Mobile Application Design for Managing Preventive Maintenance Information for Neonatal Respirators

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Abstract

This research study proposes a new alternative for monitoring and managing maintenance work in neonatal respiratory equipment at the Edgardo Rebagliati Martins General Hospital, a general health facility in Lima, Peru. This proposal is based on a Mobile Vision Optical Character Recognition (OCR) algorithm, which identifies the numerical code of each device in the field through an Android mobile application. This information is then processed using a Weibull model to determine equipment failure probabilities. Based on the mean times between failures collected from history information, the system calculates the current failure probabilities for each device. These probabilities are recalculated every time the equipment is scanned. This paper describes the variables used, obtaining an 88% accuracy when using the OCR system, thus identifying preventive maintenance needs from device information.

Keywords
Optical Character Recognition, Weibull Distribution, and Neonatology and Maintenance Information Management.

1. Introduction
The large number and variety of hospital equipment devices, such as the one this paper focuses on, requires constant innovation in information management processes to secure their preventive maintenance. The success of maintenance management is based on the time, cost, and income numbers obtained, which, in turn, are directly linked to the work environment structure in terms of the materials used, workflows established, work methodology guidelines proposed, and their work teams (Benítez et al. 2018). Hence, within the hospital complex assessed, each neonatal device is associated to intrinsic alphanumeric information, such as a unique ID code, its location, its technical installation sheet, its purchase information, and its current status.

For this study, an OCR (Optical Character Recognition) model with a number of classification techniques has been used to recognize the numerical codes from neonatal equipment through an Android application. OCR technology has proven helpful when digitizing documents or extracting information from images. For example, this technology prevents users from having to type texts, thus not only releasing them from tedious work, but also reducing typing errors, among others.

OCR-based applications capable of detecting and interpreting text information from images using Android mobile devices require to prevent operation issues (Jiménez, 2018). For this project, Android version 4.0.3 was used featuring an appropriate functionality on a daily use. On the other hand, to guarantee proper processing, only neonatal equipment placed in well-lit environments, with a minimum of 100 lux, were considered in scope.

The current process used to diagnose hospital equipment lifespans and determine whether these devices must receive maintenance or be immediately replaced is based mainly on three criteria: their usage level, which measures whether each device is being used at its full capacity; their incident history, consisting of recording device failure details; and their regulatory requirements, which are established by manufacturers (Vala et al. 2018). Therefore, the decision to provide maintenance to an equipment device seems to be purely based on imposed criteria, such as the devices most frequently used, the devices that report the largest number of failures or the data sheets provided by the manufacturers.
As the assessed hospital uses both hand-written codes and printed labels, using an OCR application will cover both aspects.

This paper has been structured as follows: Sections 2 and 3 describe the literature reviewed and our research methodology. Section 4 discusses data treatment and collection processes. Section 5 provides results and the improvements proposed. Finally, Section 6 presents our conclusions and recommendations for future lines of research on the subject matter.

1.1 Objectives
This research study seeks to design a mobile application that assesses preventive maintenance needs for neonatal respirator equipment. For these purposes, the following objectives were defined.

- To automate the recognition of the information associated with each neonatal respirator device using OCR.
- To assess preventive maintenance needs for each device through a Weibull model.

2. Literature Review
Previous research studies, such as Sgarbossa et al. (2018), assessed different preventive maintenance datasets and probability distribution models to demonstrate how feasible the implementation of the Weibull distribution is. In fact, its reliability is higher than other models, such as the exponential distribution, which is characterized by a constant failure rate. For this reason, preventive maintenance policies without an adequate failure distribution have proven not to be a good strategy. Meanwhile, Sidibe et al. (2013) argued that, as the Weibull distribution uses three parameters, it provides greater implementation flexibility, whether for experimental and operational results, which also increase its reliability against other distributions.

Likewise, there is a direct relationship between the operating conditions and Weibull distribution. In addition, since the Weibull distribution features an "s" behavior, this distribution describes maintenance operation cycle processes (Hu et al. 2021). The different reliability process components applied to maintenance systems, as studied by Liu et al (2020), demonstrate the usefulness of the Weibull distribution as a baseline for assessing different effects, such as how old each device is. Furthermore, other studies describe how the Weibull distribution parameters are useful for scheduling preventive maintenance and managing failure risks (Bracke 2020). Regarding using Weibull distribution modeling software in estimating maintenance failures, there are software packages in open-source R libraries that can be used in its implementation (Krämer et al. 2021).

For Nassar (2018), the Weibull method can be applied to either large or small samples and it describes how logarithmic transformations can be applied when modeling equipment life cycles are expressed as probability of failure during a given operation time. In this sense, Ramírez (2014) states that lifecycle modeling focuses on the operation of the object of study since its use is important within its usage scope. Likewise, it can detect monitored component issues through a list of errors based on usage times.

Here, the Weibull algorithm is so versatile that it can approximate the exponential, normal, and Raleigh distributions. These characteristics are useful for modeling different types of failures, such as early and random failures, as well as failures related to equipment obsolescence (Salazar et al. 2017).

In terms of capturing recognition images, Hubert et al. (2021) described the OCR algorithm and report adequate label recognition performance in different types of processes. Likewise, Robby et al (2019) and Cano (2018) focused on an Android OCR mobile application, but it was not integrated with a service as we have done in the study reported herein. For the design and development of the application, the agile Scrum methodology has been selected because it adds value to the development process, providing deliverables in stages known as "sprints" and uses incremental software development (Olaya et al. 2020). In fact, using agile methodologies to develop health applications is critical because they allow greater user interaction and short-term prototype validation (Kannan et al. 2019, Woodson et al. 2018, Clark et al. 2019).

This paper is of a descriptive nature and intends to highlight the importance of image recognition technology in health operations, mainly considering this field as intensive on non-structured data. The mainstream on health support operations goes this way using data processing analysis for tactical decision support.

3. Methods

When defining functional and nonfunctional requirements, the maintenance management flow used by the hospital was described. This flow consists of manually collecting equipment label codes and subsequently entering this information into the database server, wherein relevant device information, such as technical data sheets and maintenance dates are stored (Figure 1).

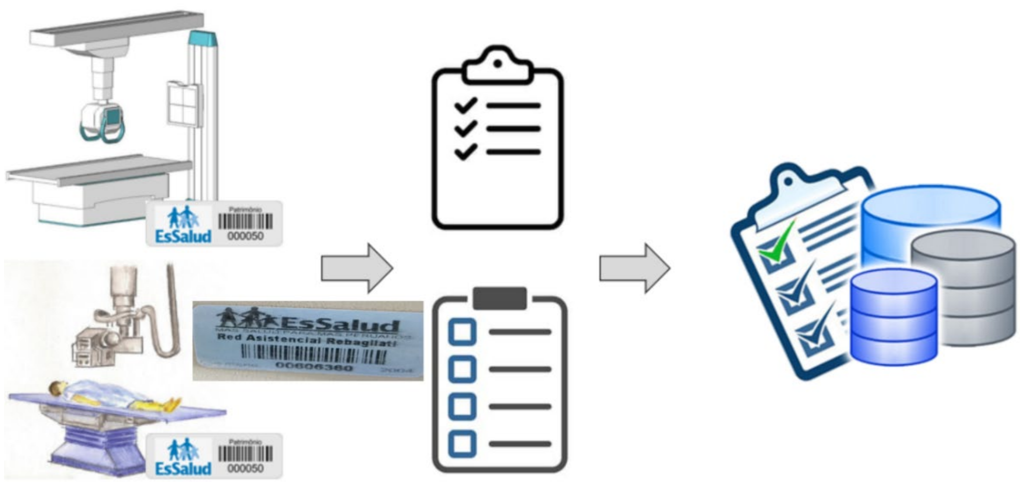

Figure 1. Device labels used at the Edgardo Rebagliati Hospital

The Android mobile application (Figure 2) was developed using the Kotlin programming language, Mobile Vision Text services from Google for detailed character recognition, and Android Software Development Kit to extract all the development tools used, such as the Android Tool, Android Simulator, and aforementioned Google service.

Figure 2. Android application: OCR screen capture details

The term of reliability (T_R) to obtain an operational lifespan for a unit with a probability of R(T) was obtained with: (Moreno et al., 2011)

$$R(T) = e^{\left(\frac{T-\gamma}{n}\right)^{\beta}}$$

$$-\left(\frac{T_e - \gamma}{n}\right)^{\beta} = h\, R(T)$$

$$\frac{T_R - \gamma}{n} = \left[-lnR(t)\,\right]^{1/\beta}$$

$$T_R = \gamma + n\,\{-h\, R(t)\}^{1/\beta}$$

The application receives the given period and time between failures (operation days until failure) as inputs. The API (Application Programming Interface) service then uses this data to calculate the time between equipment failures, thus obtaining reliability and failure probabilities for each device scanned.

4. Data Collection

As part of the data cleansing process, the start and end dates of the equipment failures reported were extracted from a legacy system (Table 1). We were able to determine device uptime rates, from the time each device became operational until a failure or any downtime was reported (*time between failures*), which provided the parameters we needed to solve the Weibull distribution.

Table 1. Description of the neonatal ventilation equipment

Details	Features	**Image**
Equipment Name	Neonatal Ventilator	
Brand	Bear	
Model	Bear Cub	
Series	750 Vs	
Manufacturer	Bears Ventilators	
Purchase Date	October 01, 2019	
Vendor	Soma Tech InTL	
Maintenance	Every 6 months	
Calibration	Subject to continuous use	
Warranty	1 year	

The information was collected from the 2016–2019 history reports of the high-frequency neonatal ventilation equipment devices used at the assessed hospital. These reports provide information on the maintenance each device has received as an example of one equipment in Table 2. This maintenance is divided into two types: (i) scheduled or preventive maintenance performed from timely to verify the proper operation of equipments and prevent possible failures and (ii) corrective maintenance, which is only performed when the corresponding device experiences a failure, hindering its proper operation. In the latter case, the corresponding device is removed from operation and an unscheduled maintenance plan is executed.

Table 2. Days between failures from 2016 to 2019

Interval (i)	Time between Failures (Days)
1	16
2	168
3	52
4	60
5	9
6	27
7	102
8	63
9	11
10	12
11	28
12	92
13	110
14	242

5. Results and Discussion

5.1 Numerical Results

As part of this study, 50 images were taken from 6 neonatal respirators, achieving an 88% effectiveness in reading labels. Some codes could not be read because the worn-out state of the label rendered them illegible. In addition, some devices had been placed in areas lighted under 100 lux with some hand-written labels, which made it difficult to understand the numbers. Here the probability of misreading 8% of the total number of labels is directly associated with worn-out and hand-written labels. The remaining 4% refers to lighting issues as poor lighting causes the application to only recognize some device code characters.

After capturing the corresponding device codes, we obtained the parameters of the Weibull distribution model. Hence, (β: 0.73; α: 22.69), since the β parameter is within the $0 \leq \beta \leq 1$ range, premature failures have occurred in the initial lifespan of the device. Table 3 below lists the device reliability results.

Table 3. Reliability results (R(t)) based on historical data

i	ti	Ln(ti)	Lag $(\text{Ln(ti)} - x)^2$	Reliability R(t)	$1 - R(t)$
1	9	2.2	0.0	90%	10%
2	11	2.4	0.0	85%	15%
3	12	2.5	0.0	80%	20%
4	16	2.8	0.2	76%	24%
5	27	3.3	0.9	72%	28%
6	28	3.3	1.0	69%	31%
7	52	4.0	2.6	66%	34%
8	60	4.1	3.1	63%	37%
9	63	4.1	3.3	60%	40%
10	92	4.5	4.8	58%	42%
11	102	4.6	5.2	56%	44%
12	110	4.7	5.6	53%	47%
13	168	5.1	7.8	51%	49%
14	242	5.5	9.9	50%	50.42%

5.2 Graphical Results

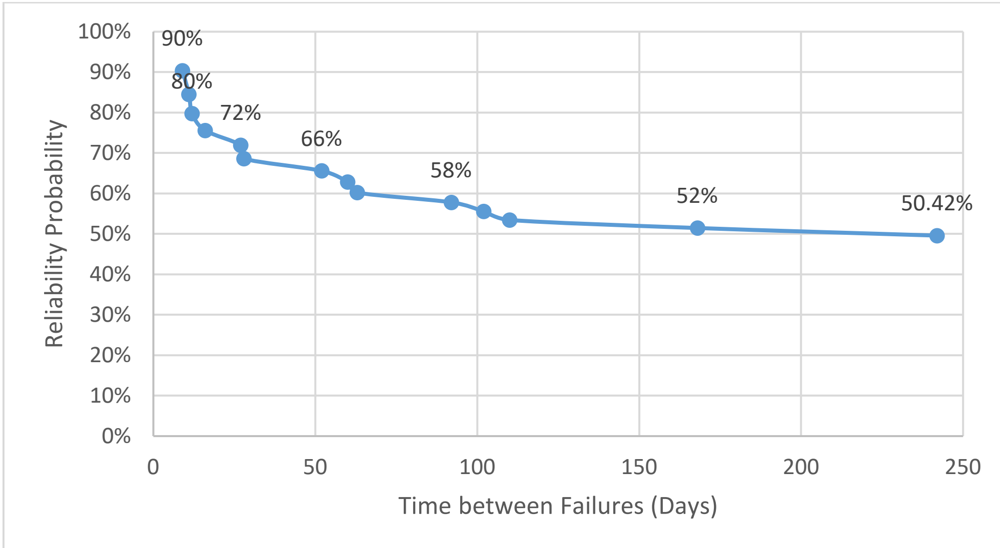

Figure 3. Survival R(t) probability based on time between failures (Days)

Based on the maintenance information provided for the neonatal ventilation equipment assessed, we can observe that device reliability has decreased over time. In fact, at the time of the analysis (Figure 3), the reliability probability is set at 50.42% since the average operation time is at 250 days. Likewise, the failure probability (F(t)) for 50.42% is within the proposed threshold of 90.00%, which indicates that these devices do not require immediate maintenance.

Failure Probability
Start Date: 10/01/2019
Current Date: 08/13/2020
Time (Days): 317
Probability (Failure): 81.76%
Maximum Operation Peak
F(t) Threshold: 90%
Start Date: 10/01/2019
Maximum Time: 401 days
Maximum Date: 11/15/2020
Return to Another Screen Capture

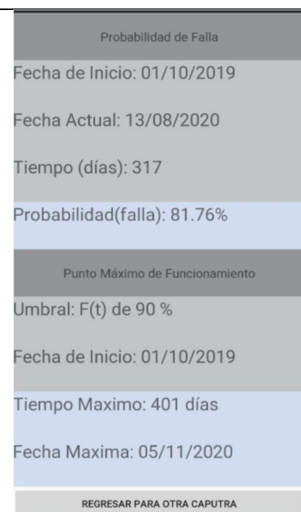

Figure 4. Equipment information and Weibull Model Calculation in the mobile application

Figure 4 is the result from another neonatal respirator, wherein the view generated with the Weibull distribution is displayed in two sections. The "Failure Probability" (F(t)) section at inspection time denotes a value of 81.76%, and the "Maximum Operating Point" section indicates the date when the equipment will reach the F(t) threshold. Hence, devices will require maintenance 401 days after their start date of operation. That is, on 11/05/2020, the equipment will reach a failure probability (F(t)) of 90.00%. At this time, a new maintenance order should be scheduled. The 90% F(t) threshold is proposed by the Maintenance Management department at the hospital. This threshold is set at this level because neonatal ventilators are considered critical equipment.

5.3 Proposed Improvements

The application was shared with the Maintenance Team at the Hospital for final approval. We received feedback on how to strengthen the application by adding new functionalities such as a graphic dashboard with equipment operation indicators.

5.4 Validation

The system recognized the numerical and alphabetical values that were displayed in the label. However, since the objective was to capture only the numerical values from the equipment code, we had to change the OCR detection parameter configuration. The application had issues reading codes in spaces lighted at less than 100 lux. Therefore, the lighting fixtures had to be changed in areas where the neonatal ventilation equipment operated.

6. Conclusions

Among our conclusions, we can mention that this study focused on improving the maintenance management of neonatal equipment using an OCR algorithm to capture the numerical codes associated to each device, thus automating the existing manual process that hindered adequate equipment monitoring. The OCR recognition algorithm was 88% effective in identifying the numerical codes printed or written on device labels, detailing device information, and calculating their failure probability to anticipate possible maintenance actions.

As part of the research study, information was collected from six machines, identifying premature failures in all of them. This evidences the usefulness of the Weibull model to represent lifespan expectancies for neonatal ventilators. This behavior can then help take action with other ventilation equipment. To reduce initial failure risks for these machines, device information must be recorded as they are commissioned, and their failure probabilities must be compared against the values accepted by the people in charge of the maintenance management process. For the equipment assessed, this value was set at 90%.

Future lines of research must be related to using remote operation sensors to monitor device operation indicators to create an indicator dashboard.

References

Benítez-Montalvo, R. I., Díaz-Concepción, A., Rodríguez Piñeiro, A. J., Villar Ledo, L., and Rodríguez Perez, H., Cálculo de la mantenibilidad usando la distribución gamma, Calculation of Maintainability using the Gamma Distribution, *Ingeniería Mecánica*, vol. 21, no. 1, pp. 52-58, 2018.

Bracke, S., Preventive maintenance planning based on Weibull distribution models: The impact of the random scatter behavior of the threshold parameter, *IFAC-PapersOnLine*, vol. 53, no. 3, pp. 161-166, 2020. Doi: 10.1016/j.ifacol.2020.11.026

Cano Sánchez, I., App móvil para el escaneo y verbalización de documentos. Mobile App for Scanning and Verbalizing Documents 958 Enginyeria Informàtica, Available: https://ddd.uab.cat/record/181550, June 28, 2017, [Consulta: 13 Mayo 2021].

Clark, K. D., Woodson, T. T., Holden, R. J., Gunn, R., and Cohen, D. J., Translating Research into Agile Development (TRIAD): Development of Electronic Health Record Tools for Primary Care Settings, *Methods of information in medicine*, vol. 58, no. 1, pp. 1-8, 2019. https://doi.org/10.1055/s-0039-1692464

Hu, W., Yang, Z., Chen, C., Wu, Y., and Xie, Q., A Weibull-based recurrent regression model for repairable systems considering double effects of operation and maintenance: A case study of machine tools, *Reliability Engineering & System Safety*, 2021.

Hubert, Phoenix, P., Sudaryono, R., and Suhartono, D., Classifying Promotion Images Using Optical Character Recognition and Naïve Bayes Classifier, *Procedia Computer Science*, pp. 498-506, 2021.

Jiménez Hernández, A., Diseño y desarrollo de una aplicación Android para el reconocimiento óptico de caracteres. (tesis), Design and Development of an Android OCR Application. (thesis), *Universidad de Valladolid. España*, 2018.

Liu, X., Vatn, J., Dijoux, Y., and Toftaker, H., Unobserved heterogeneity in stable imperfect repair models, *Reliability Engineering & System Safety*, vol. 203, p. 107039, 2020. https://doi.org/10.1016/j.ress.2020.107039

Kannan, V., Fish, J. S., Mutz, J. M., Carrington, A. R., Lai, K., Davis, L. S., and Willett, D. L., Rapid development of specialty population registries and quality measures from electronic health record data: An agile framework, *Methods of information in medicine*, vol. 56, no. 99, e74, 2017. Doi: 10.3414/ME16-02-0031

Krämer, J., Thiele, G., Johanni, T., and Krüger, J., Automation of Life Data Analysis Processes, *In IOP Conference Series: Materials Science and Engineering. IOP Publishing*, vol. 1140, no. 1, p. 012022, May 2021. doi:10.1088/1757-899X/1140/1/012022

Moreno, R. S., Aguilar, A. R., Hernández, E. F., and Soto, F. P., Aplicaciones de la distribución weibull en ingeniería de confiabilidad, Weibull Distribution Applications in Reliability Engineering, *Memoria del XXI Coloquio Mexicano de Economía Matemática y Econometría*, p. 148, 2011.

Nassar, M., Afify, A. Z., Dey, S., and Kumar, D., A new extension of Weibull distribution: properties and different methods of estimation, *Journal of Computational and Applied Mathematics*, vol. 336, pp. 439-457, 2018. https://doi.org/10.1016/j.cam.2017.12.001

Olaya, A., Bohórquez, H. D., and Barrios, A. R., CardioResyncApp: Un aplicativo móvil para recolectar datos de investigación en Cardiología, A Mobile Application for Collecting Cardiology Research Data, *Revista Colombiana de Cardiología*, vol. 27, no. 4, pp. 270-275, 2020. https://doi.org/10.1016/j.rccar.2020.01.010

Robby, A., Tandra, A., Susanto, I., Harefa, J., and Chowanda, A., Implementation of Optical Character Recognition using Tesseract with the Javanese Script Target in Android Application, *Procedia Computer Science*, pp. 499-505, 2019. doi:10.1016/j.procs.2019.09.006

Salazar, R., Fitz, E., López, I., and Rojano, A., Confiabilidad y Análisis de Fallas utilizando la Distribución Weibull, Reliability and Failure Analysis using the Weibull Distribution, Mexico, September 21, 2017.

Sidibe, I., Kathab, A., and Adjallah, K., Reliability and preventive maintenance analysis of Weibull distributed lifetime systems, *IFAC Proceedings Volumes*, pp. 306-311, 2013. https://doi.org/10.3182/20130522-3-BR-4036.00087

Sgarbossa, F., Zennaro, I., Florian, E., and Persona, A., Impacts of Weibull parameters estimation on preventive maintenance cost, *IFAC-PapersOnLine*, pp. 508-513, 2018. Doi: 10.1016/j.ifacol.2018.08.369

Vala, S., Chemweno, P., Pintelon, L., and Muchiri, P., A risk-based maintenance approach for critical care medical devices: A case study application for a large hospital in a developing country, *International Journal of System Assurance Engineering and Management*, vol. 9, no. 5, pp. 1217-1233, 2018. https://doi.org/10.1007/s13198-018-0705-1

Woodson, T. T., Gunn, R., Clark, K. D., Balasubramanian, B. A., Jetelina, K. K., Muller, B., and Cohen, D. J., Designing health information technology tools for behavioural health clinicians integrated within US-based primary care teams, *Journal of innovation in health informatics*, vol. 25, no. 3, p. 158, 2018. doi: 10.14236/jhi.v25i3.998

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Biographies

José Antonio Taquía is a Doctoral Researcher from Universidad Nacional Mayor de San Marcos and holds a Master of Science degree in Industrial Engineering from University of Lima. He is a member of the School of Engineering and Architecture teaching courses on quantitative methods, predictive analytics, and research methodology. He has a vast experience on applied technology related to machine learning and industry 4.0 disrupting applications. In the private sector he was part of several implementations of technical projects including roles as an expert user and in the leading deployment side. He worked as a senior corporate demand planner with emphasis on the statistical field for a multinational Peruvian company in the beauty and personal care industry with operations in Europe and Latin America. Mr. Taquía has a strong background in supply chain analytics and operations modeling applied at different sectors of the industry. He is also a member of the Scientific Research Institute at the Universidad de Lima being part of the exponential technology and circular economy groups. His main research interests are on statistical learning, predictive analytics, and industry 4.0.

Jhonatan Anaya is a Systems Engineer, graduated and graduated from the University of Lima, currently part of the Strategic Planning and Business Development area in the head of Commercial Management of Banco de Crédito del Perú, the main bank in the financial sector, performs commercial strategy tasks with the aim of providing a comprehensive proposal to the internal and external client. In his professional career, he participated in the technological transformation project in the role of business specialist from the wholesale banking front with the aim of repowering and redesigning the User IT, proposal and commercial management of the business executive through the Salesforce digital platform, which is a CRM used for core business processes with impact on the external client and the development of analytical information for decision making. of internal leaders. On the other hand, he led the project "Wholesale Banking Performance Sheets", which consisted of centralizing the indicators of profitability, management and satisfaction in a solid and integrated tool, which shows information at the level of client portfolio and economic group, was designed and developed on the Qliksense platform. He holds specializations in Data Applied to Business and Data Analytics with the aim of co-creating and executing decision making regarding information. On the other hand, for the design of the value proposition in the business with disruptive ideas, he obtained a Design Thinking certification by IBM. Finally, for the management of internal projects and software development using a framework, he obtained a specialization in the execution of agile methodologies.

Diego Martínez is a Systems Engineer who graduated from the University of Lima, who is currently part of the Digital Solutions area of ENGIE Energía Perú, a company part of the ENGIE group (formerly GDF SUEZ) dedicated to the generation of electricity. He fulfills the role of Office 365 Single Point of Contact, supporting and developing innovation and digitization projects related to Microsoft technology and Salesforce CRM. He developed applications focused on the preventive management of safety in administrative and operational work and the management of work which permits efficient performance, ensuring and controlling the best practices in operational work. In addition, he was the leader of the commercial data lake project of Engie Energía Peru for the management of operational data of the interconnected system of Peru (SEIN). Later, on behalf of Peru, he was the leader of the CRM Salesforce unification project at the LATAM between Chile, Colombia, Peru and Mexico, for the management of the relationship with ENGIE LATAM clients. He has a specialization in using the Microsoft PowerBI tool focused on information management for decision-making based on visualizations. Currently, he is a Global Master in Business Analytics student and Data Strategy at EAE Business School, a program focused on technology, methodologies, and strategies for developing Data Analytics projects. Likewise, he is certified in Data Science and Big Data by the Massachusetts Institute of Technology and certified in Architecting on AWS, specializing in Project Management and Quality at the Pontificia Universidad Católica del Perú. His research interests include simulation, data governance, Data Science, and Big Data.