs on the commonly used table and reduce the time required by personnel when moving through each job, which increased the workflow and the number of samples worked on (from six to ten per day), without neglecting the work of specialized areas.

When implementing kanban and checklist boards, it was possible to control the progress of materials, and by placing visual aids in the specialized work areas, the errors that workers made during the material handling process were reduced. This reduced accidents that occurred due to not following the corresponding protocols.

As future work, the company plans to implement kaizen tools for continuous improvement with the help of all staff. Finally, it seeks to expand the panorama of the use of lean tools in industries other than manufacturing. This demonstrates adaptability and effectiveness in areas that do not meet the classic characteristics of the industrial sector.

Future lines of research

The topic of implementing methodologies from the industry to direct and manage resources in construction companies is very broad due to the diversity of areas involved. This opens up a wide spectrum of possibilities for future research, which can address topics ranging from internal company management to optimization of workplace processes, whether in the parent company or in specific construction projects.

Therefore, a possible future work would be the application of the lean methodology to improve communication between the soil mechanics laboratory and other work areas, particularly those related to the execution of projects on the construction site. This approach would aim to improve the fluidity of information, especially in the administrative and managerial sphere, which could have a significant impact on the overall efficiency of the company.

Another area of research with potential is the optimization of programming and use of machinery within the soil mechanics laboratory. This approach would be aimed at improving times and processes in the operational area of the laboratory with the objective of minimizing waste associated with the use of available machinery and resources.

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Software	Does not apply
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