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Reducing Turnaround Time in a Clinical Laboratory by Using a Management Model Utilizing Process Automation and Lean Healthcare

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Abstract

A clinical Flow Cytometry laboratory underwent a diagnosis of its TAT indicator over a period of one year, finding an excess of 3.83 hours or 15.94% with respect to the 24-hour sector range. The response time (TAT) in a clinical laboratory is an indicator that measures the efficiency and quality of the service offered by delivering results reports on time. A TAT within the established parameters makes it possible to offer rapid treatment to patients, respond to the demand of an aging population and combat limited resources. As a proposal to improve the situation, pilot tests were implemented in the laboratory by applying lean Healthcare tools (KANBAN, SMED) and the automation method to its operational processes. Through a statistical validation of the results obtained through Student's t-test, a reduction of 12.86% of the TAT and the elimination of non-compliant products generated in the laboratory marking area is affirmed. Likewise, the project will be considered economically viable with an IRR of 67% and a B/C of 2.27. Finally, the project also contributes to the sustainable development goals towards 2030 number 3, 8 and 10.

Keywords

Turnaround time (TAT), clinical laboratory, KANBAN, automation, SMED lean healthcare.

1. Introduction

In Peru, 70% of cases linked to cancer are detected in advanced stages of the disease due to the late results of the current health system (Revilla 2021). Furthermore, the increase in patient management combined with limited resources for the medical sector are creating long wait lists, decreasing the quality of service, and causing dissatisfaction at the end (Kam et al. 2021). However, neoplasia diagnostic laboratories, as a support unit (Villacreces

et al. 2023) are expected to provide accurate results in the established turnaround time (TAT), to enable diagnosis, treatment, and prognosis for patients in the shortest amount of time (Haripersadh et al. 2022). An improvement in TAT could have a positive impact on the performance indicator and promote people's access to healthcare. So, it would also help to achieve the objective number 3 “Good Health” of the SDGs towards 2030 (Moran 2015). During the period from February 2023 to February 2024, the TAT indicator of a clinical laboratory has been deviated from the standard parameters. Specifically, the TAT of this laboratory includes the sum of times used to receive, process and send the results of the type of study requested for a hematological sample (pre-analytical, analytical and post-analytical phase) (Velasquez and Villacreces 2022). It is concluded that the TAT is out of range after comparing the laboratory TAT with the values used in similar companies in the sector.

For example, the TAT used by a laboratory in the sector is approximately 22 hours and it is considered that this time could be reduced by identifying the bottlenecks that generate waits (Mwogi et al. 2023). Likewise, in a Cytometry and Molecular Biology laboratory at the University of the Republic in Uruguay, the delivery of results for them tests may take between 24 to 48 hours. (Usuario 2024) With these data, it was determined that the TAT value of the sector to be used would be 24 hours, which is also the time agreed with clients under contract. Therefore, by extracting data from operational records, it is concluded that the technical gap between the company's TAT and the sector's is equivalent to 15.94%. In general, the service offered is currently provided in 27.83 hours. The problem was diagnosed using tools such as the Pareto Chart, Value Stream Mapping and the Two-Way Anova technique. All three of them together identified that the root causes came from lean waste: defects, waiting, inventories. Therefore, after a literature review of more than 40 papers, KANBAN, Automation and SMED lean healthcare were proposed as improvement tools to reduce the total time of each case study. Regarding the organization, this scientific article is divided into six parts: Introduction, State of the art, Contribution, Validation, Conclusions and References.

1.1 Objectives

The general objective is to reduce the TAT until it reaches a value close to 24 hours and minimize the current economic impact that represents 3.09% of monthly income. On the other hand, the specific objectives are to validate that the proposed engineering tools work and that the results obtained contribute to SDG 3 "Good Health".

2. Literature Review

2.1 KANBAN

Faced with the defects generated in the activity of marking samples with reagents, a visual control system-KANBAN is suggested that allows the worker to see what state of the task is, what supplies must be placed (according to bottle code, quantity per test), have the possibility of making a checklist according to their progress in real time and relate the marking area more efficiently with the area that sends requests. In a pathology laboratory, the use of an LED monitoring screen can be established for the area and a color criterion can be added for the different states of the cases; this in order to help have a better management of the tests and eliminate tasks for the human resource (Isa et al. 2020).

2.2 Process automation

The confusion in the marking area protocols is related to depending on purely human resources. Although there are already laboratories that have automated processes (plate area, incubation, images, colony selection, analysis) interconnected with conveyor belts plus the support of workers (Isa et al. 2020), this improvement will be limited only to the task of “pipetting samples and reagents” in the marking area with the help of an automated arm. Automation contributes with improved productivity, TAT response times, programming capacity according to user needs, reduces errors and generates traceability in processing (Trigueiro et al. 2024). In addition, automation is linked, by reducing errors, to using resources more efficiently (Eline et al. 2019) thus minimizing both non-conforming products and a large part of the losses in high-value inputs.

2.3 SMED lean healthcare

There is a delay in the review of cases that require moving from the waiting queue in the analysis area to marking again to mark complementary tubes. This happens because the activities are not being classified into internal and external in an efficient way, considering that the technologist can only analyze one case at a time. If before the analyst begins his main task, which is to analyze, a general review of the pending cases was made and the work area was ready to execute the central activity, better use of time could be made by up to 12%. Although initially the lean SMED

tool was intended more for industrial processes, it is also a useful tool for the health sector lately and has been applicable, for example, in emergency areas of hospitals (Bonamigo et al. 2023).

2.4 Sustainable Development Goals (SDG)

The scope of the global goals aspired to be met by 2030, which aim to generate sustainable development in the world, involve the participation of not only governments and authorities, but of the entire population (Gomez 2015) Therefore, improvement projects such as this one also generates their own significant contribution to society. In this case, reducing the TAT in a clinical laboratory using the proposed tools and methods contributes to the fulfillment of SDG 3 "Good Health and Well-being", SDG 8 "Decent Work and Economic Growth" and SDG 10 "Reduced Inequalities".

The importance of this contribution of the project to the SDGs lies in the fact that it attempts to minimize the persistent obstacle of inequality in access to health care that does not guarantee a healthy life for all. For example, in the Caribbean and Latin American regions, there are still very marked differences in the quality of health services accessed by different population groups (ONU 2024).

3. Methods

Nowadays, clinical laboratories focus on having practices that allow them to be efficient to improve their results delivery times, because the late deliveries can potentially lead to medical errors and increase the risk of being exposed to contaminated biological samples (Isa et al. 2020). Under this panorama, the proposed management model is based on the use of Lean Healthcare tools, a work philosophy brought to clinical environments, with Automation of processes that allows a company in the medical services sector to obtain a better operational efficiency, response times, precision of results and reduction of non-compliant products. From the literature review, a few previous investigations that used the mentioned tools to solve similar problems to the one the company had with the TAT were extracted (Table 1).

Table 1. Comparative Matrix.

Causes or objectives Scientifics Articles	Reduce waits	Reduce operations with bad quality	Improvement in precision results	Improvement in the workflow	Advantages of complementary times
Torres et al. (2018)	KANBAN			KANBAN	Sigma Six
Letelier et al. (2021)	KANBAN		KANBAN	KANBAN	
Pirone et al. (2023)		Automation	Automation		
Trigueiro et al. (2024)	Automatization		Automation		
Bonamigo et al. (2023)		Sigma Six		Sigma Six	SMED Lean Healthcare
Marcelino et al. (2023)					SMED Lean Healthcare
Proposal	KANBAN	Automation	Automation	KANBAN	SMED Lean Healthcare

3.1 Proposed model

A management model (Figure 1) is proposed based on Lean Healthcare tools such as KANBAN related with visual signaling of tasks (Isa et al. 2020) and SMED with the reorganization of activities. On the other hand, the automation of processes in a part of the laboratory by the implementation of a system that does the pipetting work for the technicians was proposed to improve in terms of efficiency, reduction of time and precision of results (Trigueiro et al. 2024). The implementation of the proposed model will begin with the KANBAN tool, to provide to the staff, the ability to have visual management of the laboratory workflow and the most efficient use of available resources (Lanza-Leon et al. 2021). Secondly, the automation of the pipetting process in labeling was implemented to reduce processing times and non-compliant samples that lead to reprocessing or waste. Finally, the SMED tool was used to outsource activities, improve the use of time with the purpose of reducing processing time (Bonamigo et al. 2023). To evaluate the performance of the model, key indicators were established that were measured before and after the implementation of the model.

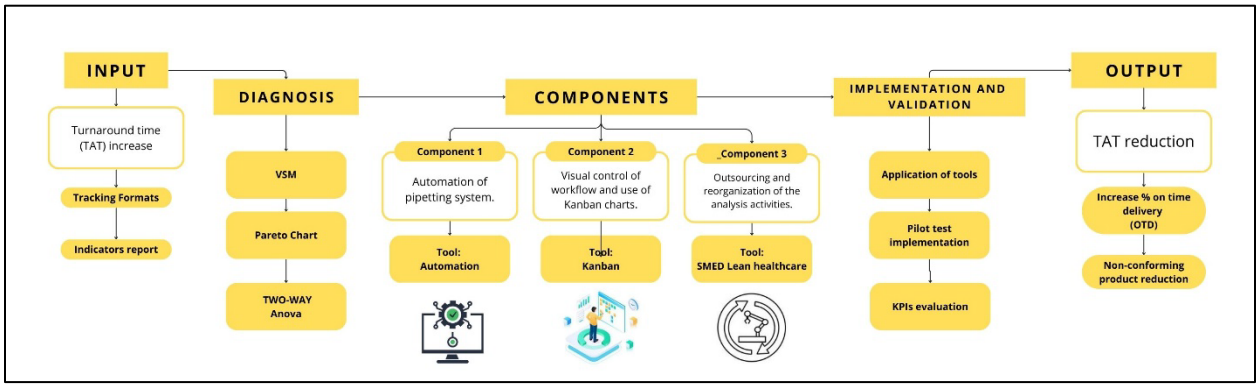

Figure 1. Model Construct

The proposed model consists of three (3) components that will be explained below

3.1.1 Component 1: Automation

The development of this component consists of the automation of the pipetting activity in the area where reagents are placed in hematological samples to increase productivity and precision (Trigueiro et al. 2024). The automation will be in charge of a robot that works linked to software, which obeys orders. It will be programmed to use predetermined templates that indicate the specific step by step of the repetitive tasks that need to replace their manual way of being carried out. The scope in the pilot covers 2.5 uL and 5 uL pipettes. The measurable variables used for this component were Number of cases processed, Time in the area and Volumetric variation in the pipetting activity.

3.1.2 Component 2: Visual control

The development of this component is composed of the KANBAN tool, which aims to provide visual control over the operations carried out in the laboratory workflow (Letelier et al. 2021). To do this, a touch screen was incorporated into the workstation where cocktails with reagents are prepared, and samples are handled. On this screen a software will be opened which contains a module to be used only by the mentioned area. This module allows the staff to respond to requests and follow protocols by making a live checklist of their progress. This tool is based on favoring a type of pull system to carry out tasks. This tool was tested with a pilot and the variables chosen to analyze their initial and final state with respect to times invested were start time, end time and total time in the area.

3.1.3 Component 3: Outsourcing of activities

The third component is composed of the SMED tool, in which use will be made of the principles of task outsourcing for the best use of time and human resources (Marcelino et al. 2023). To do this, a breakdown of the activities carried out by the analysis personnel was made to identify them as internal and external, considering the analyst's work of "analyzing with the software" as that central activity. Then the reorganization and externalization of this list of steps was carried out, allowing a before and after to be analyzed thanks to the data collected from the set-up time.

3.1.4 Component 4 - Validation

The proposed model was focused on the area of analysis and samples handling that belong to the analytical phase of the company's value chain. The following key indicators were defined with the objective of measuring the performance and impact of the improvement proposal.

First Time Through (FIT): It measures the percentage of units that comply with the correct procedure the first time, without errors involving reprocessing or scrap (Marinagi et al. 2020). Objective: Achieve a monthly FIT indicator of at least 95%

$$FIT = \frac{Units\ processed - Reprocessed\ units - Discards}{Units\ processed} * 100$$

On Time Delivery (OTD): It measures the percentage of results delivered on time, in a maximum of 24 working hours (Marinagi et al. 2020). Objective: Achieve a monthly OTD of 98%.

$$OTD = \frac{Number\ of\ on\ time\ deliveries}{Total\ number\ of\ deliveries} * 100\%$$

Average processing time (AMT): Measures the average time it takes for a sample to be processed in the first area after being received. (Marinagi et al. 2020).

$$AMT = \frac{\sum \quad Processing\ times}{Number\ of\ samples}$$

Efficiency in the marking area (E): It measures the number of samples that are processed per hour on the marking line. (Marinagi et al. 2020).

$$E = \frac{Units\ processed}{Total\ time}$$

SET UP time in analysis: It represents the total time a sample spends in the analysis area (Bonamigo et al. 2023)

4. Data Collection

The keywords considered for the search of the articles are Lean Service, laboratories, healthcare, and automation. The databases used for the information search were Scopus, Scielo and Proquest (Figure 2). For a more detailed search, exclusion and inclusion criteria were defined, such as a maximum age of 5 years, being scientific articles or conference papers, being in Spanish or English, being in the areas of engineering and business administration and being case studies or experimental cases. As a result, 839 documents were identified that met the initial inclusion criteria to be considered as potential sources of information. After conducting a more detailed investigation, focusing on the titles and abstracts of these documents, 40 were chosen that were most closely related to the research objectives.

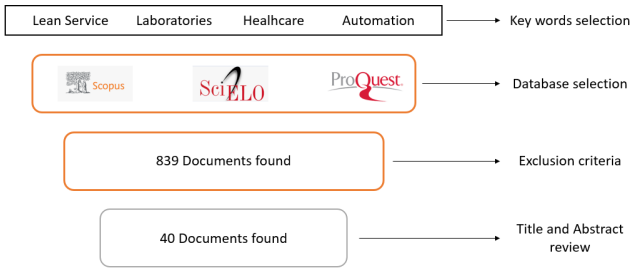

Figure 2. Database prism

The analysis unit of this project that is being monitored is the blood sample from a patient that arrives at the laboratory, which must meet certain requirements such as correct labeling and accompanied by a medical order. For the validation process, an evaluation of the defined KPIs was carried out taking as a reference the historical data of April 2024 to determine their initial performance before the implementation of the improvements and a comparison was made with the KPIs obtained with the improved model in June 2024.

5. Results and Discussion

Table 2 below shows the indicators before and after the implementation of the improvements. It can be observed that there is a significant improvement in the established KPIs.

5.1 Validation

The initial model (without improvements) involved the entire process of a patient's blood sample from the moment it is considered suitable for processing until the results are issued. The improvements were made in the analytical phase, which includes the activities called sample marking, sample acquisition, sample analysis and results validation. Initially, the marking was carried out manually and following a pre-established procedure; then, the sample acquisition is carried out on the spectral flow cytometer that provides graphic data in a software, which is sent to the analysis area, where the diagnoses indicated in the results reports are obtained; which are subsequently reviewed and validated by experts in the field. All the above was the traditional way in which the company had been working. To evaluate the time invested by each area, traceability formats and special records were used to monitor the impact of the proposed improvements. Improvements related to the KANBAN, Automation and SMED tools were added to certain sample processing activities in the analytical phase. Specifically, the steps to be followed by each tool in its corresponding area were those shown in Figure 3.

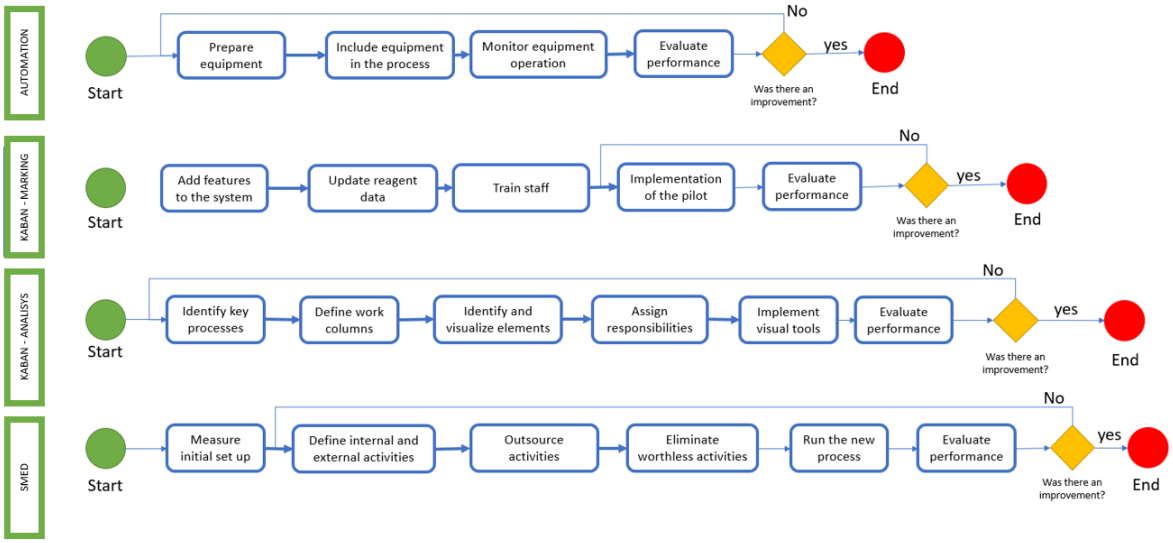

Figure 3. Validation process

The validation process of the proposed improvements was carried out through the implementation of a pilot program in which the collection and comparison of TAT data and other indicators between the improved model and the initial state of the laboratory was carried out. For both scenarios, monitoring was carried out over a month for the same number of randomly chosen samples. The validation process is limited only to control samples from patients with a disease already diagnosed; discarded samples are not considered for the evaluation. Furthermore, this study is focused only on the analytical phase, not covering the pre-analytical phase, which involves customer service activities and sample reception.

5.2 Numerical results

With the data of the indicators before and after the improvement, they were entered into a statistical software called Minitab in which it was determined that the values obtained from the proposed indicators follow a normal distribution through probability graphs (Figure 4).

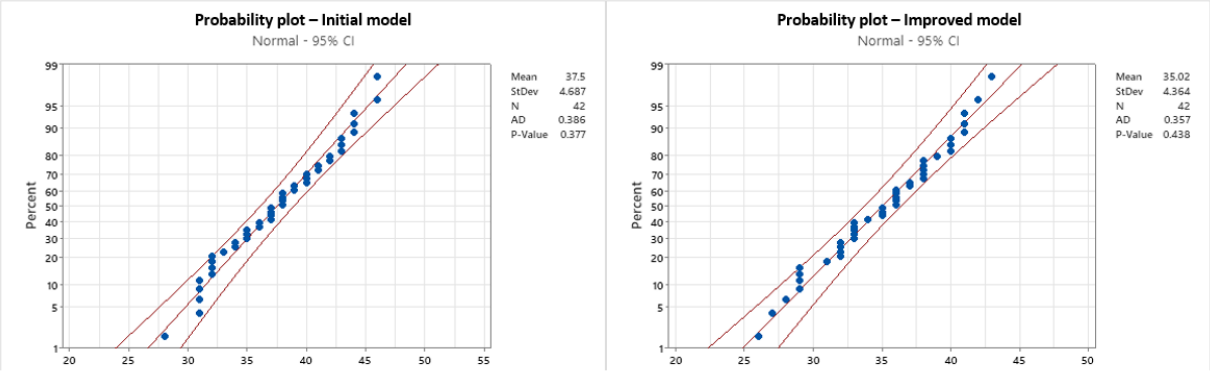

Figure 4. Model probability plots

In this program, the data were processed with t-student tests in which statistical values such as the P-Value were decisive in defining whether the addition of these actions (factor) truly influenced the main response variable TAT or other indicators. The most relevant results obtained are summarized in Table 2

Table 2. Model Results

Category	Subcategory	Initial Value	Final Value	Percentage Change
Automation	Efficiency (Samples/hour)	2.76	6.81	+146.74%
Kanban	Average marking time	37.5 min	35.9 min	-4.27%
SMED	Set up time in analytical phase	240.38 min	40 min	-83.36%
TAT	Turn Around Time	27.83 hrs	24.85 hrs	-12.86%

As the Table shows, all the indicators proposed for the measurement of each component showed improvements due to the implementation, which together contributed to reduce the general TAT indicator by -12.86%, a value very close to the technical gap defined for the research project.

6. Conclusion

The Kanban tool managed to reduce more than 4% of the time used in the marking area of a laboratory, while the SMED reduced over 80% in the analysis area. With this, the initial technical gap of 15.94% would be reduced until the TAT was placed in 24.25 business hours. Likewise, automation made it possible to reduce monthly non-compliant

products to 0 in the marking area; as well as, making more efficient use of laboratory supplies and staff time. On the other hand, it can be stated that the project is economically viable for the mype in question, since the IRR indicator was 67% and the benefit/cost was 2.27. It is worth to mention that the company did not need any type of financing because it is an improvement project and not an investment. Furthermore, it was recognized through a social evaluation that the implementation of these improvements contributes to the quality of the service in favor of people's health (related to SDG 3 "Health and Well-being"). Also, it allows to provide new job opportunities in the company under study (related to SDG 8 "Decent work and economic growth"). And the Peruvian population is favored in their access to health care, given that, with increased performance, prices can be adapted (related to SDG 10 "Reduction of inequalities").

References

Bonamigo, A., Bernardes, P. M. M., Conrado, L. F., and da Silva, D. B., Lean Healthcare: evaluation of Single-Minute Exchange of Die and Toyota Kata applied in Brazilian Emergency Care Units. *Revista Meta: Avaliação*, 3rd Edition, pp. 52-74, 2023, http://dx.doi.org/10.22347/2175-2753v0i0.4052

Gupta, S., Kapil, S., and Sharma, M., Improvement of laboratory turnaround time using lean methodology, *International Journal of Health Care Quality Assurance*, vol. 31, no. 4, pp. 295–308, 2018, https://doi.org/10.1108/IJHCQA-08-2016-0116

Haripersadh, R., Pillay, D., & Rapiti, N., Impact of rapid centrifugation on routine coagulation assays in South Africa. *African Journal of Laboratory Medicine*, vol. 11, no. 1, pp. 1-7, 2022

Isa, S., Hami, R., Hashim, H., and Salleh, M. J. M., Improvement of Urgent Tests Laboratory Turnaround Time Through Laboratory Lean Management. *Malaysian Journal of Medicine & Health Sciences*, vol. 16, no. 2, 2020

Kam, A. W., Collins, S., Park, T., Mihail, M., Stanaway, F. F., Lewis, N. L., ... and Smith, J. E., Lean Six Sigma techniques to improve efficiency in outpatient ophthalmology clinics, *BMC Health Services Research*, vol. 21, pp. 1-9, 2021

Laboratorio de Citometría y Biología Molecular "Roberto Caldeyro Barcia", Available: https://www.lcbm.hc.edu.uy/index.php/citometria-de-flujo/procedimientos, Accessed on July 12, 2024

Lanza-León P, Sanchez-Ruiz L and Cantarero-Prieto D., Kanban system applications in healthcare services: a literature review, *Int J Health Plann Mgmt*., vol. 36, no. 6, pp. 2062-2078. https://doi.org/10.1002/hpm.3276

Letelier, P., Guzmán, N., Medina, G., Calcumil, L., Huencho, P., Mora, J., … and Martín, A. S., Workflow optimization in a clinical laboratory using lean management principles in the pre-analytical phase. *Journal of Medical Biochemistry*, vol. 40, no. 1, pp. 26–32, 2021, https://doi.org/10.5937/jomb0-26055

Marcelino, S.M., Lima, T.M., Gaspar, P.D, Lean Laboratory-Designing an Application of Lean for Teaching and Research Laboratories. *Designs*, vol. 7, no. 1, p. 17, 2023, https://doi.org/ 10.3390/designs7010017

Marinagi, C., Reklitis, P., Trivellas, P. and Sakas, D, The Impact of Industry 4.0 Technologies on Key Performance Indicators for a Resilient Supply Chain 4.0, *Sustainability*, vol. 15, no. 5185, 2023 https://doi.org/10.3390/su15065185

Ministerio de Salud (MINSA) Gobierno del Perú, Available: https://www.dge.gob.pe/portal/docs/tools/teleconferencia/2021/SE252021/03.pdf, Accessed on July 12, 2024

Moran, M., Objetivo 3: Garantizar una vida sana y promover el bienestar para todos en todas las edades, Available: https://www.un.org/sustainabledevelopment/es/health/, Enero 7, 2015

Mwogi, T., Mercer, T., Tran, D. N., Tonui, R., Tylleskar, T., and Were, M. C., Therapeutic turnaround times for common laboratory tests in a tertiary hospital in Kenya, *PLoS ONE*, vol. 15, no. 4, 2020, https://doi.org/10.1371/journal.pone.0230858

Sysmex Europe, Available: https://www.sysmex-europe.com/products/products-detail/ps-10/, Accessed on July 12, 2024.

Trigueiro, G., Oliveira, C., Rodrigues, A., Seabra, S., Pinto, R., Bala, Y., Gutiérrez Granado, M., Vallejo, S., Gonzalez, V., and Cardoso, C., Conversion of a classical microbiology laboratory to a total automation laboratory enhanced by the application of lean principles, *Microbiology Spectrum*, vol. 12, no. 2, 2024, https://doi.org/10.1128/spectrum.02153-23

Tsai, E. R., Tintu, A. N., Demirtas, D., Boucherie, R. J., de Jonge, R., and de Rijke, Y. B, A critical review of laboratory performance indicators, *Critical Reviews in Clinical Laboratory Sciences*, vol. 56, no. 7, pp. 458-471, 2019, DOI: 10.1080/10408363.2019.1641789

Velasquez, M. E. L., and Villacreses, W. L., Diagnóstico de calidad basado en la norma ISO15189: 2012 aplicado en un laboratorio clínico privado. *Revista Científica Arbitrada Multidisciplinaria PENTACIENCIAS*, vol. 4, no. 4, pp. 150-160, 2022.

Villacreses, W. A. L., Pin, R. X. V., García, M. G. S., and Parrales, E. N. L. Importancia de una gestión eficiente de la calidad en la atención del paciente. Polo del Conocimiento: Revista científico-profesional, vol. 8, no. 10, pp. 48-71, 2023

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