UNIVERSIDAD DE INVESTIGACIÓN DE TECNOLOGÍA EXPERIMENTAL YACHAY

Escuela de Ciencias Biológicas e Ingeniería

TÍTULO: Statistical Analysis of the obsolescence of medical equipment in type A Health Centers in the district of Ibarra-Ecuador

Trabajo de integración curricular presentado como requisito para la obtención del título de Ingeniero Biomédico

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Dedicatoria

Dedico este trabajo a mis padres Juan Guerrero y Veronica Ligña, ya que han sido un pilar fundamental para mi desarrollo personal, academico y profesional. Gracias por enseñarme a soñar en grande y guiarme de la mejor manera para que junto con su apoyo y amor pueda cumpli mis objetivos. A mis hermanos, Andrés y Juan Sebastián Guerrero, por sus risas, cariño y amor incondinocial que siempre me han dado a pesar de estar lejos de casa. A Cami, gracias no solo por ser mi compañera de tesis, sino por ser mi mejor amiga, por acompañarme en cada etapa universitaria desde inicios de la carrera hasta la culminación de la misma, gracias por creer en nosotras, y en nuestros proyectos. A Andrés, por ser mi soporte y apoyarme en los peores momentos, y por celebrar conmigo cada logro academico, profesional y personal. Espero que este sea el inicio de mas logros juntos, ya que indudablemente esta meta no habría sido alcanzada sin ustedes. Gracias por formar parte de mi vida.

Stephanie Alejandra Guerrero Ligña

Dedicatoria

Dedico este trabajo con profundo cariño y gratitud a mis padres, Pablo Valencia y Marisol Cevallos, por ser mi fuente de inspiración y motivarme siempre a luchar por mis sueños. Gracias por siempre creer en mí y por sus constantes palabras de aliento. A mis hermanas Linda y Naty, que me han acompañado con mucho amor en cada una de mis aventuras. Estoy profundamente agradecida por tenerlas a mi lado, celebrar juntas nuestros logros y también enfrentar las dificultades. A mis sobrinas, Dome y Vale, que son como hermanas para mí, por su cariño, alegría y entusiasmo. Finalmente, a mis amigos y a todas las personas que conocí y formaron parte de mi vida durante esta etapa. Especialmente a Ale, por ser mi confidente y mejor amiga. Me siento orgullosa de poder culminar juntas nuestra tesis y graduación. A todos ustedes, que han formado parte de mi vida y de este logro, mi más sincero agradecimiento. Este trabajo es un reflejo no solo de mi esfuerzo, sino también del amor y el apoyo que he recibido de quienes me rodean.

Camila Marisol Valencia Cevallos

Agradecimientos

En mi primer lugar queremos agradecer a nuestro tutor de tesis, profesor Fernando Villalba, por confiar en nuestras capacidades desde el inicio de nuestra carrera universitaria, alentandonos siempre a superar los desafíos y a alcanzar nuestras metas. Su compromiso como docente e investigador han sido una fuente de inspiración para nosotras. Ademas, agradecemos a nuestro co-tutor, el profesor Lenin Ramírez, quien con su asesoramiento nos ayudó a culminar este proyecto. Adicionalmente, quisieramos expresar nuestros agradecimientos al Departamento de Equipamiento Sanitario del Ministerio de Salud Pública del Ecuador por abrirnos las puertas y facilitarnos el acceso a información indispensable para nuestro trabajo. Asimismo, a la Coordinación Zonal 1, al Departamento de Mantenimiento y Activos Fijos por su buena predisposición y su gentil ayuda cuantas veces han sido necesarias para el desarrollo de nuestra tesis.

Alejandra Guerrero y Camila Valencia

Resumen

El presente estudio pretende abordar el tema de la obsolescencia de los equipos médicos en los centros de salud tipo A de Ibarra, Ecuador. El objetivo principal es determinar la tasa de obsolescencia de los equipos médicos utilizando los lineamientos del Ministerio de Salud Pública (MSP). Para ello, se realiza un análisis descriptivo exhaustivo de los datos de equipamiento de los centros, destacando las principales características y estado de los equipos. Además, el estudio implementa el Escalamiento Multidimensional No Métrico (NMDS) para identificar y evaluar las variables que influyen en el índice de obsolescencia. Se determinaron cuales son las variables que presentan una alta influencia en la evaluación de la obsolescencia de los equipos médicos, y como esta influye en la disponibilidad y utilización de los servicios médicos. Adicionalmente, se muestra como el deterioro de los equipos médicos afecta negativamente a la calidad y seguridad de los servicios prestados, y como esta condición se refleja en la gestión y manejo de los equipos médicos en los centros de salud tipo A de Ibarra-Ecuador. Los resultados de este proyecto demuestra que la gestión de equipamiento medico es de gran importancia y debe ser asignada acorde a las necesidades de los centros sanitarios, con el objetivo de brindar una buena calidad de atención al paciente desde el primer nivel de atención.

Palabras Clave:
Obsolescencia de equipos médicos, análisis descriptivo, escala multidimensional no métrica (NMDS), índice de obsolescencia, eficacia de los servicios sanitarios.

Abstract

This study aims to address the issue of medical equipment obsolescence in Type A healthcare centers in Ibarra, Ecuador. The main objective is to determine the obsolescence rate of medical equipment using the guidelines of the Ministry of Public Health (MSP). To analyze this, a comprehensive descriptive analysis of the equipment data from the centers is conducted, highlighting the key characteristics and status of the equipment. In addition, the study implements Non-metric Multidimensional Scaling (NMDS) to identify and evaluate the variables that influence the obsolescence index. The factors that contribute most to equipment obsolescence were obtained, and how the obsolescence influences the accessibility and usefulness of medical services. In addition, it shows how aging equipment affects quality and safety of services provided, and how these challenges are reflected in the management of medical equipment in type A health centers. The results of the study demonstrates that the management of medical equipment is crucial and must be specific depending on the needs of the healthcare facility to maintain a high level of healthcare services.

Keywords:

Medical Equipment Obsolescence, Descriptive Analysis, Non-metric Multidimensional Scaling (NMDS),Obsolescence Index, Healthcare Service Effectiveness.

Contents

List of Tables

List of Figures

Chapter 1

Introduction

1.1 Introduction

The obsolescence of medical equipment is a result of the degradation or failure of the main functions of the medical equipment giving way to technological replacement. The analysis of the medical equipment's obsolescence index from health facilities is fundamental for anticipating the process of replacement or renewal of medical equipment as it allows to determine its functionality, assigning a rating on a rating scale that helps to make appropriate decisions based on real results [1]. It is necessary that healthcare facilities provides a detailed report of the medical needs that permits a clear overview of the medical equipment needs. In this way, the Ecuadorian Ministry of Public Health has announced the guidelines for determining the Biomedical Equipment Obsolescence Index in which they detail the specific criteria that must be considered when calculating the medical equipment's obsolescence index. It includes technical, economical and clinical evaluations [2]. In this way, this protocol identifies whether or not the equipment is in a condition to provide the services for which it was designed. The results of the calculation of the obsolescence index make it possible to decide on the immediate replacement of the equipment, that is, if the equipment requires replacement in less than one year, if the equipment requires follow-up, or if the equipment is in optimal condition [2]. In developed countries, the management of medical equipment during obsolescence tends to be carried out more timely than in countries with limited resources. Research conducted by Rodriguez et al (2020) establishes that, in most of the industrialized nations, the evaluation of the state of medical equipment is easier and faster because they manage a proper planning distribution and the enough resources that contributes to perform a replacement within the suggested times. This situation is far from the reality of emerging countries since the equipment reaches or exceeds the useful life dates given to the institutions by the manufacturer. The situation in Ecuador is even more worrying. Vargas et al. state that the management of medical supplies in Ecuador has represented an obstacle in the timely treatment of diseases due to insufficient supplies. The lack of both human and economic resources can create these inconveniences. As stated by Panchi et al (2019) Ecuadorian public health facilities don't have an adequate annual maintenance programs nor annual procurement plans for the replacement of consumables, accessories and spare parts, which results in an inadequate budget allocation designated for maintenance and spare parts, thus unnecessarily prolonging the useful life of medical equipment, and affecting the safety and health of the patient. This project is focused especially on examining the condition of medical equipment located in type A health centers in the district of Ibarra, Ecuador. This initiative arose from the need to evaluate the condition of the equipment located in health facilities that provide basic care since they are the first line of patient care. In addition, it has taken the importance of analyzing the health situation in both urban and rural areas. Proper functioning of medical equipment widely contributes to improving the quality of patient care and the rapid diagnosis of diseases. Therefore, determine and analyze the obsolescence rate of the medical equipment is essential to schedule preventive and corrective maintenance, and to anticipate the purchase or replacement of new technologies. The purpose of this study is to statistically analyze the results obtained after calculating the obsolescence of medical equipment in type A health centers belonging to Ecuador's Zonal 1, specifically in the district of Ibarra. This will allow us to have real data on the situation of medical equipment in these establishments, and to relate variables that influence their obsolescence. Using this knowledge, the management of health technology can be improved, resulting in a reduction of risks to the patient and an appropriate allocation of economic resources.

1.2 Problem statement

Using equipment that has exceeded its useful life represents a considerable risk for users. This is due to the fact that they may experience unexpected failures or a decrease in their efficiency, which could affect medical care. In this sense, it is imperative to carry out an exhaustive analysis of equipment obsolescence, not only to guarantee patient safety, but also to ensure the provision of quality service. In public health facilities, such as health centers, the allocation of budget to cover the need to renew, replace or acquire new equipment is a challege. As a result of such management, medical equipment becomes obsolete, which can cause alterations in medical diagnosis, affecting the quality of service provided to the patient. Oturu K, et al (2021) states that developing countries face the serious problem of lack of access to medical equipment compared to first world countries [3]. Geeta S (2005) states that the availability and optimal utilization of medical equipment is important to improve the quality of healthcare services [4]. Identifying obsolete equipment allows effective planning for its replacement or upgrade, which helps to optimize resources and improve efficiency in healthcare. Considering the situation of medical equipment in type A health centers in Ibarra, weaknesses in medical technology management have been identified. Although the Ministry of Public Health has a protocol for evaluating equipment obsolescence, it is rarely used or considered, resulting in vulnerable management systems. Additionally, the access to information that is needed to determine the obsolescence index lacks an organized structure and protocols making its evaluation and analysis difficult and time consuming.

1.2.1 Justification

Medical technology obsolescence is a major problem in healthcare today. If it is not properly managed, it can make care less safe, less effective and increase costs. It is crucial to deal with this in an organized and proactive way to ensure that medical care remains good and affordable in the future. For this, it is essential to implement robust and standardized information management systems in healthcare facilities that allow for collecting, storing and analyzing relevant data on equipment obsolescence, thus facilitating strategic planning and efficient management of resources in the healthcare setting. This thesis project aims to address this situation through the statistical analysis of the obsolescence rate of medical equipment. This analysis not only seeks to identify the degree of wear and tear of the equipment, but also to highlight the relevance of the different criteria that influence its obsolescence. In addition, it allows us to have a strong and statistically significant indicator to demonstrate the relationship between the variables and their effect on the obsolescence of medical equipment.

1.3 Objectives

1.3.1 General Objective:

- To conduct a statistical analysis of the obsolescence of medical equipment in type A medical centers in the Ibarra District to identify areas for improvement in the efficiency of medical equipment management and contribute to the optimization and improvement of medical care in the region.

1.3.2 Specific Objectives:

- To determine the obsolescence index of the medical equipment Type A healthcare centers from Ibarra-Ecuador.
- To develop a descriptive analysis of the main characteristics of the equipment data of the Type A healthcare centers from Ibarra-Ecuador.
- To determine which variables influences the obsolescence index in medical equipments through the implementation of the Non-metric Multidimensional scalling (NMDS).

- To assess how medical equipment obsolescence affects the availability and effectiveness of health care services in Type A health facilities.

Chapter 2

Theoretical Framework

2.1 Medical Device

Medical equipment is an indispensable part of healthcare [5]. According to the World Health Organization (WHO) a medical device is "any instrument, apparatus, implement, machine, appliance, implant, reagent for in vitro use, software, material or other similar or related article, intended by the manufacturer to be used, alone or in combination for a medical purpose" [6, 7]. They are indispensable for universal health coverage, monitoring wellbeing and addressing outbreaks or emergencies[6]. Medical device is defined as an article, instrument, apparatus or machine that is used in the prevention, diagnosis or treatment of illness or disease, or for detecting, measuring, restoring, correcting or modifying the structure or function of the body for some health purpose. Typically, the purpose of a medical device is not achieved by pharmacological, immunological or metabolic means [8]. Almost any device used in medicine that isn't classified as a medicinal or nutritional product can be considered a medical device. This classification can lead to challenges for regulators and users. For instance, some medical devices incorporate medicinal products, as seen with drug-eluting stents. In this context, the definition proposed by [7] for medical devices is "a contrivance designed and manufactured for use in healthcare, and not solely medicinal or nutritional." This means that a combination product is any equipment that works in conjunction with medicinal agents. That is, equipment that contains medicines to function, or conversely, medicines that are integrated into the product. Those should be subject to the same standards as pure medicinal products, rather than the less stringent standards currently applied to devices.

2.1.1 Classification of medical devices

Medical devices cover a wide range of categories. That is why the term ”medical device” covers simple, disposable products from hypodermic syringes and blood bags to pacemakers, surgical lasers, implantable pumps and vascular grafts [9]. There is the main reason why classifying devices becomes a difficult task. In the case of medical devices, these are classified to know how hazardous their use is for the patient, the user and for third parties (e.g.: a fl uoroscope, poses a radiation risk not only for the patient but for the physician using it and for others in the operating room), therefore how they should be tested before they are introduced to the market and how strictly they should be controlled after market introduction needs to be considered [10].

How hazardous the use of a device is, depends on multiple factors and a clear classification according to a few clear cut criteria is almost impossible.

FDA Classification

Most medical devices can be classified by finding the matching description of the device in Title 21 of the Code of Federal Regulations (CFR), Parts 862-892. FDA has classified and described over 1,700 distinct types of devices and organized them in the CFR into 16 medical specialty ”panels” [11].

Every type of these devices is categorized into one of three regulatory classes, depending on the level of oversight required to ensure their safety and efficacy. The three classes and the corresponding requirements for each are[9, 12, 13]:

- **Class I devices (general controls)** are intended for applications that do not present significant health threats. For example, stethoscopes, periodontal syringes and nebulizers. These products are generally regulated without the need for specific standards or pre-market review. Oversight requirements typically include FDA registration of devices, inventory, adequate record keeping, and compliance with Good Manufacturing Practices (GMP).

- **Class II devices (performance standards)** refers to equipment for which basic oversight requirements are insufficient to ensure its safety and effectiveness. An equipment is classified as Type II, taking into account the level of health risk it represents and other relevant data that allows for the assignment of appropriate performance standards. For example, diagnostic catheters, electrocardiographs, and percutaneous catheters.

- **Class III devices (premarket approval)** are life support and life-support equipment. These devices are “critical devices” unless their classification in another category is adequately justified. Some of the most common examples are ventilators, pacemakers and cardiopulmonary bypass.

European Union Classification

The European Union legislation distinguishes four classes (I, IIa, IIb, III) [14, 10].

The European Union separates devices using the STP classifcation of medical devices that classify them by site of application (S), time scale of use (T), and power source (P). This classification is based on the planned duration of use, the level of body contact during use, and whether the devices are "active" meaning that their power source is turned on or off. In addition, this classification distinguishes devices used in central cardiovascular and central nervous systems from other types due to their higher associated risk. [7].

Alternative Classification

Currently, the regulatory classifications for medical devices are complicated and have been established from the perspective of the regulators. [7] propose a simpler classification, based on (1) the site of application of the device, (2) the time scale of its use, and (3) whether it has an external power source.

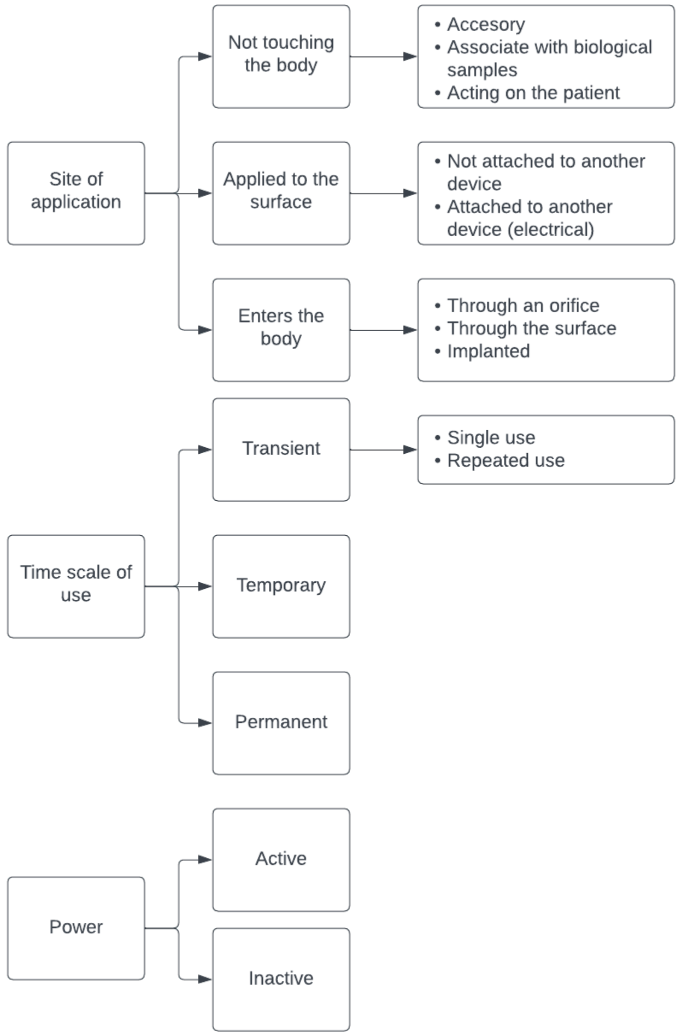

Figure 2.1: Classification of medical devices

2.2 Medical Equipment

According to the World Health Organization (WHO) "medical equipments are defined as medical devices requiring calibration, maintenance, repair, user training and decommissioning – activities usually managed by clinical engineers" [6]. Medical equipment is used for the specific purposes of diagnosis and treatment of disease or rehabilitation following disease or injury; it can be used either alone or in combination with any accessory, consumable or other piece of medical equipment. Medical equipment excludes implantable, disposable or single-use medical devices.

All medical equipment are medical devices—but not all devices should be considered equipment [15]. The figure 2.2 visually illustrates the relationship between medical equipment and medical devices. This way, the hierarchy between these terms can be better understood.

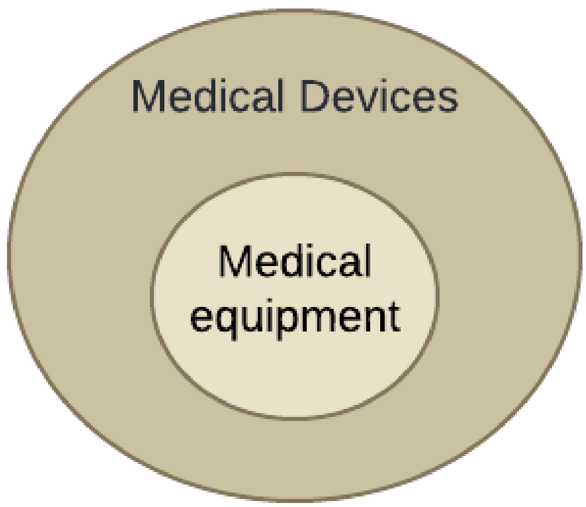

Figure 2.2: Medical devices vs. Medical equipment

2.2.1 Classification of Medical Equipment

The classification of medical equipment can follow the same categories and criteria used for the classification of medical devices. Food and Drug Administration (FDA) in the United States and in Medical Device Regulation in the European Union (MDR).Basically the classification is based on the level of risk, the use given to the equipment and its technology. Additionally, medical equipment can also be classified based on its maintenance and repair needs. Clinical engineers usually make use of risk classification technique to guide the selection of medical equipment for the preventive maintenance program and to define their inspection frequencies [16].

Fenningkoh and Smith [17] proposed three parameters for the risk classification of medical equipment: maintenance requirements, functional risk, and physical risk. However, this classification does not change during its use in the hospital, even though the risk can increase due to factors such as management quality, equipment aging, and multiple operators. To improve safety evaluation, an additional parameter should be considered: the risk factor, which includes situations favorable for equipment failure, such as inappropriate electrical installations, obsolete equipment, lack of preventive maintenance, and absence of user training programs. This classification can help in the selection of equipment for preventive maintenance and guide risk control procedures, establishing priority actions for safety.

Oshiyama et. al [18] proposes two methods for medical equipment classification based on three maintenance indicators, which could be used at any hospital, independently of the number of beds or pieces of equipment. One of the methods is based on the hypothesis that the maintenance indicators increase as equipment ages (Aging Method, AM). The second method is based on the ABC ("Always Better Control") analysis and is presented as a simpler, more limited, but yet useful method (in short, ABCM). Additionally, equipment age was chosen as the criterion for establishment of classes because, with constant use, replacement of parts tends to occur more often, and preventive maintenance may be required more frequently. Three classes were then defined according to the profile of equipment of different age ranges: A (0-4 years), B (5-9 years) and C (¿10 years) [18].

2.3 Life cycle of medical equipment

According to the Clinical Engineering Handbook [19] the life cycle of a medical device encompasses several critical stages, each contributing to the effective management and utilization of the device.

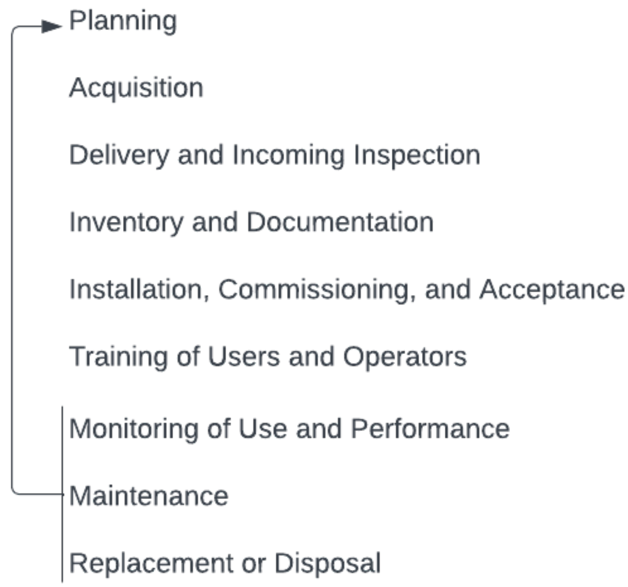

Figure 2.3: Life-cycle management of medical devices

1. **Planning:**Identify the demand for a medical device through market research and health technology assessments. Specifications and requirements are crucial to ensure that factors such as available qualified users, regulatory compliance and budgetary considerations are taken into account. Planning for the future will help minimize problems later in the life cycle, maintenance issues and operational inefficiencies.

2. **Acquisition:** In this phase, the device is purchased. This involves evaluating potential devices for safety, performance and serviceability. The procurement process must include clear specifications in the purchase order and ensure that suppliers provide the necessary documentation, training and spare parts. This phase is crucial to establish a solid foundation for the operational life of the device.

3. **Installation:**Once the medical equipment is purchased, the technical staff or external suppliers proceed to install and activate the device. A correct installation process ensures an adequate equipment functioning.

4. **Training:** Safe and effective use of the device requires proper training of users and

operators. Training and retraining are critical in environments where staff turnover is high and operator error is a major contributing factor to device failures.

5. **Maintenance:** Regular maintenance frequency, whether corrective or preventive, helps to preserve the functionality and performance of the equipment, protect the financial investment, and prevent possible failures that could put the patient at risk.

6. **Performance Evaluation** Surveillance and monitoring of medical equipment is essential to ensure its performance. In this way, buyer feedback is essential to improve the quality of medical equipment.

7. **Disposal:** Once the medical equipment has reached the end of its useful life, it is necessary to disassemble it so that, depending on its condition, parts and spare parts can be obtained that can be used for equipment that is still in service.

A device's life cycle can then proceed down either the path of disposal, donation, or reprocessing. Each of these alternatives presents benefits and challenges [20]. First, the disposal is a traditional methods of hospital waste disposal often lead to significant environmental harm, as much of this waste is processed as infectious waste despite only 15% being biohazardous. This misclassification increases disposal costs and environmental impact. In contrast, donating medical devices can improve healthcare outcomes in low- and middle-income countries (LMICs) while reducing waste. However, this practice faces challenges such as inadequate staff training in recipient facilities, which can hinder the effective use and maintenance of donated equipment. Additionally, reprocessing medical devices, which allows for the cleaning and reuse of equipment, significantly reduces waste. Focusing on the reprocessing and recycling potential during the design phase can lead to more sustainable medical devices. Approximately 80% of sustainable decisions are made at this stage.

2.4 Management of medical equipment

The non-stop technological advancement affect both, industries and healthcare services. Indeed, healthcare technologies have become a crucial part of the services provided, playing key roles in diagnosing and treating patients. There is a need to improve technology management in healthcare centers by implementing technologies that are friendly to the treating physician and the patient in order to ensure their safety. [21]. The best way to maximize the value of healthcare technology is the implementation of a system of comprehensive, "cradle-to-grave" healthcare technology life-cycle planning and management. The healthcare technology planning process includes assessment of technologies new to the health entity, replacement of existing technologies, budgeting based on these inputs along with the realities of funding, followed by acquisition of approved devices and systems [22].

Thus, a fundamental part of any medical equipment is its maintenance. Its planning evaluates the manner in which the equipment is used, its frequency of use, and the type of risk involved in its use[21].

Figure 2.4: Life-cycle management of medical devices

Once the most appropriate inclusion model has been chosen, it is necessary to decide on the appropriate maintenance strategies for medical equipment. Thus, they are divided into proactive and reactive [23]. Proactive strategies refer to predictive maintenance, or scheduled replacement. On the other hand, the reactive strategy corresponds to unplanned replacement, since it is directed to the control and management of failures and recalibration of medical equipment. It is important to mention that it is not possible to create a unified MEMP (Medical Equipment Management Program) for all organizations because it depends on the geographical area and population capacity they cover, whether health centers or hospitals [24].

Importance of Management of medical equipment

Managing medical equipment is crucial for several reasons. To begin with, poorly managed medical equipment can lead to increased risks of human error, which is a significant factor in patient injuries. Studies have shown that human error accounts for up to 69% of patient injuries, often exacerbated by complex medical technology. Furthermore, the complexity of medical technology necessitates a focus on usability. If equipment is not managed properly, it can lead to usability problems that affect the efficiency and effectiveness of its use. Consequently, medical staff may experience frustration and helplessness, which can increase stress and decrease the quality of care. Additionally, effective management ensures that medical equipment is functioning optimally, which directly impacts the efficiency of healthcare delivery. Usability issues can lead to longer operation times and increased likelihood of errors, thereby reducing overall efficiency. Finally, poor management can lead to increased costs due to equipment downtime, maintenance issues, and the potential for legal liabilities stemming from patient harm [25].

2.5 Medical Technology Standards and Regulations

Adequate regulation of healthcare equipment is significantly beneficial as it ensures access to quality and safe public health for both patients and healthcare personnel. Additionally, it restricts the use of equipment that is unsafe or has limited clinical use.

According to the OPS [26] Resolution CD42.R10, adopted during the 42nd Executive Council, urges Member States to develop and strengthen their medical device regulation programs. Subsequently, Resolution WHA60.29, approved by the 67th World Health Assembly, calls on Member States to strengthen national regulatory systems, participate in global, regional, and subregional networks of regulatory authorities, and promote international cooperation. It also requests the Director-General to prioritize the establishment and reinforcement of regional and subregional regulatory networks and to support the creation and strengthening of national and regional regulatory bodies for medical devices. More recently, Resolution WHA67.20, approved by the same assembly, addresses the strengthening of the medical product regulation system.

The Ministry of Public Health (MSP) [2], specifically the Health Equipment Department, has the mission of managing the quality of health equipment of the health services of the MSP, through the generation of technical standards, in accordance with sector policies, quality models, regulations and established strategic guidelines.

Attributions and Responsibilities

(a) Develop technical instruments with inputs for the elaboration of public policy, bills, management models, technical standards, regulations and other normative instruments for the provision, renovation and maintenance of health equipment in health facilities;

(b) Develop plans, programs, projects, tools and/or technical instruments with guidelines/strategies for the provision, optimization, renovation and maintenance of sanitary equipment to be applied in the health facilities of the Ministry of Public Health;

(c) Manage, implement and evaluate the application of technical regulations, plans, programs, programs, projects, tools and/or technical instruments with guidelines/strategies for the provision, availability, optimization, renovation and maintenance of sanitary equipment in the health facilities of the Ministry of Public Health;

(d) Develop, standardize and update the catalog of sanitary equipment;

(e) Coordinate the updating of the technical inventory of sanitary equipment provided by the health facilities of the Ministry of Public Health through its Zonal Health Coordinating Offices;

(f) Develop, standardize and update the list of the minimum sanitary equipment required for a service of the health facilities of the Ministry of Public Health, in coordination with the corresponding competent authorities;

(g) Manage the consolidation of the annual plan for the acquisition, renovation and maintenance of sanitary equipment of the health facilities of the Ministry of Public Health based on the information provided by the deconcentrated level;

(h) Develop standardized operating procedures for the receipt of maintenance services for the sanitary equipment of the health facilities of the Ministry of Public Health; h. Develop standardized operating procedures for the receipt of maintenance services for the sanitary equipment of the health facilities of the Ministry of Public Health;

(i) Develop and manage predictive, preventive and corrective maintenance protocols for the biomedical equipment of the health facilities of the Ministry of Public Health; j. Develop and manage predictive, preventive and corrective maintenance protocols for the biomedical equipment of the health facilities of the Ministry of Public Health;

(j) Develop feasibility studies for the provision of medical, biomedical and hospital equipment, according to the level of care and complexity of the health facilities of the Ministry of Public Health; j. Develop feasibility studies for the provision of medical, biomedical and hospital equipment, according to the level of care and complexity of the health facilities of the Ministry of Public Health;

(k) Participate, if required, in the situational room of the Ministry of Public Health within the scope of its competence; and,

(l) Supervise compliance with sanitary equipment standards in the health facilities of the Ministry of Public Health.

Internal Management involves the planning and management of medical equipment, as well as the supervision, monitoring, and administration of this equipment.

On the other hand, the National Agency for Regulation, Control, and Health Surveillance (Arcsa) [27] is the public entity under the Ministry of Public Health (MSP) responsible for controlling and monitoring the hygienic and sanitary conditions of products intended for human use and consumption. It also provides services to facilitate obtaining operating permits and Health Notifications. The technical regulations consist of 10 chapters, ranging from “object and scope of application” to “surveillance and control.”

Chapter I, Article 1 - Object: The purpose of these technical health regulations is to establish the parameters of quality, safety, and efficacy under which a Health Registration will be granted for Medical Devices for Human Use, as well as the criteria for the control and monitoring of these products. Additionally, this document aims to set the parameters for the operation, control, and monitoring of establishments where Medical Devices for Human Use are manufactured, imported, dispensed, sold, and marketed.

Chapter I, Article 2 - Scope: These technical health regulations are mandatory for individuals or legal entities responsible for the manufacture, importation, dispensing, sale, and marketing of Medical Devices for Human Use within the national territory.

2.6 Obsolescence

Obsolescence is the act of becoming obsolete, outdated, outmoded, etc. It is a trend to make something “out-of-date” [28]. Obsolescence is the end point of any technology, which can go through a life cycle that includes ideas, innovation, invention, research, dissemination, application, reduced use, and obsolescence [29]. Also, it is depreciation in value, impairment of desirability and/or usefulness caused by new inventions, current changes in design, improved processes of production, or external factors that make a system less desirable and valuable for a continued use [30]. Over time, everything ages, which makes obsolescence inevitable [31].

Whatever is human-made, tends to become obsolete over time due to physical factors such as chemical degradation, physical damage, etc. However, the process of obsolescence is not limited to materialistic and physical factors. Social, cultural, technological and political factors (such as technology innovation; variation in customer demands; change in existing legislation; social pressures; advancement of knowledge; inflation of currency; civil unrest or conflict of interests; etc.) can also drive obsolescence [32].

In the context of medical equipment, the implications of local regulations and standards play a crucial role in shaping obsolescence. In Ecuador, for instance, specific norms and regulatory frameworks govern the lifecycle of medical technologies [2]. These regulations can influence the rate at which equipment becomes obsolete, either by setting stringent requirements that necessitate frequent updates or by failing to address emerging technological advancements. An in-depth analysis of how Ecuadorian standards affect medical equipment obsolescence is essential to understanding the broader implications of regulatory practices. Examining these regulations can provide insights into how compliance and updates to standards might either mitigate or accelerate the obsolescence process, and highlight potential areas where regulatory adjustments could improve the management of medical technology lifecycles.

2.6.1 Types of Obsolescence

According to Butt et al. (2015) [32],

1. **Financial and Functional Obsolescence** Financial obsolescence means loss in value where as functional obsolescence is loss of usefulness, effectiveness, efficiency or productivity . Financial Obsolescence refers to the loss in value of an asset that can be influenced by different economic indicators. In the other hand, when an asset becomes less useful or efficient due to changes in standards or user needs, it is called Functional Obsolescence. Functional obsolescence highlights the importance of keeping assets updated to maintain their relevance and operational effectiveness.

2. **Internal and External Obsolescence** Internal obsolescence is that which is affected by intrinsic factors of the equipment, such as obsolete technology or deterioration over time. On the other hand, external obsolescence is that which is affected by extrinsic factors, such as changes in legislation, technological advances or environmental factors.

3. **Permanent and Temporary Obsolescence** Permanent Obsolescence refers to lasting changes that render an asset obsolete. An example is the decline of rotary dial

phones, which are now considered antiques and are no longer functional in modern contexts. Once an asset becomes permanently obsolete, it typically cannot be revived or updated to meet current standards. Temporary Obsolescence is due to short-term factors that can be reversed. For instance, a temporary decline in demand for a product due to economic conditions may lead to a perception of obsolescence, but once conditions improve, the asset may regain its value and relevance.

4. **Planned and Unplanned Obsolescence** Planned obsolescence is a technique in which devices are specially designed to have a short service life, which encourages users to buy alternatives or replacements. On the other hand, unplanned obsolescence occurs unintentionally, due to technological advances, or because of market conditions.

Schallmo et al. (2012) [33] classify the types of obsolescence as follows:

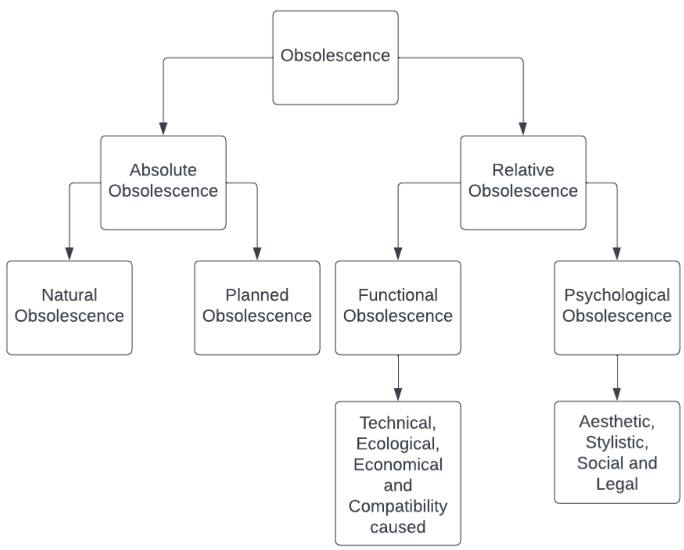

Figure 2.5: Types of Obsolescence

Factors contributing to obsolescence

The obsolescence of equipment can be caused by various factors, including the lack of spare parts, supplies, or accessories; adverse events triggering recalls, or simply the end of the equipment's lifespan. It is in fact important to note that obsolete medical equipment can also pose a risk to patient safety. This is why it is crucial to perform an obsolescence analysis to evaluate the functionality of the medical equipment and assess its accuracy, as the lack of it can lead to misdiagnosis. Therefore, it is needed to conduct regular obsolescence assessments to ensure that medical equipment remains safe and reliable for use on patients [34]. Regarding technological factors, the arrival of new technologies can render existing ones obsolete as more efficient options emerge. Additionally, continuous technological innovation enhances production processes, thereby reducing the appeal of older systems. It is important to mention that social and cultural factors play an important role as the demand for certain products or assets can be influenced due to evolving consumer preferences. In addition, the influence of social groups can impact the development of rules and policies. Physical factors include general wear and tear, which over time diminishes the utility of an asset, and aging infrastructure, which may not meet current standards or user needs, leading to functional obsolescence. Lastly, market and employment factors, such as changes in the labor market that affect the availability of specific skill sets, can influence the operational efficiency of assets and contribute to obsolescence. Moreover, economic downturns decrease the demand for certain assets, thereby affecting their value [32].

2.7 Obsolescence Index

The obsolescence index is a management tool designed to enhance the planning of preventive maintenance, corrective maintenance, and replacement of biomedical equipment by relying on measurable and verifiable factors throughout the equipment's lifecycle. It also helps identify factors that impact the performance of biomedical equipment over time, aiding administrative and operational stakeholders in making timely decisions to ensure the optimal functioning of all healthcare technology [2]. The criteria used to determine the obsolescence index of medical equipment are summarized in the figure 2.6.

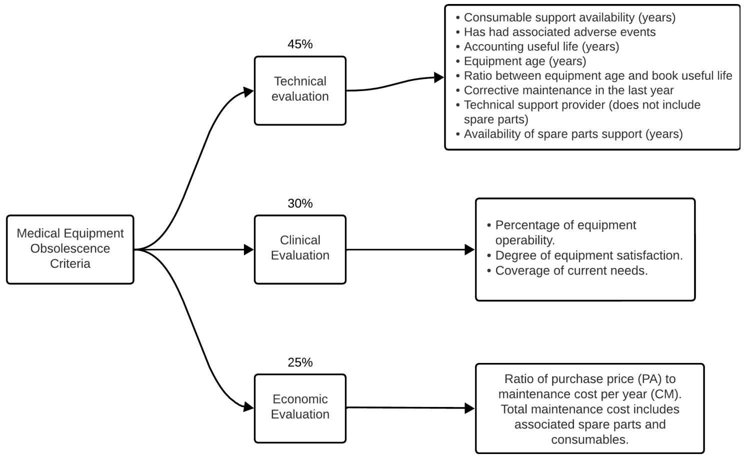

Figure 2.6: Criteria for the Obsolescence Index of medical equipment

1. **Technical evaluation** The Technical Evaluation (TE) criterion has a total weight of 45% of the final score. The purpose of this evaluation is to analyze the technical specifications of the equipment. The parameters to be evaluated were the following:

   Availability of consumables support: this criterion refers to the time of availability of the additional elements that the equipment needs for its operation. Original consumables, or those authorized by the manufacturer, are considered. One of the following options is chosen:

   - Greater than 7 years
   - From 5 to 7 years: There is availability from 5 to 7 years, including the time until reaching 7 years, such as 6 years and 11 months.
   - 1 to 4 years: 1 to 4 years available, includes time to 5 years, such as 4 years and 11 months.
   - No consumables support: There is no supplier that can provide consumables.
   - No consumables required: The equipment does not require consumables to operate.

   Associated adverse events: This criterion analyzes the unexpected complications the medical equipment has had during its use; these should have been previously reported to the National Technovigilance System. One of the following options is chosen:

- No: The equipment has never had adverse events either in the institution or in other institutions reporting to the national TV program.
- Less than 2: The team has had up to 2 adverse events in the institution or other institutions reporting to the national TV program.
- 3 or more: The equipment has had three or more adverse events at the institution or other institutions reporting to the national TV program.

Accounting useful life (Years): This parameter considers the quantity of years that the medical equipment needs to accomplih its functions. The information was obtained from the Fixed Assets Department at Coordinacion Zonal 1.

Age of the equipment: This criterion considers the number of years since the equipment was manufactured, acquired, or put into operation. The ratio of the accounting useful life and the equipment Age: This parameter is obtained automatically from the ratio between the accounting useful life and the equipment Age.

$$\text{Ratio} = \frac{\text{Age of the equipment}}{\text{Accounting useful life}} \tag{1}$$

Corrective maintenance in the last year: This criterion refers to the amount of corrective maintenance that the equipment has performed during the previous year. This parameter was obtained through the market research documents provided by the institution's maintenance area. One of the following options was chosen:

- Up to 2: In the last year, a maximum of 2 corrective maintenance has been performed.
- Between 3 and 7: In the last year, 3 to 7 corrective maintenance have been performed.

- More than 8: In the last year, more than 8 corrective maintenance have been performed.

Technical support provider: This criterion defines the activities carried out to ensure that the medical equipment is in good working order, involving preventive and corrective maintenance and calibration verification, among others. For this, the equipment warranty is considered, i.e., if the equipment needs maintenance within the warranty period, the factory or authorized representatives of the brand are responsible for providing technical support. On the other hand, for equipment that is no longer under warranty, the technical support provider is different from the one authorized by the manufacturer or its representative in Ecuador. One of the following options is chosen:

- With the factory: Technical support is provided directly by the manufacturer or its representative in Ecuador.
- Another supplier: There is a different technical support supplier that does not compromise the safety or operation of the equipment and is jointly and severally responsible for it.
- There is no technical support.

Availability of spare parts: Refers to the supplier's guarantee of finding spare parts in the market; those original spare parts or those authorized by the manufacturer are considered. One of the following options is chosen:

- More than 7 years: Spare parts older than 7 years are available.
- Between 5 and 7 years: Spare parts are available between 5 and 7 years, including the time until reaching 7 years, such as 6 years and 11 months.
- Between 1 and 4 years: Spare parts are available from 1 to 4 years, including the time up to 4 years, such as 3 years and 11 months.
- No spare parts support.

2.7.1 Interpretation criteria for the Obsolescence Index

Table 2.1: Criteria for the comprehension of the obsolescence index. Adapted from the "Lineamientos para la Determinacion del Indice de Obsolescencia – 2023"

Activity to be performed	**Index value**	**Meaning**	**Alert**
Immediate equipment replacement.	Index ≥ 90	The equipment is not viable to keep in service and it is recommended for immediate replacement.	Black
Replacement of the equipment within one year.	≤ 40 Index < 90	The equipment can be kept in service. However, it is recommended for replacement in less than one year.	Red
Technological evaluation within one year.	≤ 11 Index < 40	The equipment is in acceptable working condition but needs constant monitoring and evaluation.	Yellow
Does not require evaluation or renewal.	Index < 11	The equipment is in optimal conditions.	Green

Table 2.1 represents the criteria that must be considered to determine the critical level of the medical equipment and the actions that must be taken to mitigate the negative impacts. The index will show if the equipment has to be replaced, renewed, or if it does not require either renovation or renewal. The software shows the alert depending on the index; that is, the alert will be black if the index is greater than 90, and the alert will be red if it is between 40 and 90. If the index is between 11 and 40 the yellow alarm will appear. Finally, if the index is less than 10, the index alarm will become gree.

2. **Clinical evaluation**

The Clinical Evaluation (CE) criterion represents a total weight of 30% of the final score. A questionnaire with multiple-choice questions was applied to the leaders of the health centers. The purpose of this tool was to learn about the equipment's operation, the medical staff's satisfaction with the equipment's operation and the degree of compliance with the functions of the medical team. This questionnaire involves the medical equipment's name, the person responsible for the information and multiple choice questions. For the development of this stage, we accessed the health centers from November 2023 to January 2024, where the data was collected. The parameters to be evaluated were:

Percentage of equipment operability: This criterion relates the functionality of medical equipment, in which the number of functions offered by the equipment is analyzed with the number of times the medical staff uses it.

- More than 60%: More than 60% of the functions offered by the equipment are used by the service.
- Between 30% and 60%: Between 30% and 59% of the functions offered by the equipment are used by the service.
- Less than 30%: Below 30% of the equipment's functions are used within the healthcare service.

Degree of satisfaction of the medical equipment: This is a subjective criteria and is directed to the medical workers in charge of the medical equipment management. They have to indicate the level of satisfaction they experience with the functioning of the medical equipment.

- More than 75%
- Between 31% and 75%
- Less than 30%

Coverage of needs: This criterion relates to the medical staff's view of the equipment's ability to meet the needs in the service in which it is located.

- High: More than 75%
- Medium: Between 31% and 75%
- Low: Less than 30%

3. **Economic evaluation** The Economic Evaluation (EC) criterion has a weight of 25% of the total evaluation. All aspects related to the acquisition and maintenance costs

of the medical equipment are analyzed here. The parameters to be evaluated are the following:

Acquisition price: This parameter is related to the purchase price when the medical equipment was acquired. The institution's fixed assets area provided this information.

Maintenance cost/year: This parameter refers to the price paid by the financial institution for the maintenance performed last year; this information was obtained through the maintenance contracting processes carried out by the National Public Procurement Service (Sercop).

2.8 Statistic Analysis

Statistical analysis is a fundamental tool in scientific research, especially in studies involving large data sets. The Word statistics is used to describe the collection, reliability, organization, representation, analysis and interpretation of data and not just the collection of numerical results. Statistics is, above all, a tool to be used in many sciences [35].

Descriptive statistics and inferential statistics are the two major groups of data analysis and synthesis. Descriptive statistics present data concisely and briefly. In addition, graphs are used to facilitate the visualization of the data, which can allow patterns within the data to be uncovered. When there are large amounts of data that need to be interpreted, descriptive statistics are used to organize and summarize them [36].

Variables

The characteristics, or traits, that we measure in an individual or other source are often called variables, because they vary from one individual to another. Variables fall into two main categories: qualitative and quantitative. Qualitative variables are also often referred to as categorical variables [36]. It refers to characteristics that cannot be measured numerically and are subdivided into nominal, which have no natural order, and ordinal, which have a natural order but the magnitude is not important. On the other hand, quantitative can be measured according to an amount or quantity and are also called numeric, scaled, or metric variables. They are subdivided into discrete, which take integer values or a limited number of values, and continuous, which can take any value within a range.

A response variable (also called a dependent variable) is a measure that can be influenced by different variables and is of primary interest. Conversely, an explanatory (also called independent) variable is one that is actively collected or controlled to better understand the variation observed in the response variable [36]. Response and explanatory variables can be quantitative or qualitative. [37].

Describing Data

Categorical variables, including ordinal variables, describe qualities or attributes. To describe these variables, counts or frequencies of individuals in each category are often displayed visually. Occasionally, the mode, or the most frequent observation, may be reported[36]. For quantitative variables, measures of center (location) and variability (dispersion) should be mandatorily reported. Although there is a wide range of measures of location, two of the most common measures are the mean and the median. On the other hand, mode is most commonly used for qualitative data, and is rarely used to present quantitative data. To measure dispersion, the two most useful statistics are the standard deviation and the outer quartiles.

Measures of Location

- Mean: The average value, sensitive to extreme values. Formula[38]

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \tag{2.1}$$

  where $\sum$ is the uppercase Greek letter sigma denoting summation.

- Median: Also called the 50th percentile. Is the middle value when data is ordered, less influenced by outliers as the mean.

- Quantiles: Values that divide the data into equal parts, such as quartiles (0.25 and 0.75) which are useful for summarizing data distributions, especially when they are asymmetrical [39]. It is important to order the data from smallest to largest. The q-th quantile is then obtained by calculating the rank = q × (n + 1) and then estimating the value between the two values that are just on either side of that rank.

Measures of Spread

When analyzing data it is necessary to know the spread of the data set. The range is the simplest measure of spread [36].

- Range: The difference between the largest and smallest values, best for small datasets without extreme values. When there are at least 10 observations, the outer quantiles are preferred as a measure of spread [37].
- Interquartile Range (IQR): The difference between the 0.25 and 0.75 quantiles, providing a robust measure of spread that is less sensitive to outliers.
- Standard Deviation: The standard deviation, commonly denoted as s or SD, indicates how much individual data points deviate from the mean. Its calculation involves an intermediate step, the variance. The variance, s2, is the sum of the squared deviations of each individual value from the mean [36] and is defined as

$$s^2 = \frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1} \tag{2.2}$$

where $n-1$ is the number of degrees of freedom of the variance estimate. The standard deviation is obtained by taking the square root of the variance and is defined as

$$s = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}} \tag{2.3}$$

Displaying Data

Statistical methodology that can be applied to descriptively define the data. These methods are numerical procedures or graphical techniques e.g. bar charts, histograms, frequency polygons and pie charts, used to organise, present and describe the characteristics of a sample e.g. they provide a summary measures of the characteristics [40].

A **histogram** is a graphical representation that shows the frequency distribution with which certain values of a variable occur. The ”x” is the range of the variable and the ”y” is the frequency of observations. The height of the bars represents these frequencies. When the distribution is normal, it is shown in the form of a bell, where the mean is the highest point of the graph. [36].

2.9 Multivariate Analysis Techniques

Multivariate data consist of observations on several different variables for a number of individuals or objects. Data of this type arise in all branches of science, ranging from psychology to biology, and methods of analysing multivariate data constitute an increasingly important area of statistics [41]. Methods of statistical data analysis that examine several variables simultaneously and quantitatively analyze their relationships with the aim of describing and explaining these relationships or predicting future developments. These methods are collectively referred to as multivariate analysis techniques [42]. To classify the methods, we can distinguish between structure-testing and structure-discovering method.

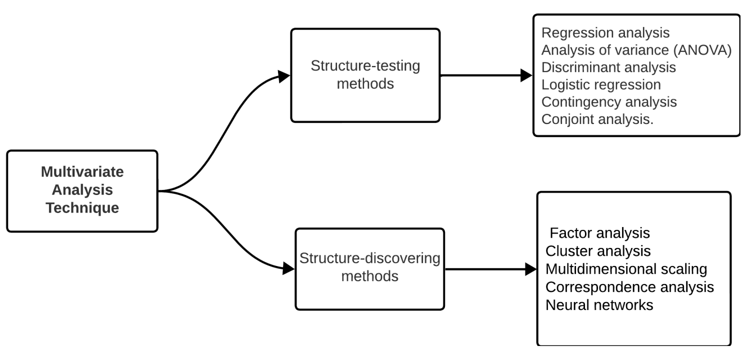

Figure 2.7: Multivariate Analysis Techniques

1. **Structure-testing methods** are procedures of multivariate analysis with the pri-

mary goal of testing relationships between variables. In doing so, the dependence of a variable on one or more independent variables (infuencing factors) is considered. The user has propositions about the relationships between the variables based on logical or theoretical considerations and would like to test these with the help of methods of multivariate analysis. Structure-testing methods are: regression analysis, analysis of variance (ANOVA), discriminant analysis, logistic regression, contingency analysis, and conjoint analysis.

2. **Structure-discovering methods** are procedures of multivariate analysis with the primary goal of discovering relationships between variables or between objects (subjects). At the outset, the user has no propositions about the relationships existing between the variables in a data set. Structure-discovering methods are: factor analysis and cluster analysis, multidimensional scaling, correspondence analysis, and neural networks.

However, it needs to be stressed that the methods cannot always be assigned exclusively to the above two categories because sometimes the objectives of the different procedures may overlap [42].

Multidimensional Scaling Technique

Scaling is an individual-directed technique that is appropriate when the data are in the form (or can readily be put in the form) of similarities or dissimilarities between individuals. The main objective of scaling is to produce a 'map' or configuration of the individuals in a small number of dimensions so as to compare the individuals more easily. In classical scaling (sometimes called principal co-ordinates analysis), the aim is an algebraic reconstruction of the positions of the individuals assuming that the distances are approximately Euclidean. An alternative scaling technique, often called non-metric multidimensional scaling, has a similar aim but only uses the rank order of the distances, and so we prefer to use the description ordinal scaling.

Ordinal scaling focuses on finding n points, such that their distances match the given dissimilarities between n objects. In this sense, it is possible to represent the data in two or three dimensions. The difference with classical scaling is that it allows to use the range of dissimilarities. [42].

Euclidean distance is the most conceptually and computationally straightforward, since it is analogous to simple geographic distance between two points on a map [43].

$$\mathrm{ED}_{pq} = \sqrt{\sum_{i=1}^{n}(p_i - q_i)^2} \tag{2.4}$$

where p_i and q_i are the i-th elements of the data vectors p and q. The Euclidean distance is a metric.

In contrast, the Bray–Curtis dissimilarity coefficient is non-metric (and thus, it is a dissimilarity rather than a distance). The formula is:

$$\mathrm{BC}_{pq} = \frac{\sum_{i=1}^{n} |p_i - q_i|}{\sum_{i=1}^{n}(p_i + q_i)} \tag{2.5}$$

2.9.1 Non-Metrical MDS

A non-metric approach to MDS was developed by Shepard (1962a, b) and further improved by Kruskal (1964a, b). In summary, suppose there are n objects with dissimilarities $\{\delta_{rs}\}$. The procedure is to find a configuration of n points in a space, which is usually chosen to be Euclidean, so that each object is represented by a point in the space. A configuration is sought so that distances between pairs of points $\{d_{rs}\}$ in the space match "as well as possible" the original dissimilarities $\{\delta_{rs}\}$. Here matching means the rank order of $\{d_{rs}\}$ matches the rank order of $\{\delta_{rs}\}$as best as possible. The matching of the distances $\{d_{rs}\}$ to the dissimilarities $\{\delta_{rs}\}$ for a particular configuration is measured by the STRESS (S), where

$$S = \sqrt{\frac{\sum_{r,s}(d_{rs} - \hat{d}_{rs})^2}{\sum_{r,s} d_{rs}^2}} \tag{2.6}$$

Here, $\{d_{rs}\}$ is the primary monotone least-squares regression of $\{d_{rs}\}$ on $\{\delta_{rs}\}$, also known as isotonic regression [44].

Metric MDS uses a linear function to map the proximities onto disparities, (torgerson1952multidimensional) whereas nonmetric models use any positive monotonic function, without the constraint of linearity.(shepard1962analysis–shepard1962analysis) For quantitative data (i.e., interval or ratio level values), metric MDS is used, but for qualitative data (i.e., ordinal level values), nonmetric MDS is performed.

The following list presented involves the steps for calculating the NMDS. [45]:

1. Obtain the Distance Matrix (MD): First, it is needed to calculate a distance matrix from the original dataset.

2. Specify the Number of Dimensions: The number of dimensions (generally two) to represent the data in the ordination space is determined a priori. If multiple configurations with different numbers of axes are desired, they should be calculated separately.

3. Initial Configuration: An initial configuration in m dimensions is created. This configuration is usually generated randomly and is critical, so starting with multiple different configurations is recommended to improve robustness.

4. Calculate Distances in the Ordination Space: A new matrix of distances is calculated through the Euclidean distances technique. Then, in the first iteration, distances are calculated from the arbitrary configuration.

5. Shepard's Diagram: A Shepard's diagram is plotted, showing observed distances versus distances in the ordination space. This plot is used to verify the relationship between observed distances and ordination distances through a non-parametric regression.

6. Measure Stress: Stress is calculated, which indicates how well the distances in the ordination space reflect the original distances. Lower values indicate better representation.

7. Optimize the Configuration: Steepest descent is a numerical configuration method used to minimize the stress.

8. Iterate the Process: Calculations and optimization are repeated until stress no longer decreases, indicating convergence of the process.

9. Rotate for Interpretation: Most software rotates the final solution using PCA to facilitate the interpretation of the results.

2.10 Medical Equipment Management: Related Works

The table compiles a selection of papers whose methodology and/or results are comparable to those of the present research on medical equipment obsolescence. These papers also highlight the importance of good technological management, including maintenance and replacement plans. Iadanza et al., Alvarado & Rocha, and Saleh, show a methodology and way of analyzing the factors that affect obsolescence and the management of medical equipment similar to our research.

Table 2.2: Related Works Table

Authors	Inputs	Methodology	Outputs
Giovanni Mummolo et al. [46]	Maintenance ratio, M. Downtime ratio, Age ratio, Usage ratio, Redundancy ratio, Life support and Technological obsolescence	Fuzzy inference system	Priority replacement index
Vahid Khodadadi et al. [47]	Manpower, physical space, equipment, management, information technology, and instructions.	Qualitative and Quantitative method. Statistic Analysis	Instruction component, management component, information technology component, equipment component, manpower component, and physical space component had the highest and lowest priority in managing medical equipment in critical situations, respectively.
Poonam & Pankaj et al. [48]	Number of days used, number of hours the equipment actually used for a working day, the number of days the medical equipment could have been available (if the equipment was put in working order) and the number of hours the medical diagnostic equipment could have been available on a working day (if the equipment was put in working order).	Exploratory and observational in nature	Utilization coefficient (UC) and factors affecting the UC
Iadanza et al. [21]	Financial Techonological Organizational	Key performance indicators	Type of failure
Kihiu et al. [21]	Technological Assessment and Selection Procurement and Logistics Installation and Commissioning Training and Skill Development Training and Skill Development Operation and Safety Maintenance and Repair Decommissioning and Disposal	Statistical analysis and data management system	Equipment identified to be repaired
Alvarado & Rocha [49]	Technical Economic Clinical aspects	The methodology is based on a system of scores, medical equipment can obtain different values depending on the parameter that is being evaluated, at the end these values that the equipment obtained will be introduced in a mathematical model.	Replacement Thresholds
Liao et al. [50]	Three factors, including the immediate cost of repair or replacement, operating revenues, and future profits, are considered to form the objective function. A dataset of 24,516 records of repair and maintenance of a medical device from 2008 to 2018 is used to show the application of the model	Discrete-time markov chain (DTMC) with an optimization framework	Optimal repair or replacement decision
Dondelinger [51]	Age factor Repair factor Repair cost factor Advancement in technology Fit into Five-Year Plan	Complex Methodology	Equipment Replacement Planning
Saleh et al. [52]	Technical Safety Financial	Integrated Quality Function Deployment (QFD) and Genetic Algorithm (GA) in one framework.	Replacement decision in medical equipment
Ouda et al. [53]	Hazards and Alerts The Useful Life ratio The Cost Vendor Support	Fault tree analysis (FTA)	Replacement of Medical Equipment

Chapter 3

Methodology

In this chapter, we will focus on the steps taken to develop this project. First, we selected the area and the health centers we wanted to work with, that is, type A medical centers from Ibarra. It was necessary to obtain permission from the Ministry of Public Health (MSP) in order to access and get information from healthcare facilities during November 2023 to January 2024. Then, we selected the equipment to be analyzed based on the "List of priority medical devices for the first level of care in the countries of the Region of the Americas" of the Pan American Health Association. Subsequently, informative data on the devices was collected, and three evaluations were carried out: clinical, technical and economic. To process the data, the "Obsolescence Validator Software" was used to obtain the obsolescence index. Then, R software was used to obtain the statistical parameters, including non-metric multidimensional scaling (NMDS). Figure 3.1 shows the process by which the project was carried out.

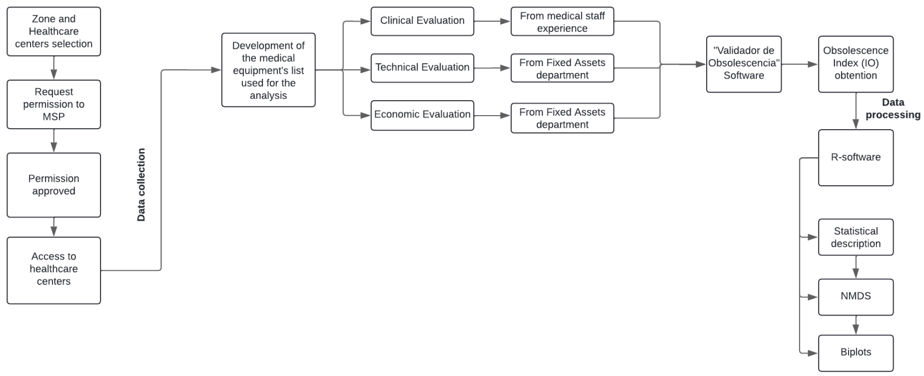

Figure 3.1: Applied methodology for the Obsolescence Index (IO) obtention and development of the statistical analysis

3.1 Type of study

This is an exploratory and observational study, designed to accomplish the specific objectives of the project.

3.2 Study area

The study was conducted in the Type A Healthcare Centers from Ibarra-Ecuador.

3.3 Sampling technique

The selection of the medical equipment was made based on the ”List of priority medical devices for the first level of care in the countries of the Region of the Americas” created by the Pan American Health Association in collaboration with the World Health Organization [54].

3.4 Period of study

The medical visits to the Healthcare centers were made during November 2023 to January 2024.

3.5 Study population

- Our investigation included various types of medical equipments of different cost categories.
- Healthcare personnel involved in the handling, monitoring, and maintenance of medical diagnostic equipment were included in the study population, which comprised of doctors or the healthcare professional in charged of the management of the medical equipment.
- Also, our study comprised data from the Fixed Assets Department of Coordinacion Zonal 1.

3.6 Data acquisition

Our process to evaluate the obsolescence index in type A health centers in the district of Ibarra began with the identification of the type A health centers that constitute the first level of care of Ibarra-Ecuador. The data was sourced from the GeoSalud web page (https://geosalud.msp.gob.ec/), an information system that spatially locates every facility in the integrated health network based on its level of care. This thorough approach led to the classification of the thirteen type A health centers in the district of Ibarra.

- Alpachaca Health Center.
- Ambuquí Health Center.
- Caranqui Health Center.

- Carpuela Health Center.
- El Tejar Health Center.
- La Carolina Health Center.
- La Esperanza Health Center.
- Lita Health Center.
- Priorato Health Center.
- Pugacho Health Center.
- Salinas Health Center.
- San Antonio Health Center.
- Zuleta (Angochahua) Health Center.

Afterward, the permits to enter the health centers were requested and authorized by the Ecuadorian Ministry of Public Health (MSP), according to Memorandum No. MSP-CZONAL1-2023-18353-M. This memorandum establishes that the period of visits will be from November 14, 2023 to January 25, 2024.

Then, it was decided to start with the collection of the informative data of the medical equipments, then the clinical evaluations due to the period of visits in which the permits from the Ministry of Health and Zonal Coordination 1 were accepted. Next, data from the technical and economic evaluations were obtained.

Informative data collection: We information documentation related to the medical equipment general information such as model, brand, serial number, service area through inventories lists.

Clinical evaluation: This is a subjective evaluation that was obtained from the personal experience of the medical staff in the health centers. So, to collect this information, we conducted a survey directed to the medical staff or the person in charge of the management of the medical equipment.

Technical evaluation: In order to obtain information about the technical evaluation, we worked with the Fixed Assets Department from the Coordinacion Zonal 1 in order to have information related to the availability of consumables support, associated adverse events, useful life, age of equipment, corrective maintenance in the last year, technical support provider, availability of spare parts support.

Economic evaluation: Infromation such as costs of the medical equipment purchase, maintenance, as well as the date of acquisition was give from the Fixed Assets Department from the Coordinacion Zonal 1 located in Ibarra.

3.7 Data selection

The equipment was classified according to the List of priority medical devices for the first level of care in the countries of the Region of the Americas [54]. Out of 2600 medical devices, 145 devices were analyzed. Table 3.1 shows the essential equipment that a type A health center should have according to the PAHO list.

Table 3.1: List of priority equipment of first level health centers according to PAHO.

Category	List
Medical equipment	Ambu-type hand-held resuscitator for patients.
	Ambu-type hand-held resuscitator for pediatric patients.
	Autoclave.
	Basic vital signs monitor.
	Child and adult scale.
	Digital thermometer.
	Electrocardiograph.
	Electronic babyscale.
	Examination lamp
	Finger pulse oximeter
	Flowmeter for measurement of peak expiratory flow
	Glucometer
	Hand-held pulse oximeter
	Infrared thermometer
	Laryngoscope
	Nebulizer
	Negatoscope
	Non-invasive automatic blood pressure
	Ophthalmoscope
	Otoscope
	Oxygen concentrator
	Sphygmomanometer
	Sterilizer
	Stethoscope

3.7.1 Exclusion criteria

The exclusion criteria included equipments that were in storage, or those that were reported as stolen or lost. Additionally, equipment that was considered to have a single life, i.e., equipment that had no maintenance or consumables support, was excluded. Therefore, we analyzed seven types of medical equipments: sterilizers, autoclaves, oxygen concentrators, electronic babyscale, portable scale and scale with measuring rod.

3.8 Data processing

Obsolescense index calculations with the ”Validador de Obsolescencia” Software

To collect the obsolescence index of medical equipment, we used the ”Validador de Obsolescencia Software” provided by the Ministry of Public Health, and developed by Biomedical Engineers Mario Gualsaquí and Franklin Ponce. This software has an extensive database that classifies health centers by zone, province, city, facility, and Unicode, see Figure 3.2. The informative data is composed of the following elements:

- **Equipments name:** This section allows to enter the name of the equipment according to the technical datasheet available on the National Direction of Sanitary Equipment platform.
- **Brand and Model:** The criteria refers to the type of equipment (sterilizer, babyscale,etc) and model of the medical equipment must be fulfilled.
- **Serial number:** It refers to the medical equipment codification or number identification. It can be composed of numbers, or in combination with letters.
- **Acquisition date:** This criteria refers to the time when the medical equipment was purchase or acquired.
- **DNES code:** This codification is assigned by the National Direction of Sanitary Equipment (DNES). It was obtained on the technical datasheet provided by the DNES.
- **Service:** This parameter corresponds to the area within the healthcare center in which the medical equipment works.
- **Person responsible for the income:** This sections must be fulfilled by the person who is in charged of entering the whole information to the software.

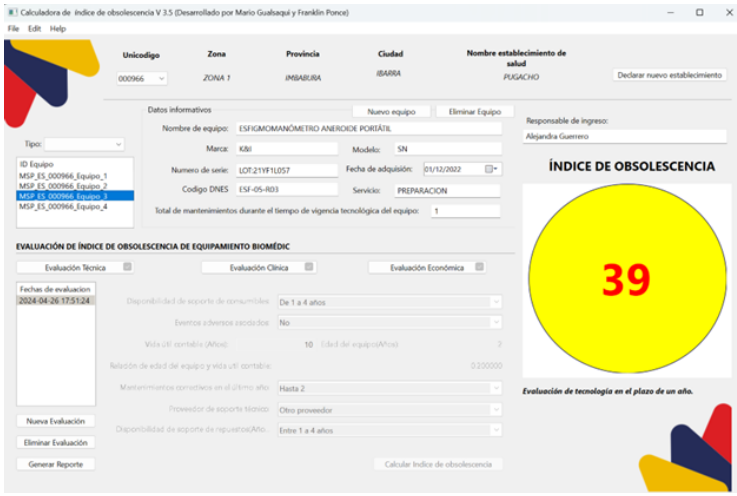

Figure 3.2: Graphical interface of the Validador de Obsolescencia software

3.8.1 R software management

We used the R software to process the data. This section is divided into two parts, the first phase includes the descriptive analysis of the data in order to have an overview of the economic situation of the medical equipments in healthcare centers type A of Ibarra through the years In the second phase, the implementation of the non-metric multidimensional scaling is carried out to find out which variables most affect the obsolescence index.

3.8.2 Descriptive Analysis

During its development, descriptive analysis elements were used, such as graphs, tables that can establish a general overview of the behavior of the data, where mean, median, mode, minimum and maximum values are presented.

3.8.2.1 Variables definition

Table 3.2: Variables used for the descriptive analysis.

Variable	Description
Obsolescence index	Cuantitative data that is obtained from the obsolesence software.
Acquisition cost	Cost of the medical equipment purchase.
Maintenance cost	Cost of the anual maintenance cost.
Equipment years	Years of functional use of the medical equipment.

Table 3.2 shows the variables chosen for the descriptive analysis. In total145 variables medical equipments were analyzed, providing a thorough assessment of their current state and relevance.

factors affecting

3.8.3 Non-metric Multidimensional Scaling

MDS is a data analysis technique used to visualize similarities or differences between several elements, some of which may show proximity between a set of elements as distances in a reduced space of dimensions. There are two types of multidimensional scaling, metric factors affecting MDS and non-metric MDS (NMDS). For our analysis we will use the non-metric multidimensional scaling due to the ordinal variables we are dealing with.

3.8.3.1 Variables definition for the NMDS

Table 3.3: Variables definition for the study

Variable	**Description**
Equipment	Numerical variables between 1 and 13 were assigned according to the type of equipment.
Obsolesence Index	Value obtained after being processed in the software.
Zone	Binary values were assigned, 0 corresponds to the rural zone and 1 to the urban zone.
Use_frequency	How often the medical equipment is used. Numerical values are assigned corresponding to 3 high, 2 medium, 1 low.
Use_difficulty	Is the equipment easy to use for medical personnel. Numerical values are assigned corresponding to 3 high, 2 medium, 1 low.
Necessity	How necessary is the equipment in the area in which it is located. Numerical values are assigned corresponding to 3 high, 2 medium, 1 low.
Adaptation_capacity	Can the equipment adapt to the new demands and challenges of the clinical area. Numerical values corresponding to 3 high, 2 medium, 1 low are assigned.

Table 3.3 shows the variables used for the development and study of the NMDS. It can be seen that seven variables were selected for the second part of the study. Equipment is a variable assigned as a random number in R software. Obsolescence index is obtained from the Validador de Obsolescencia Software”. Zone is a binary variable in which 0 corresponds to the rural sector and 1 to the urban sectors. Use_frequency as well as Use_difficulty, Neccesity and Adaptation_capacity were categorical variables that were coded as ordinal variables because they have an inherent order.

Chapter 4

Results and Discussion

This section presents the results of the descriptive analysis, followed by the non-metric multidimensional scaling analysis.

4.1 Descriptive analysis

Table 4.1: Mean, median and standard deviation of the variables.

Variables	**Mean**	**Median**	**Standard deviation**
Obsolescence index	32.49	28.99	17.73
Acquisition cost	562.63	605	3.95
Maintenance cost	42.16	20	44.20
Equipment years	10.98	12	3.95

Table 4.1 shows the mean, media and mode values of the obsolescence index, the acquisition cost, maintenance cost, and the equipment years. It can be seen that the mean value for the obsolescence index is 32.49, the median value is 28.99 and the mode in 10.99. For acquisition cost the mean value is 562.63, the median value is 605 ad the mode value is 35.81. For maintenance cost, the mean value is 42.16, the median value is 20 and the mode is 20. For the equipment years variables, the mean value is 10.98, the median value is 12 and the mode is 13.

Table 4.2: Quantiles distribution

	Quantiles		
Variables	**25%**	**50%**	**75%**
Obsolescence index	15.40	28.99	47.94
Acquisition cost	72.8	605	758.9
Maintenance cost	20	20	20
Equipment years	11	12	13

Table 4.2 reflects the quantiles distribution for the Obsolescence index, Acquisition cost, Maintenance cost and Equipment years. For obsolescense index it indicates that The 25% of the medical equipments presents an obsolescence index of 15.40. The 50% represents an obsolescence index of 28.99 or more, and the 75% of the medical equipments have an Obsolescense index of 47.94%, which means that the majority of the equipments can continue on service, but it needs constant monitoring. This is a challenge for both, patients and medical staff because they have to adapt to the medical functioning rather than having the equipment adapt to them. According to Dasanayaka (2006) in his study he aimed to determine the factors that contributes to the failure of healthcare equipments in Sri Lanka's public hospitals. He establishes that poor maintenance, inadequate funding for maintenance and timely replacement of obsolete equipment, lack of financial and personnel resources are the principal factors that affects healthcare system in India [55].

The medical equipment purchase cost shows that the 25% of the equipments have a cost of 72.8 USD or less. The 50% of the equipments have a cost of 605.0 USD or less, and the remaining 50% have a cost of 605.0 USD or more. The 75% of the equipments have a cost of 758.9 USD. Even though this cost is relative low compared to more complex medical equipment such imagenology devices, it represents the basic amount for the proper functioning of the basic healthcare centers in Ibarra. For maintenance cost we can see that the value ranges 20USD. This result appears as a result of the actual maintenance cost for scales with rods, portable scales, babyscales and sphygmomanometers. It is important to note that as these are the most common types of medical equipment on our study. However, it must be highlighted that the maintenance of the medical equipment is given once a year. Additionally, for Equipment years it shows that the 25% of the equipments are 11 years old or younger. The 50% of the equipments have an age of 12 years or less, and the remaining 50% have an age of 12 years or more. And the 75% of the equipments are 13 years old or younger. According to Eze. et al [1] developed a study in which he explored the causes of the unavailability of medical equipment in developing countries. He establishes that the cause of unappropriate distribution of financial resourses on third-world countries is the lack of efficient economic models that can be implemented from basic healthcare centers to specialized hospitals [56]. Also equipment the lack of spare parts leads to delays in diagnostics andan increase in cost of ownership of medical equipment[57]. As a result, much of the available medical equipment obsolete but ontinues to be kept in service even if it exceeded its useful life[58].

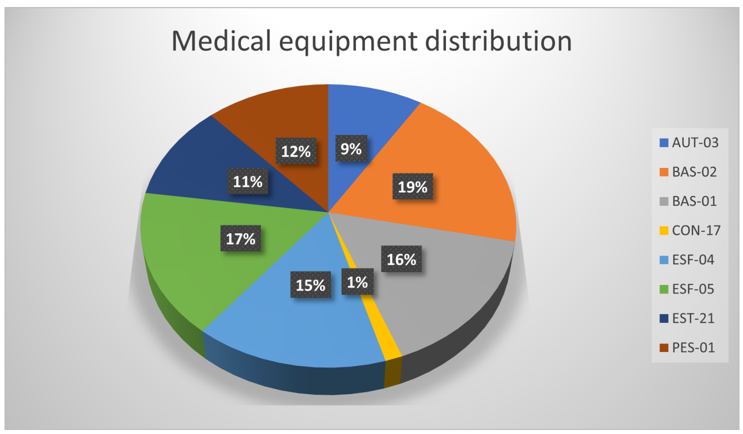

Figure 4.1: Number of medical equipments analyzed.

Figure 4.1 represents the quantity of the medical equipments analyzed for our study. It can be seen that the 19% (28) corresponds to portable scales, the 17% (24) corresponds to the aneroid sphygmomanometer, then the 16% (23) corresponds to scale with measuring rod, the 15% (22) digital sphygmomanometer. However, the 12% (17) of the medical equipment correspond to babyscales, the 11% (16) corresponds to tabletop sterilizer, the 9% (13) corresponds to autoclave, and the 1% (2) corresponds to oxygen concentrators. The amount of equipment is related to its use, i.e., scales are diagnostic equipment that receive a high frequency of use due to the demand that the health center receives. On the other hand, equipment such as the oxygen concentrator is found in only 2% of the health centers. This implies that since it is specialized equipment, its use is relatively low. In this sense, it can be said that since these are first level health centers, the equipment used is mainly basic diagnostic equipment.

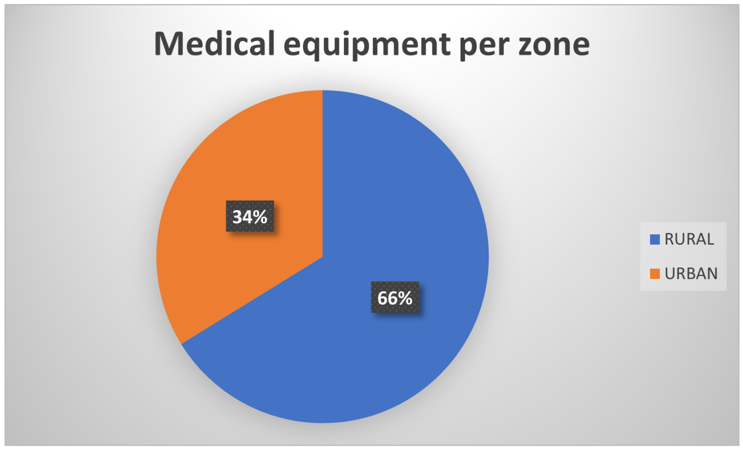

Figure 4.2: Percentage of medical equipment analyzed in the healthcare centers of rural and urban areas of Ibarra.

Figure 4.2 represents the percentage of medical equipment analyzed in both the rural and urban areas of the type A centers in the district of Ibarra. It is observed that 66% of the equipment (96 medical equipment) correspond to the rural zone while 34% (49 medical equipment) correspond to the urban zone.

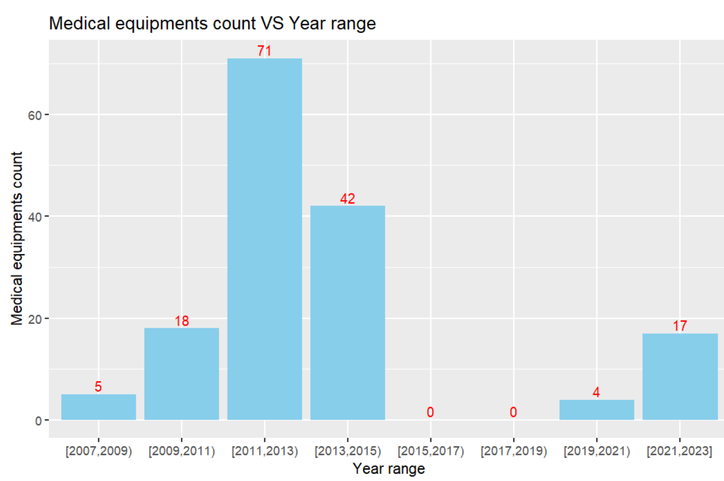

Figure 4.3: Medical equipment acquisition by year from 2007 to 2023.

Figure 4.3 shows the number of medical equipment acquired during the years from 2006 to 2024. During 2010 and 2011 the largest amount of medical equipment was acquired. During the years 2016 to 2018 there is no acquisition of medical equipment. However, from 2019 to 2023 there is evidence of medical equipment acquirement. In order to obtain information about the average quantity of medical equipment acquisition. In this regard, the economic factor is an important axis to understand this behavior. According to Carpio, et al (2021) state that during 2010 there was greater purchasing power because the Gross Domestic Product (GDP) of Ecuador had an increase of 7.9%, which explains the high level of acquisition of medical equipment for health centers. However, during 2015 and 2016 there was a decrease of -1.2% in the GDP. So because of this economic recession during these years, there is a lower amount of investment and acquisition in primary care equipment. During 2017, 2018 and 2019, Ecuador showed a minimum sign of recovery; however, the economic slowdown due to the various political problems faced by the country explains the lack of economic support for the renewal of medical equipment until 2023.

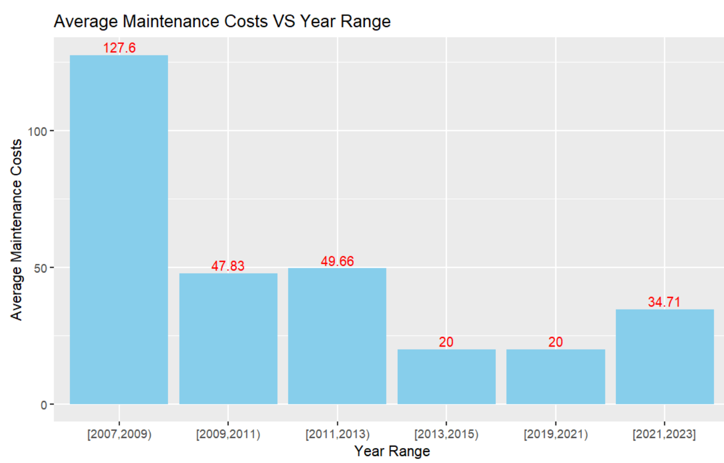

Figure 4.4: Average maintenance cost by year from 2007 to 2023.

Figure 4.4 indicates the average maintenance cost by year. It can be seen that during 2007 to 2012 the cost of corrective maintenance ranges from $127.6 to $50.00. It is important to note that the prices of maintenance obtained for this study ranges from $20.00 to $150.00 depending on the type of equipment. However, this indicates that there is a period of time where the maintenance given to the equipment in healthcare establishments have decreased notably. Authors such as Vizcaino et al (2019) establish that the main problems detected in a hospital that concern maintenance are a high unavailability of equipment and the non-execution of equipment maintenance according to the established program [59].

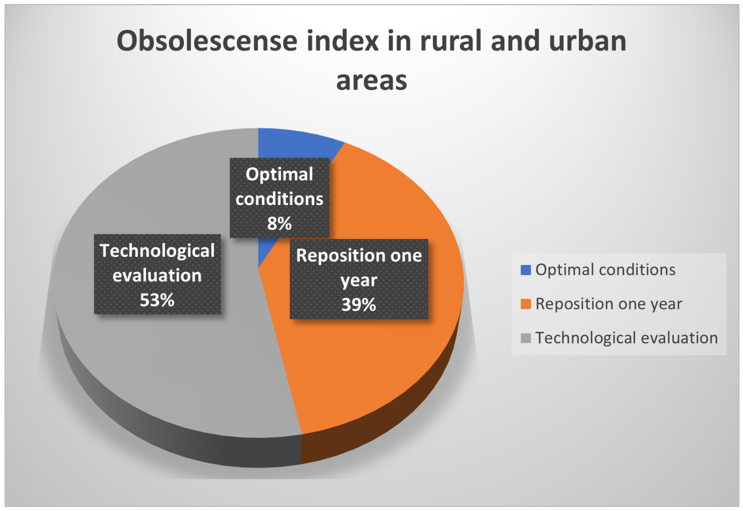

Figure 4.5: Number of medical equipment with different levels of obsolescence according to their index.

Figure 4.5 represents the percentage of obsolescence of the medical equipment analyzed. It can be seen that the 53% corresponds to technological evaluation, which means that the equipment conditions enables them to stay working but it needs constant monitoring. This indicates that 77 medical equipments analyzed fulfill their functions, however, they need to be analyzed to evaluate their replacement or upgrade, i.e. they are still working but need to be monitored for a final decision. Then, the 39% of the equipments needs to be replaced in less than 1 year. This means that 56 equipments are nearing their useful life, and should be renewed or replaced quickly. This is related to Table3.2, where we can see that the average number of years of the equipment purchased is approximately 11, and the trend shows that there are several pieces of equipment that are 13 years old in the health center and have not yet been replaced. Failure to replace equipment on time can mean, in the first instance, risk to the user, risk to the physician, in addition to mentioning economic losses. In many cases, the cost of maintenance is much higher than the cost of acquiring new equipment. Panchi et al. (2019) states that in the Health Facilities of the MSP and IESS at the moment, there are no adequate Annual Preventive Maintenance Programs, nor Annual Acquisition Plans for the replacement of consumables, accessories and spare parts, they do not have a catastre of medical technology assets that keeps a record through a unique code, so it has an impact of an inadequate budget allocation in the Budgetary Items designated for maintenance and spare parts. This makes it much more difficult to ensure that the medical equipment is in proper working condition and meets the objective of providing good patient care [60].

4.2 Non-metric Multidimensional Scaling

According to the literature, Heo et al (2020) establish the following table for the stress[61].

Table 4.3: Stress values and Goodness of fit

Stress	**Goodness of fit**
0.15-02	Poor
0.1-0.15	Acceptable
0.05-0.1	Good
0.01-0.05	Acceptable
0.00 – 0.01	Excellent

Stress is a value that indicates the disparity in the distances of the model, i.e., the higher the stress, the worse the model will be.

Table 4.4: Stress value and RSQ according to the k value

k	**Stress**	RSQ
2	0.148	0.999
3	0.099	0.999

In this case, figure 4.4 the 2-dimensional model shows S-stress value of 0.148, and in 3 dimensions the S-stress value is 0.099. It can be said that according to the literature, it is within the acceptable model values. The RSQ A value close to 1 indicates that the distances in the reduced space represents a good ans suitable model, while a low value close to 0 indicates an inadequate representation of the model.

By increasing the number of dimensions from 2 to 3, the stress decreases from 0.148 to 0.099. This indicates an improvement in model fit with increasing dimensionality, since the distances in the ordination space are better matched to the original distances. According to the literature, a stress value less than 0.05 is considered an excellent representation, between 0.05 and 0.10 is very good, and between 0.10 and 0.20 is good. In this case our S-stress value corresponds to an acceptable model.

- With k=2, the stress value (0.148) is in the range of good representation.
- With k=3 the stress value (0.099) falls in the range of very good representation.

It is important to know that even if the 2 dimensions of the model provides a good fit, it is necessary to get a more accurate model [62]. In this study, three dimensions were chosen as they allow a clearer and more manageable visualization of the data, facilitating a more obvious grouping of the data.

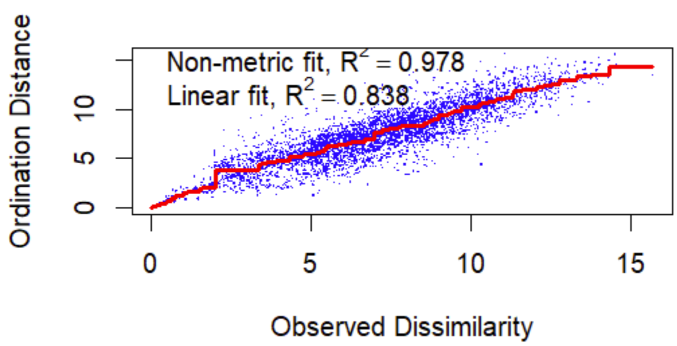

Figure 4.6: Shepard analysis

The Shepard plot shows the relationship between the proximities and distances between the points of the the smaller the dispersion the better the fit. The ideal location of the points on this diagram is a monotonically increasing line that describes the disparities in the Shepard plot shows the relationship between the proximities and distances between the points of the configuration, the smaller the dispersion the better the fit; in non-metric DSM the ideal location of the points in this plot is a monotonically increasing line describing the disparities [63].

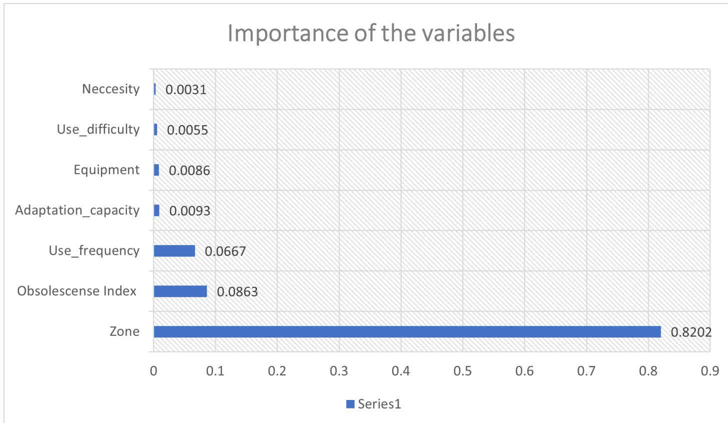

Figure 4.7: Variables importance in 3 dimensions

According to Figure 4.7 , it can be observed that Zone, Obsolescense Index, and Use_frequency are the variables that indicates the greatest weight in the calculation of the obsolescence of medical equipment. In the study realized by [48], the principal factors affecting the utilization of medical equipment are obsolescence, maintenance delays and limited availability.

4.2.1 Biplot analysis

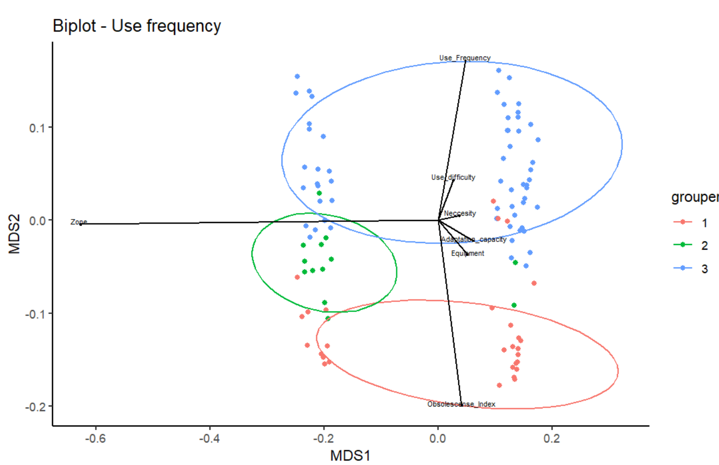

Figure 4.8: NMDS use frequency biplot

The non-metric multidimensional analysis shows the different groupings of variables [62] . Figure 4.8 shows the distribution of three groups. In addition, the influence of the variables Zone, Frequency of use and Obsolescence index is observed. Some related studies have shown that variable such as usage rate and patient safety are relevant for replacement decisions [64]. The obsolescence index has a negative correlation with frequency of use, which means that as equipment is used more frequently, it is subject to upgrades, maintenance, cleaning or availability of reports and spare parts, which slows down technological obsolescence . In a hospital environment, understanding this correlation can help make decisions about when medical equipment needs to be upgraded or replaced. Frequently used equipment may need less replacement if properly maintained. With age, both the failure rate and the corresponding maintenance cost increase considerably as deterioration due to wear and ageing of components [65]. However, equipment that is used frequently may receive more attention and maintenance, which helps to extend its useful life and reduce the need for premature replacements. An effective maintenance management can result in a significant reduction of operational costs. However, medical devices are often not properly managed and this leads to their rapid obsolescence [64]. When purchasing new medical equipment, a hospital could consider not only technology and cost, but also how frequency of use will influence its obsolescence, thus optimizing long-term investments. Also, we can note that a correlation close to zero is presented between the obsolescence index and the area. This indicates that the area in which the medical equipment is located does not affect the obsolescence rate. This suggest that other factors such as maintenance frequency or upgrades are more important determinants of obsolescence. It also indicates that in both urban and rural areas, medical equipment follows similar patterns of use. It also indicates that factors such as equipment procurement policy and maintenance practices have a greater impact on obsolescence than location.

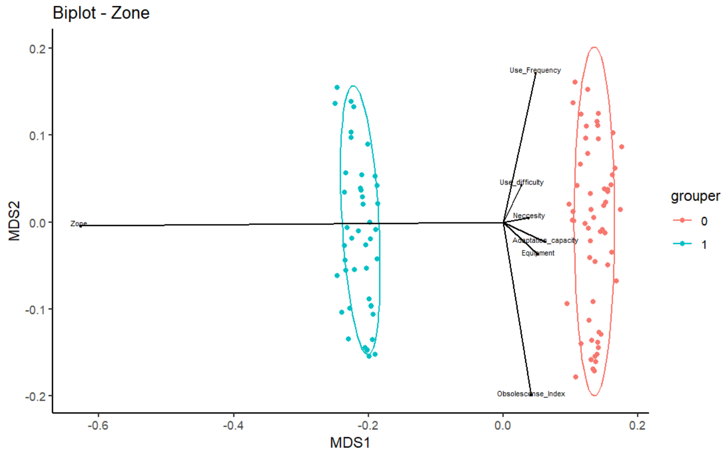

Figure 4.9: NMDS Zone biplot

Likewise, Figure 4.9 shows two well distributed groups, urban (1) and rural (0). Because of the size of our study in rural areas it is logical to see more density on that area rather than in the urban zone. Even if the zone did not show a clear influence on the obsolescence index, more specific variables about the zone could be analyzed: such as climate, level of oxidation of the equipment, oxidation, evaporation, among other characteristics [32]. Additionally, it is observed that the variables have a more pronounced impact on the rural area, as reflected by their greater concentration on the right side of the graph. Specifically, the vectors are clustered in the orange-colored region (0), indicating a strong correlation with the rural area. Among these vectors, those with the greatest length are the frequency of use and the obsolescence index, suggesting that these factors have the most significant impact on the rural area compared to the rest of the group.

4.3 Repositories Results

In this section, we performed a critical review between our investigation and and other author's research. This will allow us to make a comparative analysis of the main factors that contribute to the obsolescence of medical equipment in healthcare centers. As shown in 4.5 Authors like Poonam and Pankaj performed their analysis by using the utilization coefficient (UC) and they found that the factors that contribute to the unavailability of

Table 4.5: Comparative Analysis Table

Authors	Year of publication	Methodology	Results
Poonam Chaudhary & Pankaj Kaul [48]	2015	Utilization coefficients (UCs)	Factors that contributed to the lack of usage of medical equipments are obsolescence, nonavailability of spares, and maintenance delays.
Ernesto Iadanza et al. [21]	2019	Corrective Maintenance (CM), Schedule Maintenance (SV)	They found out that the age of the equipment does not correlate with the obsolescence. They suggest that failures of the equipments are consequences of the incorrect operation from the personnel.
Prashant J Patil et al.[66]	2015	Observational study	The authors found an inadequate maintenance register, thus making it difficult for hospitals to know the real status of medical equipments. As well as, they found the maintenance to be done by non-expert technicians. The inadequate manipulation of the medical devices leads to its log-term obsolescence being a risk factor not only for the hospital but for the patients.
W. Altalabi et al. [70]	2020	Deterministic dynamic programming approach and Stochastic dynamic programming approach	The investigation suggests that having a proper replacement guide leads to effective budget management before it reaches its lifespan, preventing the medical technology obsolescence.
Guyow Hassan Aliow [67]	2021	Descriptive survey design	The study showed that the personnel handling the medical equipment are not adequately trained. As a consequence, medical equipment may not be used to its maximum capacity resulting in obsolescence due to lack of use.
Reyes Santias et al. [71]	2012	Main components analysis	Factors such as aging or technological obsolescence affect the decision to upgrade or replace technologies.
Christopher O. Anyaeche & Peter O. Omagu [72]	2018	Replacement index calculation	The results revealed that 40% of departments replace equipment based on obsolescence. Evaluating the relationship between maintenance cost and initial cost, as well as useful life, could optimize decision making, ensuring greater efficiency and prolonging the usefulness of equipment.
Giovanni Mummolo et al. [46]	2018	Fuzzy model implementation	This model offers a more comprehensive and accurate method for assessing when to replace a medical device. Rather than relying solely on chronological obsolescence (i.e., equipment age), this model considers additional factors such as usage rate and patient safety, which may be indicative of functional or technological obsolescence.
Ciklacandir et al. [68]	2023	Analysis of variance (ANOVA) test	This study developed a decision support system based on fuzzy logic to prioritize the renewal of medical devices, considering technical service, financial, hospital and device characteristics. This approach allows evaluating functional and contextual obsolescence beyond the age of the equipment.
Dominguez Sergio et al. [69]	2020	Fuzzy Multi-Criteria Model	The multi-criteria model allows for a periodic and detailed evaluation of medical devices to identify which require renewal. By establishing an annual or biennial re-evaluation horizon, the system helps to detect both functional obsolescence (decrease in performance or efficiency) and technological obsolescence (advances in medical technology that make certain equipment less competitive).

medical devices in Chandigarh are maintenance delays, the lack of spare parts, and the medical equipment aging [48]. However, Ernesto Iadanza et al., establish that the age of the equipment does not directly relates to its obsolescence. They affirm that the incorrect manipulation of the medical devices produces operational failures [21]. Parshant et al. ad Guyow performed a similar study by implementing observational strategies and descriptive survey designs and concluded that the inadequate maintenance and manipulation leads to its malfunctioning and obsolescence [66][67]. Therefore, authors like Mummolo, Cinklacandir and Dominguez, presented different models to predict and assess the replacement of the medical equipents. These aprroaches allows to evaluate the obsolescence behind each medcal device [46][68][69].

4.4 Limitations

One of the main challenges encountered during data collection was the lack of unification in the nomenclature of medical equipment, as each health center used different criteria to catalog them. This variability complicated the process of standardizing the information. In addition, significant deficiencies were identified in the public procurement system (SERCOP), which did not provide detailed or consistent information on the equipment purchased. On the other hand, data related to the acquisition and maintenance costs of medical equipment were under the exclusive custody of the personnel in charge of fixed assets in each institution. This implied the need to adapt to the schedules and availability of such personnel in order to access the required information.

Chapter 5

Conclusions & Recommendations

- After calculating the obsolescence index of the medical equipment of the Healthcare Center from Ibarra-Ecuador, it is concluded that only the 8% of the medical equipment analyzed are in optimal working conditions. While the 39% needs to be replaced immediately. The proper functioning and conditions is essential to ensure operational efficiency, safety and quality in the performance of its functions. Maintaining equipment in this condition is crucial to minimize the risk of failure, guarantee equipment longevity and ensure that the results obtained are reliable and of high quality.
- Descriptive analysis showed that from 2012 to 2015 health centers received more economic support for the acquisition and maintenance of medical equipment. However, as of 2016 the economic recession has decreased significantly, which negatively impacts the health service. It is important to note that the lack of maintenance can affect not only to the equipment working but it is a risk for the patients.
- After analyzing the correlation of the variables: necessity, complexity, adaptability, frequency of use, zone and obsolescence index, it is concluded that the frequency of use has a negative correlation with the obsolescence index. The variables necessity, use_difficulty, adaptation_capacity have a close correlation between them, indicating that they behave similarly. Since there is a negative correlation between area and frequency of use, it can be concluded that in rural sectors the frequency of use is

much higher than in urban sectors.

- It is recommended that a more rigorous preventive and corrective maintenance program be implemented, ensuring that all equipment is regularly evaluated and that the necessary resources are allocated for its maintenance. In addition, training personnel on the correct use and care of medical equipment could increase its useful life and efficiency. It would also be beneficial to establish an inventory management system that prioritizes the acquisition of equipment based on its need and frequency of use, especially in rural areas, where access to adequate technology is limited.

Chapter 6

Future Works

It is proposed to extend the analysis to a national level, covering various geographical areas that include the three regions of the country: Coast, Highlands, and Amazon. This approach will provide a representative view of the obsolescence of medical equipment across the country. Additionally, the geographic factor could be considered for future studies. It is important to make further comparisons between the obsolescence between regions to determine the impact of humidity and temperature on medical equipment deterioration. Although this project has focused on certain variables to determine the obsolescence rate of the medical equipments, there are other type of variables that could be considered such as the frequency of maintenance, the training of the medical staff that operates the medical equipments, the temperature and corrosion levels that can affect the durability and performance of the devices. In this way, we will be able to know in depth the obsolescence of medical equipment in different areas. It would be innovative to develop a predictive model that can prevent the obsolescence of medical equipment by implementing different machine learning models. These new tools could be of great help to the administrative staff because with a more specific maintenance plan, high costs for the acquisition of new equipment could be reduced, equipment downtime could be prevented, and a better allocation of resources could be achieved. Finally, it is proposed to investigate and develop preventive and corrective maintenance strategies that can reduce the obsolescence of medical equipment.

This perspective involves the evaluation and monitoring of different maintenance programs that fucuses on identifying the most adequate methods to promote a long-term life of the equipment. Moreover, the application of real-time monitoring systems could early warn technicians about the possible errors. Therefore, the implementation of these strategies will contribute to the improvement of the healthcare system.

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Appendices

Annex 1. Healthcare Visits Schedule

Healthcare Visits Schedule

Urcuqui, 17 de noviembre del 2023

Por medio de la presente me permito remitir el cronograma actualizado destinado a la planificación de las visitas a los centros de salud de tipo A en la ciudad de Ibarra.

Cronograma Visitas Centros de Salud Tipo A

Mes: Noviembre		
Fecha	**Horario**	**Lugar**
21 – 11 - 2023	08H00 – 12H00	Centro de salud de Alpachaca
22 – 11 - 2023	08H00 – 12H00 13H00 – 16H00	Centro de salud de Alpachaca
24 – 11 - 2023	08H00 – 12H00	Centro de salud de Caranqui
28 – 11 - 2023	08H00 – 12H00	Centro de salud de Caranqui
29 – 11 - 2023	08H00 – 12H00 13H00 – 16H00	Centro de salud de El Tejar
Mes: Diciembre		
Fecha	**Horario**	**Lugar**
01 – 12 - 2023	08H00 – 12H00	Centro de salud de El Tejar
18 – 12 - 2023	08H00 – 12H00 13H00 – 16H00	Centro de salud de La esperanza
19 – 12 - 2023	08H00 – 12H00 13H00 – 16H00	Centro de salud de La esperanza
20 – 12 - 2023	08H00 – 12H00 13H00 – 16H00	Centro de salud de Priorato
21 – 20 - 2023	08H00 – 12H00 13H00 – 16H00	Centro de salud de Priorato
Mes: Enero		
Fecha	**Horario**	**Lugar**
08 – 01 - 2024	08H00 – 12H00 13H00 – 16H00	Centro de salud de Pugacho
09 – 01 - 2024	08H00 – 12H00 13H00 – 16H00	Centro de salud de Zuleta (Angochahua)
10 – 01 - 2024	08H00 – 12H00 13H00 – 16H00	Centro de salud de Zuleta (Angochahua)
11 – 01 - 2024	08H00 – 12H00 13H00 – 16H00	Centro de salud de Ambuquí
12 – 01 - 2024	08H00 – 12H00 13H00 – 16H00	Centro de salud de Ambuquí
15 – 01 - 2024	08H00 – 12H00 13H00 – 16H00	Centro de salud de Carpuela
16 – 01 - 2024	08H00 – 12H00 13H00 – 16H00	Centro de salud de Carpuela
17 – 01 - 2024	08H00 – 12H00	Centro de salud de La Carolina

10 – 01 - 2024	08H00 – 12H00 13H00 – 16H00	Centro de salud de Zuleta (Angochahua)
11 – 01 - 2024	08H00 – 12H00 13H00 – 16H00	Centro de salud de Ambuquí
12 – 01 - 2024	08H00 – 12H00 13H00 – 16H00	Centro de salud de Ambuquí
15 – 01 - 2024	08H00 – 12H00 13H00 – 16H00	Centro de salud de Carpuela
16 – 01 - 2024	08H00 – 12H00 13H00 – 16H00	Centro de salud de Carpuela
17 – 01 - 2024	08H00 – 12H00 13H00 – 16H00	Centro de salud de La Carolina
18 – 01 - 2024	08H00 – 12H00 13H00 – 16H00	Centro de salud de La Carolina
19 – 01 - 2024	08H00 – 12H00 13H00 – 16H00	Centro de salud de Lita
22 – 01 - 2024	08H00 – 12H00 13H00 – 16H00	Centro de salud de Lita
23 – 01 - 2024	08H00 – 12H00 13H00 – 16H00	Centro de salud de Salinas
24 – 01 - 2024	08H00 – 12H00 13H00 – 16H00	Centro de salud de Salinas
25 – 01 - 2024	08H00 – 12H00 13H00 – 16H00	Centro de salud de San Antonio
26 – 01 - 2024	08H00 – 12H00 13H00 – 16H00	Centro de salud de San Antonio

Annex 2.Complete dataset of 145 samples for the descriptive analysis

Equipment	Purchase date	Maintenance cost	IO	Zone	Purchase cost
EQUIPOS MEDICO QUIRURGICOS/ESTERILIZADOR	2007	$ 130.00	38.1	1	$ 605.00
BIENES SUJETOS A CONTROL/ESTERILIZADOR	2007	$ 130.00	47.94	1	$ 605.00
BIENES SUJETOS A CONTROL/ESTERILIZADOR	2007	$ 130.00	47.85	1	$ 605.00
BIENES SUJETOS A CONTROL/ESTERILIZADOR	2007	$ 130.00	40.6	0	$ 700.00
EQUIPOS MEDICO QUIRURGICOS/AUTOCLAVE	2008	$ 118.00	40.69	1	$ 200.00
PESABEBES ELECTRONICO	2009	$ 15.00	10.99	1	$ 1,659.00
AUTOCLAVE	2009	$ 118.00	40.69	1	$ 1,659.00
PESABEBE ELECTRONICO	2009	$ 15.00	15.4	1	$ 98.40
BALANZA DE PIE DIGITAL	2009	$ 20.00	40.69	1	$ 40.40
BALANCA DE PIE DIGITAL	2009	$ 20.00	15.4	1	$ 72.80
EQUIPOS MEDICO QUIRURGICOS/ESTERILIZADOR	2010	$ 130.00	25.6	1	$ 72.80
EQUIPOS MEDICO QUIRURGICOS/ESTERILIZADOR	2010	$ 130.00	32.85	0	$ 535.00
BIENES SUJETOS A CONTROL/BALANZA	2011	$ 20.00	25.69	1	$ 680.00
BIENES SUJETOS A CONTROL/BALANZA	2011	$ 20.00	25.69	1	$ 1,002.34
BIENES SUJETOS A CONTROL/BALANZA	2011	$ 20.00	25.69	1	$ 35.81
BIENES SUJETOS A CONTROL/BALANZA	2011	$ 20.00	25.60	1	$ 35.81
BIENES SUJETOS A CONTROL/PESABEBES	2011	$ 15.00	10.99	1	$ 35.81
EQUIPOS MEDICO QUIRURGICOS/BALANZA CON TALLIMETRO	2011	$ 20.00	25.69	1	$ 35.81
EQUIPOS DE LABORATORIO; CIENCIA; OBSERVACION Y COMPROBACION/BALANZA/DIGITAL	2011	$ 20.00	20.545	1	$ 35.81
EQUIPOS MEDICO QUIRURGICOS/BALANZA CON TALLIMETRO	2011	$ 20.00	30.94	1	$ 72.80
EQUIPOS MEDICO QUIRURGICOS/PESABEBES	2011	$ 15.00	34.2475	1	$ 658.34
EQUIPOS DE LABORATORIO;CIENCIA; OBSERVACIÓN Y COMPROBACION/BALANZA/DIGITAL	2011	$ 20.00	30.295	1	$ 535.00

EQUIPOS MEDICO QUIRURGICOS/BALANZA CON TALLIMETRO	2011	$ 20.00	30.19	1	$ 3,304.00
EQUIPOS MEDICO QUIRURGICOS/PESABEBES	2011	$ 15.00	25.69	1	$ 758.90
BIENES SUJETOS A CONTROL/BALANZA	2011	$ 20.00	20.045	1	$ 200.00
BIENES SUJETOS A CONTROL/BALANZA	2011	$ 20.00	20.545	1	$ 72.80
EQUIPOS MEDICO QUIRURGICOS/BALANZA CON TALLIMETRO	2011	$ 20.00	25.69	1	$ 30.00
BIENES SUJETOS A CONTROL/BALANZA	2011	$ 20.00	30.94	1	$ 1,002.34
BIENES SUJETOS A CONTROL/BALANZA DIGITAL	2011	$ 20.00	20.545	1	$ 658.34
BIENES SUJETOS A CONTROL/PESABEBES	2011	$ 15.00	40.69	1	$ 680.00
EQUIPOS MEDICO QUIRURGICOS/BÁSCULA CON TALLÍMETRO	2011	$ 20.00	25.69	1	$ 200.00
EQUIPOS MEDICO QUIRURGICOS/BÁSCULA SIN TALLÍMETRO PORTÁTIL	2011	$ 20.00	25.69	1	$ 1,259.48
EQUIPOS MEDICO QUIRURGICOS/BÁSCULA SIN TALLÍMETRO PORTÁTIL	2011	$ 20.00	28.9975	1	$ 929.00
EQUIPOS MEDICO QUIRURGICOS/PESABEBES	2011	$ 15.00	25.69	1	$ 700.00
EQUIPOS DE LABORATORIO; CIENCIA; OBSERVACION Y COMPROBACION/BALANZA/DIGITAL	2011	$ 20.00	25.69	0	$ 700.00
BIENES SUJETOS A CONTROL/BALANZA	2011	$ 20.00	20.545	0	$ 1,259.48
BIENES SUJETOS A CONTROL/BALANZA	2011	$ 20.00	20.545	0	$ 1,259.48
BIENES SUJETOS A CONTROL/BALANZA	2011	$ 20.00	25.69	0	$ 40.40
BIENES SUJETOS A CONTROL/BALANZA	2011	$ 20.00	24.955	0	$ 200.00
BIENES SUJETOS A CONTROL/BALANZA	2011	$ 20.00	40.69	0	$ 1,002.34
BIENES SUJETOS A CONTROL/BALANZA	2011	$ 20.00	16.135	0	$ 700.00
EQUIPOS MEDICO QUIRURGICOS/BASCULA CON TALLIMETRO	2011	$ 20.00	17.2375	0	$ 605.00

BÁSCULA SIN TALLÍMETRO PORTÁTIL	2011	$ 20.00	10.99	1	$ 200.00
PESABEBES ELECTRONICO	2011	$ 15.00	10.99	1	$ 35.81
BALANZA CON TALLIMETRO	2011	$ 20.00	15.4	1	$ 35.81
BIENES SUJETOS A CONTROL/ESTERILIZADOR	2012	$ 130.00	20.455	1	$ 35.81
BIENES SUJETOS A CONTROL/ESTERILIZADOR	2012	$ 130.00	20.455	1	$ 35.81
EQUIPOS Y SUMINISTROS ODONTOLOGICOS/ AUTOCLAVE	2012	$ 118.00	47.94	1	$ 35.81
EQUIPOS DE LABORATORIO; CIENCIA; OBSERVACION Y COMPROBACION/AUTOCLAVE	2012	$ 118.00	40.69	1	$ 35.81
EQUIPOS Y SUMINISTROS ODONTOLOGICOS/ AUTOCLAVE	2012	$ 118.00	47.94	1	$ 35.81
BIENES SUJETOS A CONTROL/TENSIOMETRO	2013	$ 20.00	65.35	0	$ 35.81
BIENES SUJETOS A CONTROL/TENSIOMETRO	2013	$ 20.00	50.35	0	$ 35.81
BIENES SUJETOS A CONTROL/TENSIOMETRO	2013	$ 20.00	65.35	0	$ 35.81
BIENES SUJETOS A CONTROL/TENSIOMETRO	2019	$ 20.00	44.3	0	$ 98.40
EQUIPO MEDICO /ESTERILIZADOR	2012	$ 130.00	25.6	0	$ 1,659.00
EQUIPOS MEDICO QUIRURGICOS/BALANZA CON TALLIMETRO	2011	$ 20.00	23.8525	0	$ 680.00
EQUIPOS MEDICO QUIRURGICOS/BALANZA CON TALLIMETRO	2011	$ 20.00	25.6	0	$ 605.00
EQUIPOS MEDICO QUIRURGICOS/PESABEBES	2011	$ 15.00	40.69	0	$ 200.00
EQUIPOS MEDICO QUIRURGICOS/ESTERILIZADOR	2012	$ 130.00	32.85	0	$ 758.90
EQUIPOS Y SUMINISTROS ODONTOLOGICOS/AUTOCLAVE	2012	$ 118.00	27.795	0	$ 658.34
EQUIPOS Y SUMINISTROS ODONTOLOGICOS/ AUTOCLAVE	2012	$ 118.00	47.94	0	$ 658.34
AUTOCLAVE	2012	$ 118.00	22.65	1	$ 732.46
BIENES SUJETOS A CONTROL/TENSIOMETRO	2013	$ 20.00	50.35	1	$ 72.80
BIENES SUJETOS A CONTROL/TENSIOMETRO	2013	$ 20.00	65.35	1	$ 35.81
BIENES SUJETOS A CONTROL/TENSIOMETRO	2013	$ 20.00	54.85	1	$ 40.00
BIENES SUJETOS A CONTROL/TENSIOMETRO	2013	$ 20.00	60.1	1	$ 30.00

BIENES SUJETOS A CONTROL/TENSIOMETRO	2013	$ 20.00	60.19	1	$ 605.00
BIENES SUJETOS A CONTROL/TENSIOMETRO	2013	$ 20.00	65.35	1	$ 1,259.48
BIENES SUJETOS A CONTROL/TENSIOMETRO	2013	$ 20.00	65.35	1	$ 929.00
BIENES SUJETOS A CONTROL/TENSIOMETRO	2013	$ 20.00	65.35	1	$ 1,002.34
BIENES SUJETOS A CONTROL/TENSIOMETRO	2013	$ 20.00	50.35	1	$ 732.46
BIENES SUJETOS A CONTROL/TENSIOMETRO	2013	$ 20.00	65.35	1	$ 605.00
BIENES SUJETOS A CONTROL/TENSIOMETRO	2013	$ 20.00	54.85	1	$ 605.00
BIENES SUJETOS A CONTROL/TENSIOMETRO	2013	$ 20.00	65.35	1	$ 605.00
BIENES SUJETOS A CONTROL/TENSIOMETRO	2013	$ 20.00	60.1	1	$ 605.00
BIENES SUJETOS A CONTROL/TENSIOMETRO	2013	$ 20.00	65.35	1	$ 605.00
BIENES SUJETOS A CONTROL/TENSIOMETRO	2013	$ 20.00	65.35	1	$ 1,259.48
BIENES SUJETOS A CONTROL/TENSIOMETRO	2013	$ 20.00	27.705	0	$ 115.26
TENSIOMETRO ANAEROIDE	2013	$ 20.00	40.88	1	$ 97.40
BIENES SUJETOS A CONTROL/TENSIOMETRO	2014	$ 20.00	41.69	1	$ 72.80
BIENES SUJETOS A CONTROL/TENSIOMETRO	2014	$ 20.00	41.69	1	$ 72.80
BIENES SUJETOS A CONTROL/TENSIOMETRO	2014	$ 20.00	59.9975	1	$ 758.90
BIENES SUJETOS A CONTROL/TENSIOMETRO	2014	$ 20.00	56.69	1	$ 995.00
EQUIPOS MEDICO QUIRURGICOS/TENSIOMETRO	2014	$ 20.00	56.69	1	$ 758.90
BIENES SUJETOS A CONTROL/TENSIOMETRO	2014	$ 20.00	54.955	1	$ 758.90
BIENES SUJETOS A CONTROL/TENSIOMETRO	2014	$ 20.00	51.44	0	$ 758.90
BIENES SUJETOS A CONTROL/TENSIOMETRO	2014	$ 20.00	56.69	0	$ 225.00
TENSIOMETRO ANAEROIDE	2014	$ 20.00	35.74	1	$ 225.00
TENSIOMETRODIGITAL	2014	$ 20.00	32.13	1	$ 680.00
BIENES SUJETOS A CONTROL/TENSIOMETRO	2019	$ 20.00	56.69	1	$ 732.46
BIENES SUJETOS A CONTROL/TENSIOMETRO	2019	$ 20.00	36.545	0	$ 590.00

EQUIPOS DE REHABILITACION Y TERAPIA FISICA/ CONCENTRADOR DE OXIGENO	2022	$ 150.00	38.345	1	$ 40.00
EQUIPOS DE REHABILITACION Y TERAPIA FISICA/CONCENTRADOR DE OXIGENO	2022	$ 150.00	17.0	1	$ 40.40
BIENES SUJETOS A CONTROL/TENSIOMETRO	2022	$ 20.00	45.205	1	$ 72.80
BIENES SUJETOS A CONTROL/TENSIOMETRO	2022	$ 20.00	35.65	0	$ 1,500.00
BÁSCULA CON TALLÍMETRO	2023	$ 20.00	1	0	$ 1,002.34
BÁSCULA CON TALLÍMETRO	2023	$ 20.00	1	0	$ 1,659.00
BÁSCULA CON TALLÍMETRO	2023	$ 20.00	1	0	$ 1,659.00
BÁSCULA SIN TALLÍMETRO PORTÁTIL	2023	$ 20.00	1	0	$ 225.00
BÁSCULA SIN TALLÍMETRO PORTÁTIL	2023	$ 20.00	1	0	$ 658.34
BÁSCULA SIN TALLÍMETRO PORTÁTIL	2011	$ 20.00	10.99	1	$ 658.34
PESABEBES ELECTRONICO	2011	$ 15.00	10.99	1	$ 758.90
PESABEBES ELECTRONICO	2009	$ 15.00	10.99	1	$ 732.46
TENSIOMETRO ANAEROIDE	2014	$ 20.00	35.74	1	$ 45.00
TENSIOMETRO ANAEROIDE	2013	$ 20.00	40.88	1	$ 72.80
TENSIOMETRODIGITAL	2014	$ 20.00	32.13	1	$ 35.81
AUTOCLAVE	2009	$ 118.00	40.69	1	$ 1,659.00
AUTOCLAVE	2012	$ 118.00	47.94	0	$ 732.46
ESTERILIZADOR	2012	$ 130.00	10.99	0	$ 758.90
ESTERILIZADOR	2012	$ 130.00	10.99	0	$ 72.80
BÁSCULA SIN TALLIMETRO PORTATIL	2009	$ 20.00	10.99	0	$ 98.40
BÁSCULA SIN TALLIMETRO PORTATIL	2009	$ 20.00	10.99	0	$ 1,002.34
BALANZA CON TALLIMETRO	2011	$ 20.00	10.99	0	$ 1,002.34
BALANZA CON TALLIMETRO	2011	$ 20.00	15.4	0	$ 1,659.00
PESABEBE ELECTRONICO	2011	$ 15.00	10.99	0	$ 225.00
TENSIOMETRO DIGITAL	2014	$ 20.00	46.94	0	$ 225.00
TENSIOMETRO DIGITAL	2022	$ 20.00	35.74	0	$ 758.90
TENSIOMETRO DIGITAL	2013	$ 20.00	25.32	0	$ 680.00
AUTOCLAVE	2012	$ 118.00	18.24	0	$ 732.46
ESTERILIZADOR	2012	$ 130.00	15.4	0	$ 40.00
BÁSCULA SIN TALLIMETRO PORTATIL	2009	$ 20.00	10.99	0	$ 72.80
BÁSCULA SIN TALLIMETRO PORTATIL	2023	$ 20.00	10.99	0	$ 40.40
BÁSCULA SIN TALLIMETRO PORTATIL	2023	$ 20.00	1	0	$ 1,659.00
BÁSCULA CON TALLÍMETRO	2011	$ 20.00	10.99	0	$ 1,002.34
PESABEBES ELECTRONICO	2011	$ 15.00	10.99	0	$ 590.00

TENSIOMETRO DIGITAL	2014	$	20.00	35.74	0	$	1,002.34
TENSIOMETRO DIGITAL	2014	$	20.00	56.69	0	$	225.00
TENSIOMETRO ANAEROIDE	2013	$	20.00	35.74	0	$	225.00
ESTERILIZADOR	2012	$	130.00	10.99	0	$	225.00
PESABEBES ELECTRONICA	2011	$	15.00	10.99	0	$	758.90
BALANZA CON TALLIMETRO	2011	$	20.00	10.99	0	$	758.90
TENSIOMETRO	2014	$	20.00	56.69	0	$	658.34
TENSIOMETRO	2019	$	20.00	56.69	0	$	658.34
AUTOCLAVE	2012	$	118.00	47.94	0	$	732.46
AUTOCLAVE	2012	$	118.00	47.94	0	$	732.46
ESTERILIZADOR	2010	$	130.00	20.54	0	$	225.00
BÁSCULA SIN TALLIMETRO PORTATIL	2011	$	20.00	10.99	0	$	225.00
BÁSCULA SIN TALLIMETRO PORTATIL	2009	$	20.00	15.4	0	$	680.00
BALANZA CON TALLIMETRO	2011	$	20.00	40.69	0	$	700.00
BALANZA CON TALLIMETRO	2011	$	20.00	10.99	0	$	732.46
PESABEBE ELECTRONICO	2011	$	15.00	10.99	0	$	72.80
TENSIOMETRO DIGITAL	2013	$	20.00	40.88	0	$	40.00
TENSIOMETRO DIGITAL	2014	$	20.00	56.69	0	$	115.26
TENSIOMETRO ANAEROIDE	2013	$	20.00	54.94	0	$	1,002.34
ESTERILIZADOR	2012	$	130.00	10.99	0	$	1,659.00
AUTOCLAVE	2012	$	118.00	40.69	0	$	1,002.34
PESABEBE ELECTRONICO	2009	$	15.00	40.69	0	$	590.00
AUTOCLAVE	2012	$	118.00	22.65	1	$	1,002.34
PESABEBE ELECTRONICO	2009	$	15.00	15.4	1	$	225.00
BALANZA DE PIE DIGITAL	2009	$	20.00	40.69	1	$	225.00
BALANCA DE PIE DIGITAL	2009	$	20.00	15.4	1	$	225.00
BALANZA CON TALLIMETRO	2011	$	20.00	15.4	1	$	758.90
BASCULA CON TALLIMETRO	2023	$	20.00	1	1	$	758.90
BASCULA SIN TALLIMETRO PORTATIL	2023	$	20.00	1	1	$	658.34
BASCULA SIN TALLIMETRO PORTATIL	2023	$	20.00	1	1	$	658.34
PESA BEBE	2023	$	15.00	1	1	$	732.46
PESA BEBE	2023	$	15.00	1	1	$	732.46

Annex 3.Complete dataset of 145 samples for NMDS

Equipment	Obsolescense_Index	Zone	Use_Frequency	Use_difficulty	Neccesity	Adaptation_capacity
BAS-01	25.69	1	3	3	3	1
BAS-01	25.69	1	3	3	3	1
BAS-01	25.69	1	3	3	3	1
BAS-01	25.60	1	3	3	3	1
PES-01	10.99	1	3	3	3	1
EST-21	20.455	1	3	2	3	2
EST-21	20.455	1	3	2	3	2
ESF-04	56.69	1	3	3	2	3
ESF-05	50.35	1	2	3	2	3
ESF-04	41.69	1	2	3	2	3
ESF-04	41.69	1	3	3	2	3
CON-17	38.345	1	2	2	2	2
BAS-01	25.69	1	3	3	3	1
AUT-03	47.94	1	3	2	3	2
ESF-05	65.35	1	1	1	3	3
ESF-05	54.85	1	1	1	3	3
ESF-05	60.1	1	1	1	2	3
ESF-05	60.19	1	1	1	2	3
ESF-05	65.35	1	1	1	2	3
ESF-04	59.9975	1	1	1	2	3
BAS-02	20.545	1	3	1	3	3
CON-17	17.0	1	2	2	3	2
AUT-03	40.69	1	3	1	3	2
BAS-01	30.94	1	3	1	3	1
PES-01	34.2475	1	3	1	3	1
ESF-04	56.69	0	1	1	2	3
ESF-05	45.205	0	1	1	2	3
AUT-03	40.69	0	1	2	3	2

BAS-01	30.94	1	3	1	3	1
PES-01	34.2475	1	3	1	3	1
ESF-04	56.69	0	1	1	2	3
ESF-05	45.205	0	1	1	2	3
AUT-03	40.69	0	1	2	3	2
BAS-02	30.295	0	3	1	3	3
BAS-01	30.19	0	3	1	3	1
PES-01	25.69	0	3	1	3	1
EST-21	38.1	0	3	2	2	2
EST-21	25.6	0	3	2	2	2
BAS-02	20.045	1	3	1	3	3
BAS-02	20.545	1	3	1	3	3
EST-21	47.94	1	1	2	3	2
EST-21	47.85	1	1	2	3	2
ESF-05	65.35	1	1	1	2	3
BAS-01	25.69	1	3	1	3	1
AUT-03	47.94	1	2	2	3	2
BAL-02	30.94	0	3	1	3	3
BAL-02	20.545	0	3	1	3	3
PES-01	40.69	0	3	1	3	2
ESF-05	65.35	0	1	1	2	3
ESF-05	50.35	0	1	1	2	3
ESF-05	65.35	0	1	1	2	3
ESF-05	54.85	0	1	1	2	3
ESF-05	65.35	0	1	1	2	3
ESF-05	60.1	0	1	1	2	3
ESF-05	65.35	0	1	1	2	3
ESF-05	65.35	0	1	1	2	3
ESF-05	50.35	0	1	1	2	3

EST-21	32.85	1	3	1	3	2
AUT-03	27.795	1	3	2	3	2
PES-01	20.545	0	3	1	3	2
BAS-02	20.545	0	3	1	3	3
BAS-02	25.69	0	3	1	3	3
BAS-02	24.955	0	3	1	3	3
BAS-02	40.69	0	3	1	3	3
BAS02	16.135	0	3	1	3	3
EST-21	40.6	0	3	2	3	2
ESF-05	27.705	0	3	1	2	3
ESF-04	36.545	0	3	1	2	3
ESF-04	51.44	0	1	1	2	3
ESF-04	56.69	0	1	1	2	3
BAS-01	17.2375	0	1	1	3	1
AUT-03	47.94	0	3	2	3	1
BAS-01	10.99	0	3	1	1	1
BAS-01	10.99	0	3	1	1	1
BAS-01	10.99	0	3	1	1	1
BAS-02	10.99	0	3	1	1	3
BAS-02	10.99	0	3	1	1	3
BAS-02	10.99	1	3	1	1	3
PES-01	10.99	1	3	3	3	2
PES-01	10.99	1	3	3	3	2
ESF-05	35.74	1	2	1	2	1
ESF-05	40.88	1	2	1	2	1
ESF-04	32.13	1	2	1	2	1
AUT-03	40.69	1	1	2	3	2
AUT-03	47.94	0	1	2	3	2
EST-21	10.99	0	3	2	3	2
EST-21	10.99	0	3	2	3	2

BAS-02	10.99	0	3	1	1	3
BAS-02	10.99	0	3	1	1	3
BAS-02	10.99	0	3	1	1	3
BAS-01	10.99	0	3	1	1	1
PES-01	10.99	0	3	3	3	2
ESF-04	35.74	0	3	1	2	1
ESF-04	56.69	0	3	1	1	1
ESF-05	35.74	0	3	1	2	1
EST-21	10.99	0	3	2	3	2
PES-01	10.99	0	3	3	3	2
BAS-01	10.99	0	3	1	1	1
ESF-04	56.69	0	1	1	1	1
ESF-04	56.69	0	1	1	1	1
AUT-03	47.94	0	1	2	3	2
AUT-03	47.94	0	1	2	3	2
EST-21	20.54	0	3	2	3	2
BAS-02	10.99	0	3	1	1	3
BAS-02	15.4	0	3	1	1	3
BAS-01	40.69	0	1	1	1	1
BAS-01	10.99	0	1	1	1	1
PES-01	10.99	0	1	3	3	2
ESF-04	40.88	0	2	1	1	1
ESF-04	56.69	0	1	1	1	1
ESF-05	54.94	0	2	1	2	1
EST-21	10.99	0	3	2	3	2
AUT-03	40.69	0	1	3	3	2
PES-01	40.69	0	1	3	3	1
AUT-03	22.65	0	3	2	3	2
PES-01	15.4	0	3	3	3	2
BAS-02	40.69	0	1	1	1	3

BAS-02	10.99	0	3	1	1	3
PES-01	10.99	0	3	3	3	3
PES-01	10.99	0	3	3	3	3
BAS-02	10.99	1	3	1	1	3
BAS-02	10.99	1	3	1	1	3
BAS-01	10.99	1	3	1	1	1
BAS-01	15.4	1	3	1	1	1
PES-01	10.99	1	3	3	3	2
ESF-04	46.94	1	1	1	1	1
ESF-04	35.74	1	1	1	1	1
ESF-04	25.32	1	1	1	1	1
AUT-03	18.24	1	3	2	3	1
EST-21	15.4	1	3	2	3	2

Annex 4.Access Permission for Healthcare Centers from Ibarra-Ecuador

Memorando Nro. MSP-CZONAL1-2023-18353-M

Ibarra, 17 de noviembre de 2023

PARA: Sr. Mgs. Walter Fabricio Girón
Director Nacional de Equipamiento Sanitario, Encargado

ASUNTO: RESPUESTA. SOLICITUD DE ACCESO A CENTROS MSP - TRABAJO DE TITULACIÓN

De mi consideración:

En referencia al Memorando Nro. MSP-DNES-2023-2071-M, suscrito por su Autoridad, en el cual se solicita:

"En referencia al memorando No. MSP-DNES-2023-0004-E, donde textualmente se solicita (...) " Por medio de la presente, le solicito de la manera más comedida se autorice a las señoritas ***Stephanie Alejandra Guerrero Ligña*** *con cedula de identidad* ***185009490-3****, y* ***Camila Marisol Valencia Cevallos*** *con cedula de identidad* ***100464457-9****, estudiantes de noveno semestre de la carrera de Ingeniería Biomédica de la Universidad de Investigación de Tecnología Experimental Yachay, a llevar a cabo las acciones que se detallan a continuación, con el fin de realizar oportuna y adecuadamente su trabajo de integración curricular para la obtención del título de ingeniero/a biomédico/a denominado "ANÁLISIS ESTADÍSTICO DE LA OBSOLESCENCIA DE LOS EQUIPOS MÉDICOS EN LOS CENTROS DE SALUD TIPO A DEL DISTRITO DE IBARRA – ECUADOR". Este trabajo tiene como objetivo analizar el índice de obsolescencia mediante tres evaluaciones: técnica, clínica y económica, como lo marca los lineamientos del Ministerio de Salud Pública de Ecuador. La solicitud incluye:*

- *Ingreso a los centros de salud tipo A del distrito de Ibarra:*
    - *Centro de salud de Alpachaca.*
    - *Centro de salud de Ambuquí.*
    - *Centro de salud de Caranqui.*
    - *Centro de salud de Carpuela.*
    - *Centro de salud de El Tejar.*
    - *Centro de salud de La Carolina.*
    - *Centro de salud de La esperanza.*
    - *Centro de salud de Lita.*
    - *Centro de salud de Priorato.*
    - *Centro de salud de Pugacho.*
    - *Centro de salud de Salinas.*
    - *Centro de salud de San Antonio.*
    - *Centro de salud de Zuleta (Angochahua).*

Memorando Nro. MSP-CZONAL1-2023-18353-M

Ibarra, 17 de noviembre de 2023

A continuación, se detalla el horario en el que se estima realizar las visitas a los centros de salud:

Mes: Noviembre		
Fecha	***Horario***	***Lugar***
14 – 11 - 2023	*08H00 – 12H00*	*Centro de salud de Alpachaca*
15 – 11 - 2023	*08H00 – 12H00* *13H00 – 16H00*	*Centro de salud de Alpachaca*
17 – 11 - 2023	*08H00 – 12H00*	*Centro de salud de Caranqui*
21 – 11 - 2023	*08H00 – 12H00*	*Centro de salud de Caranqui*
22 – 11 - 2023	*08H00 – 12H00* *13H00 – 16H00*	*Centro de salud de El Tejar*
24 – 11 - 2023	*08H00 – 12H00*	*Centro de salud de El Tejar*
28 – 11 - 2023	*08H00 – 12H00*	*Centro de salud de La esperanza*
29 – 11 - 2023	*08H00 – 12H00* *13H00 – 16H00*	*Centro de salud de La esperanza*
Mes: Diciembre		
Fecha	***Horario***	***Lugar***
19 – 12 - 2023	*08H00 – 12H00* *13H00 – 16H00*	*Centro de salud de Priorato*
20 – 20 - 2023	*08H00 – 12H00* *13H00 – 16H00*	*Centro de salud de Priorato*
21 – 12 - 2023	*08H00 – 12H00* *13H00 – 16H00*	*Centro de salud de Pugacho*
22 – 12 - 2023	*08H00 – 12H00* *13H00 – 16H00*	*Centro de salud de Pugacho*
Mes: Enero		
Fecha	***Horario***	***Lugar***

Memorando Nro. MSP-CZONAL1-2023-18353-M

Ibarra, 17 de noviembre de 2023

08 – 01 - 2024	*08H00 – 12H00* *13H00 – 16H00*	*Centro de salud de Zuleta (Angochahua)*
09 – 01 - 2024	*08H00 – 12H00* *13H00 – 16H00*	*Centro de salud de Zuleta (Angochahua)*
10 – 01 - 2024	*08H00 – 12H00* *13H00 – 16H00*	*Centro de salud de Ambuquí*
11 – 01 - 2024	*08H00 – 12H00* *13H00 – 16H00*	*Centro de salud de Ambuquí*
12 – 01 - 2024	*08H00 – 12H00* *13H00 – 16H00*	*Centro de salud de Carpuela*
15 – 01 - 2024	*08H00 – 12H00* *13H00 – 16H00*	*Centro de salud de Carpuela*
16 – 01 - 2024	*08H00 – 12H00* *13H00 – 16H00*	*Centro de salud de La Carolina*
17 – 01 - 2024	*08H00 – 12H00* *13H00 – 16H00*	*Centro de salud de La Carolina*
18 – 01 - 2024	*08H00 – 12H00* *13H00 – 16H00*	*Centro de salud de Lita*
19 – 01 - 2024	*08H00 – 12H00* *13H00 – 16H00*	*Centro de salud de Lita*
22 – 01 - 2024	*08H00 – 12H00* *13H00 – 16H00*	*Centro de salud de Salinas*
23 – 01 - 2024	*08H00 – 12H00* *13H00 – 16H00*	*Centro de salud de Salinas*
24 – 01 - 2024	*08H00 – 12H00* *13H00 – 16H00*	*Centro de salud de San Antonio*
25 – 01 - 2024	*08H00 – 12H00* *13H00 – 16H00*	*Centro de salud de San Antonio*

Memorando Nro. MSP-CZONAL1-2023-18353-M

Ibarra, 17 de noviembre de 2023

- *Para realizar las evaluaciones técnicas, clínica y económica se requiere la siguiente información (de estar disponible):*
    - *Evaluación técnica:*
        - *Inventario de los equipos biomédicos ya sean comprados, por donación, de apoyo o complementarios y consumibles. Donde se incluyan datos como: edad del equipo, la vida útil contable del equipo médico, el proveedor de soporte técnico y soporte de repuestos.*
        - *Información verificable que nos pueda ser otorgada por parte del departamento de "Activos Fijos" y el personal de mantenimiento. Como: disponibilidad de soporte de consumibles, reporte de eventos adversos asociados, reporte de mantenimientos en el último año.*
    - *Evaluación clínica:*
        - *Apertura para realizar una encuesta al personal que maneja y es responsable del equipo.*
    - *Evaluación económica:*
        - *Documento donde se refleje el precio de adquisición del equipo.*
        - *Documento donde se refleje el costo de mantenimiento realizado en el último año al equipo. Se incluye la parte de consumibles y repuestos relacionados con el mantenimiento.*

Cabe mencionar que el proyecto se desarrollará en dos fases. La primera fase, durante los meses de noviembre a enero, que consistirá en la creación de un catastro actualizado de los equipos biomédicos que se encuentran en funcionamiento en los centros de salud Tipo A en la ciudad de Ibarra. En la segunda fase, durante los meses de febrero del 2024 hasta junio del 2024, se analizarán los datos, tanto del catastro actualizado como de la información proporcionada por el personal encargado, para responder a las evaluaciones clínicas, técnicas y económicas, con el propósito de calcular el índice de obsolescencia de dichos equipos biomédicos para posteriormente implementar un modelo estadístico adecuado que responda a la problemática del proyecto.(...)"

Solicito su gentil atención y autorización para que las estudiantes en mención realicen el "ANÁLISIS ESTADÍSTICO DE LA OBSOLESCENCIA DE LOS EQUIPOS MÉDICOS EN LOS CENTROS DE SALUD TIPO A DEL DISTRITO DE IBARRA – ECUADOR"

La Coordinación Zonal 1 Salud, autoriza que las estudiantes Stephanie Alejandra Guerrero Ligña con cedula de identidad 185009490-3, y Camila Marisol Valencia Cevallos con cédula de identidad 100464457-9, realicen el trabajo de titulación "ANÁLISIS ESTADÍSTICO DE LA OBSOLESCENCIA DE LOS EQUIPOS MÉDICOS EN LOS CENTROS DE SALUD TIPO A DEL DISTRITO DE IBARRA –

Memorando Nro. MSP-CZONAL1-2023-18353-M

Ibarra, 17 de noviembre de 2023

ECUADOR", se les permitirá el ingreso a los respectivos Centros de Salud para que realicen el levantamiento de información. Las estudiantes deberán tomar contacto con el Ing. Marcelo Cruz 0988209734, para coordinar aspectos de las visitas.

Con sentimientos de distinguida consideración.

Atentamente,

Documento firmado electrónicamente

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