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Optimization through Inventory Models in Meficaments and Supplies in Iess Hospitals

M.Sc. Kelvin Howard Pizarro Romero[1], Dr. Luis Jhony Caucha Morales[2], M.Sc. Michael Andrés Zamora Campoverde[3]

[1]Esc. Posgrado, Universidad Nacional de Tumbes, Email: kpizarro@utmachala.edu.ec
[2]Dept. Matemática, Estadística e Informática de la Universidad Nacional de Tumbes
[3]Universidad Técnica de Machala, Email: mazamora@utmachala.edu.ec

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ABSTRACT
Inventory management and price control of medicines and medical supplies in the hospitals of the Ecuadorian Social Security Institute (IESS) faces significant challenges at the national level, which highlights the need to implement optimization software. The objective of this study was to design software that optimizes economic resources and supports the management of inventory models within hospital planning. The methodological approach was mixed, combining quantitative and qualitative techniques, which allowed iterations to be carried out in each inventory model within the software until the robust validation of the equations applied in the system was obtained.
The study was carried out in 12 IESS hospitals in Ecuador, located in cities with a high concentration of inhabitants and affiliates such as Quito, Guayaquil, Cuenca, Ambato, Santo Domingo, Manta, Machala, Portoviejo, Durán and Quevedo. The database used was obtained from the web portal of the National Public Procurement Service (SERCOP). Statistical analyses using ANOVA tests revealed significant fluctuations in drug purchases during the years 2017 to 2020, with a p-value of 0.000925, confirming substantial differences. Likewise, important variations were observed in medical supplies, with a p-value of 0.00275 when comparing the means. Significant differences were also identified between the means of the different IESS hospitals, with a p-value lower than 2e-16, evidencing the heterogeneity in the management of supplies and medicines among these hospitals.
The software developed incorporates mathematical calculations in various deterministic and probabilistic models, optimizing inventory management through reliable data to calculate the economic quantity of orders and establish reorder points, adjusting to variations in demand and delivery times. In addition, the software monitors purchase prices, ensuring that they are made at reference prices, which is crucial to strengthen strategic decision-making in IESS hospitals.

Keywords: Deterministic, Stochastic, IESS Hospitals, Inventory Models, SERCOP, Optimization Software.

1. INTRODUCTION
Statistics, a fundamental branch of mathematics, plays a crucial role in the development of intellectual abilities of human beings. No science can do without the use of mathematics and statistics; Everyone, from medicine, engineering, computer science, artificial intelligence, agronomy, psychology, economics to administration, depend on these disciplines to advance. The origin of statistics dates back to the Greek philosophers Plato and Aristotle, who laid the foundations of this science.
The concept of inventory has deep roots in history, dating back to early civilizations such as the Egyptians and other ancient cultures. These societies were already storing large amounts of food to cope with difficult times, such as drought or natural calamities. Inventory emerged as a practice inherent to private property, allowing ancient societies to store abundant food goods and other essential resources, ensuring subsistence and the development of economic and social activities.
In hospitals, medication management is a vital task to ensure an efficient healthcare system. Proper drug administration is essential to maintain and improve patient health. However, the lack and waste of essential medicines remain critical public health problems both in Ecuador and globally. The economic losses derived from expired medicines and the shortage of medical supplies in the hospitals of the Ecuadorian Institute of Social Security (IESS) in Ecuador are significant. In addition, speculation and overpricing in the acquisition of these products underscore the need for rigorous inventory control.

The problem of shortages of medicines in IESS hospitals not only affects patients, but also generates inconveniences for their families, who, on many occasions, must unexpectedly raise funds to acquire medicines that should be available in hospital inventories. This situation is aggravated when one considers the numerous cases of corruption and lack of transparency in the management of resources.
Faced with these challenges, the need arises to implement optimization software that facilitates better inventory management in IESS hospitals. This software, based on advanced mathematical models, is designed to optimize economic resources and improve efficiency in hospital management. The mathematical models used will allow simulating future scenarios and evaluating the probability of their occurrence, thus facilitating more informed and effective decision-making.

Problem situation

The World Health Organization (2016) has pointed to persistent problems in the production and supply of medicines over the past two decades, attributed to the lack of accurate and timely information from supply chains. Recent studies, such as those by Guerrero & Escobar (2020), have revealed that a large number of IESS members cannot access essential medicines due to shortages. In addition, IESS hospitals face significant economic losses due to expired medicines, with a notable financial impact of $5,574 million, according to Cárdenas (2020).
Audits carried out by the Comptroller General of the State have detected numerous irregularities in the acquisition of medicines, from overpricing to unqualified suppliers, which exacerbates the problems of shortages and waste. These failures in inventory management not only compromise the quality of the health service, but also generate a high economic and social cost.
Given this problem, the implementation of optimization software that uses mathematical models for network inventory control at the national level is presented as a viable solution to improve efficiency in resource management in IESS hospitals. This approach would mitigate shortages, control costs and prevent the expiration of medicines, thus optimizing financial resources that could be better used in other critical areas of the health system.
In conclusion, effective management of inventories of medicines and medical supplies is critical to ensuring efficient hospital management, reducing costs, and improving health outcomes for patients.

1.1 Problem statement

Will the design of optimization software for inventory models improve the price control of medicines and supplies in hospitals of the Ecuadorian Social Security Institute?

1.2 Specific Issues

a) What characteristics should be considered in the database of prices, quantity of purchases of medicines and medical supplies of the hospitals of the Ecuadorian Social Security Institute?
b) Which model will optimize the inventories of prices of medicines and supplies in hospitals of the Ecuadorian Social Security Institute?
c) What software allows the optimization for inventories and price control of medicines and supplies in hospitals of the Ecuadorian Institute of Social Security?

2. Objectives and hypotheses

2.1 Objectives

2.1.1 General objective

Design optimization software for inventory models and price control of medicines and supplies in hospitals of the Ecuadorian Institute of Social Security.

2.1.2 Specific objectives

(a) To analyse the database on the quantity of purchases of medicines and medical supplies from the hospitals of the Ecuadorian Social Security Institute;
b) To develop the optimization model to inventory and control the prices of medicines and supplies in hospitals of the Ecuadorian Social Security Institute.
c) Design and verify the optimization software for inventories and price control of medicines and supplies in hospitals of the Ecuadorian Social Security Institute.

2.2 Hypothesis

2.2.1 General hypothesis

The design of optimization software for inventory models allows the improvement of price control of medicines and supplies in hospitals of the Ecuadorian Institute of Social Security.

2.2.2 Specific hypotheses

(a) The database among hospitals allows for the control of prices and quantity of purchases of medicines and medical supplies from the hospitals of the Ecuadorian Social Security Institute.
b) Deterministic and probabilistic models make it possible to optimize the inventories of prices of medicines and supplies in hospitals of the Ecuadorian Social Security Institute.
c) The software, based on deterministic and probabilistic models, allows the optimization of inventories and price control of medicines and supplies in hospitals of the Ecuadorian Social Security Institute.

3. MATERIALS AND METHODS

3.1 Type of study and hypothesis testing design

With Hernández's (2018) theory, a non-experimental study with a casual correlational cross-sectional design will be used, this because the independent variables cannot be manipulated because they have already happened and the data are collected at a single moment and in a single time.
The hypothesis will be tested through an analysis of variance with a significance level of 5%, to establish the significant difference between the vector of means of purchases of medicines and medical supplies of the different hospitals of the IESS, using the Tukey test. After the hypothesis test, inferences can be made, depending on the directionality of the results.

3.2 Place of study

This study will be carried out in the hospitals of the IESS, a health institution that provides the service of in- and out-of-hospital medical care. This institution aims to restore the health of members and also referrals from other public hospitals in the event that they do not have availability within their portfolio of services; The member has the benefit of care for outpatient consultations from Monday to Friday, surgical operations, hospitalization and emergency always 24 hours a day.
Through the National Public Procurement Service (SERCOP), database information will be obtained on the purchases made by each IESS hospital, with the regulations of a small amount. SERCOP is an institution of the Ecuadorian State that was created on August 4, 2008, and is in charge of supervising public institutions so that they comply with the legal framework of each good or service that they wish to carry out public procurement, in the same way it controls the suppliers that participate in these processes.

3.3 Population, sample and sampling

3.3.1 Population

For the development of this research work, a population that consists of the IESS hospitals in the cities of Quito, Guayaquil, Cuenca, Santo Domingo, Ambato, Portoviejo, Machala, Duran, and Manta, which are the ones with the largest number of inhabitants in the country, is considered (INEC, 2010).

3.3.2 Sample

The sample consists of a quantitative and ratio scale database, which will be obtained through the SERCOP web portal. This data will contain information from the last 4 years (2017-2020) of purchases made under the modality of Tiny Amounts, regarding medicines and supplies for its affiliates that have been acquired by the IESS hospitals of the aforementioned cities in the population.

3.4 Data collection methods, techniques and instruments

In general, the research is focused on the search for the verification of the hypothesis that was raised, as well as the objectives indicated. The work developed is through a methodological approach of mixed quantitative-qualitative, observational orientation and also retrospective methodology.

3.4.1 Using a quantitative approach

Based on the conjectures referred to by Hernández (2006), the research work consists of compiling databases that will be further analyzed to answer the questions established in this study and examine the hypothesis based on numerical measurements. The contribution of statistical science will allow, through the use of techniques such as Anova, to accurately determine patterns of behavior and verification theories.

3.4.2 Descriptive or Explanatory Method

This approach is used because in this study the behavior of the unmanipulated variables will be investigated, since ethical principles were followed. The study variables will be carefully observed using the most appropriate statistical methods to obtain the most reliable data.

3.5 Data processing and analysis

3.5.1 Data Analysis Processing Techniques

The compilation of the database belongs to the years 2017 - 2020 of public purchases made in the form of a small amount, and this will be done through the website of the National Public Procurement System (SERCOP).
Then we will analyze the data collected using the Anova statistical technique, which according to Cuadras (2019), measures of central tendency, box plot, hypothesis tests to compare means, Tukey's test, Shapiro Will satatistic, correlation matrices, Principal Component Analysis (PCA), will allow us to determine the following:
If the differences between the vectors of the mean of the groups are statistically significant.

a) To examine the vectors of the average purchases of medicines and medical supplies in the different groups.
b) To examine the vectors of the average purchases of IESS hospitals in the different groups.
c) To compare the vectors of the means of purchases of medicines and medical supplies from different periods.
d) Histogram and density analysis.
e) Determine what is the point that the model can fit into your data.
f) Correlation matrix of variables, medicines, supplies and hospitals.
g) Determine the main PCA components of medicines and medical supplies.
h) Determine the main PCA components of the IESS Hospitals.
i) Determine whether data on medicines and medical supplies come from a population with a normal distribution.
j) To determine if the data from the Hospitals come from a population with a normal distribution.

This data analysis will be carried out using preferably Rstudio version 4.4.0 statistical software.

3.5.2 Inventory Model

To establish the optimal order quantity to be placed by the IESS Hospitals, it will be developed using EOQ modeling. Once the appropriate inventory model has been obtained for the optimization of hospital resources, this model is designed using algorithms in the software that will help process the information.

3.5.3 Operation of the Software

The software will be fed by a networked database, which will provide reliable inventory data on an ongoing basis by all IESS hospitals in the country. The software will provide information regarding the most convenient price in the market for the acquisition of the medicine or supply that the hospital is requesting, or in turn if the system detects an inventory in some other hospital that does not have rotation of the medicine so that it can be loaned, thus also avoiding the expiration of the medicine in the hospital that will make the loan if necessary.
The software also provides information on the inventory of medicines and supplies so that the user can place a new order at the IESS hospitals. With all the aforementioned functions, good decision-making will be achieved in the administrations of the management of the Hospitals.

4. Results

4.1 Descriptive analysis of purchases of medicines and medical supplies in IESS Hospitals (2017-2020)

Table 1 presents the list of the names of the 12 IESS hospitals that were investigated, as well as the cities where each of them is located.

Table 1. Hospitals and Cities of the IESS of Ecuador

City	**Hospitals in Ecuador**
Quito	Carlos Andrade Marín IESS
Quito	Quito on IESS
Guayaquil	Ceibos IESS
Guayaquil	Teodoro Maldonado Carbo IESS
Basin	José Carrasco Arteaga IESS
Santo Domingo	General Santo Domingo IESS
Ambato	General Ambato IESS
Portoviejo	Portoviejo IESS
Crush it	General Machala IESS
Duran	Básico de Durán IESS
Blanket	General Manta IESS
Quevedo	General Quevedo IESS

Table 1. Descriptive summary of quantitative variables - medication and medical supply of each hospital during the years (2017-2020)

Hospital	Tipo	Min	Q1	Median	Mean	Q3	Max	Mode	SD	Variance	Skewness	Kurtosis
1 Carlos Andra...	INPUT	833	954.	1006.	1031.	1084.	1277	994	184.	33744.	0.444	2.03
2 Carlos Andra...	MEDIC	335	349.	396.	499.	546	867	867	250.	62315.	1.05	2.24
3 Quito Sur IE…	INSUMO	0	167.	290.	312.	435.	671	0	281.	78694.	0.260	1.87
4 Quito on IE...	MEDIC	0	54.8	97.5	92.8	136.	176	0	74.8	5593.	-0.187	1.75
5 Ceibos IESS	INSUMO	0	21.8	51	146.	176.	484	0	227.	51526.	1.10	2.29
6 Ceibos IESS	MEDIC	2	56	81	64.2	89.2	93	2	42.3	1787.	-1.04	2.23
7 Teodoro Mald...	INSUMO	63	63.8	163	188.	288.	364	64	150.	22484.	0.222	1.29
8 Teodoro Mald…	MEDIC	24	28.5	61.5	70	103	133	24	52.3	2738	0.271	1.37
9 José Carrasc...	INPUT	89	142.	184.	185.	228.	283	209	81.7	6674.	0.0280	1.77
10 José Carrasc...	MEDIC	77	82.2	93.5	99	110.	132	132	24.6	605.	0.569	1.79
11 General Sant…	INSUMO	0	5.25	10.5	9.5	14.8	17	297	7.59	57.7	-0.316	1.57
12 General Sant…	MEDIC	0	0	3	10.5	13.5	36	0	17.2	297	1.07	2.25
13 General Amba…	INSUMO	70	71.5	128	153.	209.	285	285	103.	10612.	0.440	1.56
14 General Amba…	MEDIC	30	37.5	44	74	80.5	178	178	69.7	4861.	1.12	2.30
15 Portoviejo I...	INSUMO	33	91.5	184	206.	298	421	257	171.	29260.	0.321	1.62
26 Portoviejo I...	MEDIC	120	147	203	244	300	450	450	148.	21864	0.733	1.95
17 General Mach…	INSUMO	100	179.	250.	239.	310.	354	205	111.	12317.	-0.279	1.64
18 General Mach…	MEDIC	28	61	84	81.2	104.	129	129	42.5	1806.	-0.199	1.81
19 Du...	INPUT	43	46	50.5	76	80.5	160	43	56.2	3157.	1.13	2.32
20 Dude Basic...	MEDIC	63	90.8	112.	124.	145.	212	212	63.4	4014.	0.640	2.02
21 General Mant…	INSUMO	42	51	63	60.5	72.5	74	42	15.3	233	-0.284	1.39
22 General Mant…	MEDIC	5	26	58.5	59	91.5	114	114	49.1	2414	0.0226	1.41
23 General Quev...	INPUT	0	10.5	39	66.2	94.8	187	0	85.1	7235.	0.830	2.03
24 General Quev…	MEDIC	8	38.8	62.5	136.	160	412	412	186.	34576.	1.08	2.28

General Machala IESS

The descriptive values presented by the medical supplies in the Machala hospital are with a mean of 239 units with a standard deviation of 111, which suggests considerable variability. The asymmetry is negative (skewness = -0.28) and the kurtosis is 1.64. As for medications, they have a mean of 81.2 units and a standard deviation of 42.5. The distribution is slightly negative asymmetric (skewness = -0.20) and has a kurtosis of 1.81. The descriptive results of Table 1 on medicines and medical supplies in several IESS hospitals during the period from 2017 to 2020 allow a detailed understanding of the distribution and variability of these essential resources. This analysis is important to identify consumption patterns and possible areas for improvement in hospital inventory management.

Descriptive Statistics

The descriptive statistics calculated include the minimum, the first quartile (Q1), the median, the mean, the third quartile (Q3), the maximum, the mode, the standard deviation (SD), the variance, the skewness and the kurtosis. Below is a detailed analysis of some of the featured hospitals:

Carlos Andrade Marín IESS

The inputs have a mean of 1031 units and a standard deviation of 184, the variability is considerable. The distribution is slightly asymmetric positive (skewness = 0.44) and has a kurtosis of 2.03. The mean in medicines is 499 units, with a high standard deviation of 250, indicating significant variability. The distribution is positively asymmetric (skewness = 1.05) with a kurtosis of 2.24.

Quito on IESS

The mean of this hospital in terms of supplies is 312 units with a standard deviation of 281, indicating a high variability. The skewness is positive (skewness = 0.26) and the kurtosis is 1.87. The descriptive values of Table 1 of the drugs are on average 92.8 units and a standard deviation of 74.8. The distribution is slightly negative asymmetric (skewness = -0.19) and has a kurtosis of 1.75.

Ceibos IESS

In this hospital, the mean of the supplies is 146 units and with a high standard deviation of 227 indicate a great variability in the amount of supplies. Positive skewness (skewness = 1.10) and kurtosis of 2.29 suggest a heavy-tailed distribution. In medicines, the mean is 64.2 units and a standard deviation of 42.3. The distribution is negative asymmetric (skewness = -1.04) and has a kurtosis of 2.23.

Teodoro Maldonado Carbo IESS

The mean in inputs is 188 units with a standard deviation of 150, indicating high variability. The asymmetry is positive (skewness = 0.22) and the kurtosis is 1.29. The drugs have a mean of 70 units and a standard deviation of 52.3. The distribution is positively asymmetric (skewness = 0.27) and has a kurtosis of 1.37.

José Carrasco Arteaga IESS

Inputs has a mean of 185 units with a standard deviation of 81.7, indicating moderate variability. The skewness is almost neutral (skewness = 0.03) and the kurtosis is 1.77. On the other hand, medicines have a mean of 99 units and a standard deviation of 24.6. The distribution is positively asymmetric (skewness = 0.57) and has a kurtosis of 1.79.

General Santo Domingo IESS

The inputs have a mean of 9.5 units with a standard deviation of 297, indicating low variability. The skewness is negative (skewness = -0.32) and the kurtosis is 1.57. Medicines have a mean of 10.5 units and a standard deviation of 17.2. The distribution is positively asymmetric (skewness = 1.07) and has a kurtosis of 2.25.

General Ambato IESS

Inputs with a mean of 153 units and a standard deviation of 103, the variability is moderate. The skewness is positive (skewness = 0.44) and the kurtosis is 1.56, indicating a close to normal distribution. The drugs have a mean of 74 units with a standard deviation of 69.7. The distribution is positively asymmetric (skewness = 1.12) and presents a kurtosis of 2.30.

Portoviejo IESS

The mean for medical supplies is 206 units with a standard deviation of 171, indicating high variability. The skewness is positive (skewness = 0.32) and the kurtosis is 1.62. The drugs have a mean of 244 units and a standard deviation of 148. The distribution is positively asymmetric (skewness = 0.73) and has a kurtosis of 1.95.

Básico de Durán IESS

The amount of inputs shows a mean of 76 units with a standard deviation of 56.2, indicating moderate variability. The distribution is slightly positive asymmetric (skewness = 1.13) and presents a kurtosis of 2.32, which suggests a distribution with somewhat heavier tails than normal. The drugs have a mean of 124 units and a standard deviation of 63.4. The skewness is positive (skewness = 0.64) and the kurtosis is 2.02, indicating a less biased distribution and moderately heavy tails.

General Manta IESS

The mean that corresponds to the inputs is 60.5 units with a standard deviation of 15.3, indicating a low variability. The skewness is negative (skewness = -0.28) and the kurtosis is 1.39. The medication variable has a mean of 59 units and a standard deviation of 49.1. The distribution is slightly asymmetric positive (skewness = 0.02) and has a kurtosis of 1.41.

General Quevedo IESS

The mean of medical supplies at the Quevedo hospital is 66.2 units with a standard deviation of 85.1, indicating a high variability. The asymmetry is positive (skewness = 0.83) and the kurtosis is 2.03. In this hospital, the drugs have a mean of 136 units and a standard deviation of 186. The distribution is positively asymmetric (skewness = 1.08) and has a kurtosis of 2.28.

General Interpretation

The data reveal a significant dispersion in the quantities of medicines and supplies, with notable differences in the means and standard deviations between the different IESS hospitals. In addition, the variability in the distribution of supplies and medicines among hospitals reflects differences in needs and inventory management.

Significant Dispersion and Deviation from Normal:

The quantities of supplies in hospitals such as Ceibos IESS and General Machala IESS show a significant dispersion with respect to their means, indicated by the high standard deviations and variance. In addition, in most hospitals, the distribution of supplies and medicines is leptocurtic, with a kurtosis greater than 1, indicating that there is a remarkable number of data around the central value of each variable. The asymmetry in many hospitals is positive, suggesting the presence of extremely high values that distort the mean.

Consumption Patterns and Inventory Management:

Hospitals such as Carlos Andrade Marín IESS and Ceibos IESS present high variability and asymmetry in their distributions, which may indicate fluctuating demand or problems in the supply chain. The mode and median records provide valuable information on the most common and central values of the distribution, highlighting differences between hospitals in terms of regular resource consumption.

Table 2. Descriptive summary of unified purchases of medicines and medical supplies of each hospital during (2017-2020)

Hospital	Min	Q1	Median	Mean	Q3	Max	Mode	SD	Variance	Skewness	Kurto
1 Carlos Andrade Ma	335	417.75	850.0	764.750	1000.25	1277	867	349.33	122032.21	-0.06788	1.6418
2 South Quito	0	54.75	149.0	202.625	256.25	671	0	223.42	49919.98	1.19135	3.4314
3 Ceibos	0	22.25	73.5	105.375	89.25	484	2	157.42	24781.12	2.01561	5.5364
4 Teodoro Maldonado C.	24	54.75	78.5	129.125	165.25	364	24	121.67	14804.69	1.06442	2.6909
5 José Carrasco A.	77	87.75	117.5	142.125	172.25	283	132	72.42	5244.69	0.97188	2.6927
6 General Sant. D.	0	0.00	6.5	10.000	14.75	36	0	12.34	152.28	1.21021	3.4494
7 General Ambato	30	46.00	71.0	113.375	179.50	285	178	91.66	8403.12	0.84676	2.3398
8 Portoviejo	33	117.75	203.0	224.750	298.00	450	450	149.44	22333.64	0.41365	1.8726
9 General Machala	28	90.00	114.5	160.000	227.75	354	129	114.63	13140.28	0.65077	2.0394
10Basics of Durán	43	52.25	81.5	100.250	132.25	212	212	61.19	3745.07	0.75390	2.2611
11General Manta	5	39.75	63.0	59.750	76.50	114	114	33.69	1135.07	-0.04148	2.3657
12General Quevedo	0	12.50	56.5	101.250	103.75	412	412	138.99	19319.07	1.58764	4.2114

Each hospital presents a unique pattern in its total purchases during the years 2017 to 2020, with significant variations in trends and data dispersion. Most hospitals show a downward trend in total purchases with distributions that mostly have a slight negative skewness and negative kurtosis observed in figures 11 and 12, indicating distributions with fewer extreme values and lighter tails. This analysis can help identify areas where efficiency and purchasing management can be improved in each specific hospital.

4.2 Analysis of Density Curve, Histogram and Box Graph of Purchases of Medicines and Medical Supplies, IESS Hospitals (2017-2020)

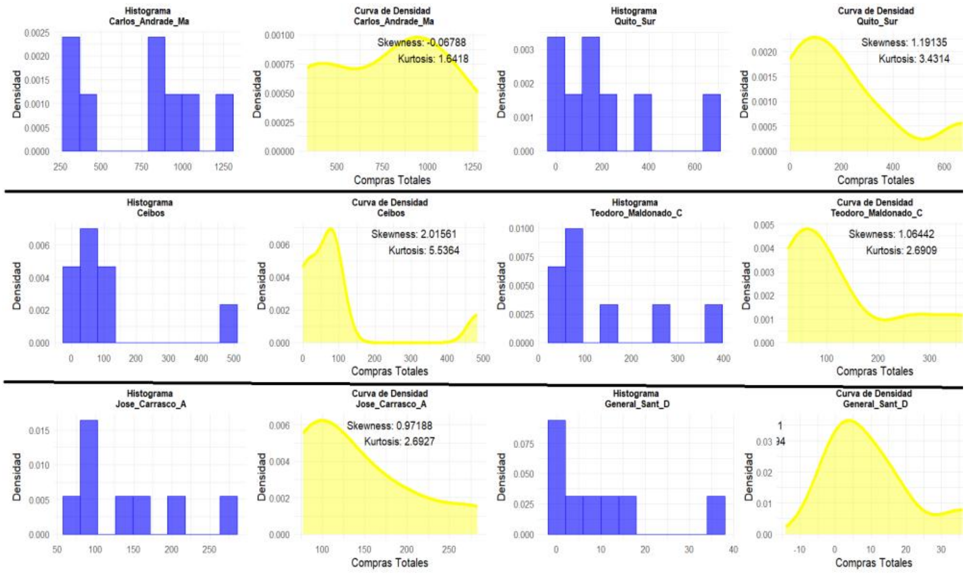


Figure 1. Density curve and Histogram of the purchases of Medicines and Medical Supplies (2017-2020), of the Carlos Andrade Marín, Quito Sur, Ceibos, Teodoro Maldonado, José Carrasco and General Santo Domingo Hospitals.In original language Spanish

The Carlos Andrade Marín IESS Hospital shows in table 2 a constant decrease in total purchases from 2017 to 2020, with a mean of 764.75 and a standard deviation of 349.33. Figure 11 of the box diagram shows that purchases are widely distributed between 335 and 1277 units, with a median of 850 units. The density curve suggests a slightly left-leaning distribution, as indicated by negative skewness (-0.06788). Kurtosis (1.6418) indicates that there are fewer extreme values compared to a normal distribution, which shows a relatively flatter distribution.

The Hospital Quito Sur IESS shows a notable variability in total purchases with a start of 0 in 2017 and an increase to 671 in 2018. The mean is 202.63, a median of 149 units, and a standard deviation of 223.42. The density curve indicates a positively skewed distribution, suggesting that there is more buying at the lower end of the range. Kurtosis (3.4314) indicates a distribution with more extreme values, or more pointed, compared to a normal distribution.

At the Ceibos IESS Hospital, purchases vary from 0 to 484 units, with a median of 73.5 units, a mean of purchases of 105.38 and a standard deviation of 157.42. Figure 11 also shows a density curve where it reveals a positively skewed distribution, suggesting a concentration of buying at the lower end of the range. Kurtosis (5.5364) indicates a distribution with more extreme values than a normal distribution.

The Teodoro Maldonado Carbo IESS Hospital has a mean of 129.13 and a standard deviation of 121.67. The distribution of purchases varies from 24 to 364 units, with a median of 78.5 units. The density curve shown in Figure 11 suggests a positively skewed distribution (skewness = 1.06442). Kurtosis (2.6909) indicates a distribution with more extreme values than a normal distribution.

The José Carrasco Arteaga IESS Hospital shows a mean purchase of 142.13 and a standard deviation of 72.42. Purchases range from 77 to 283 units, with a median of 117.5 units. The density curve shows a positively skewed distribution that can be visualized in Figure 11, indicated by a positive skewness (0.97188). Kurtosis (2.6927) suggests a distribution with more extreme values than a normal distribution.

The Santo Domingo IESS General Hospital shows a relatively low variability in purchases, ranging from 0 to 36 units, which is observed as minimum and maximum values in Table 2, with a median of 6.5 units, a mean of 10 and a standard deviation of 12.34. The density distribution shown in Figure 11 suggests a positively skewed distribution (skewness = 1.21021), and kurtosis (3.4494) indicates a distribution with more extreme values.

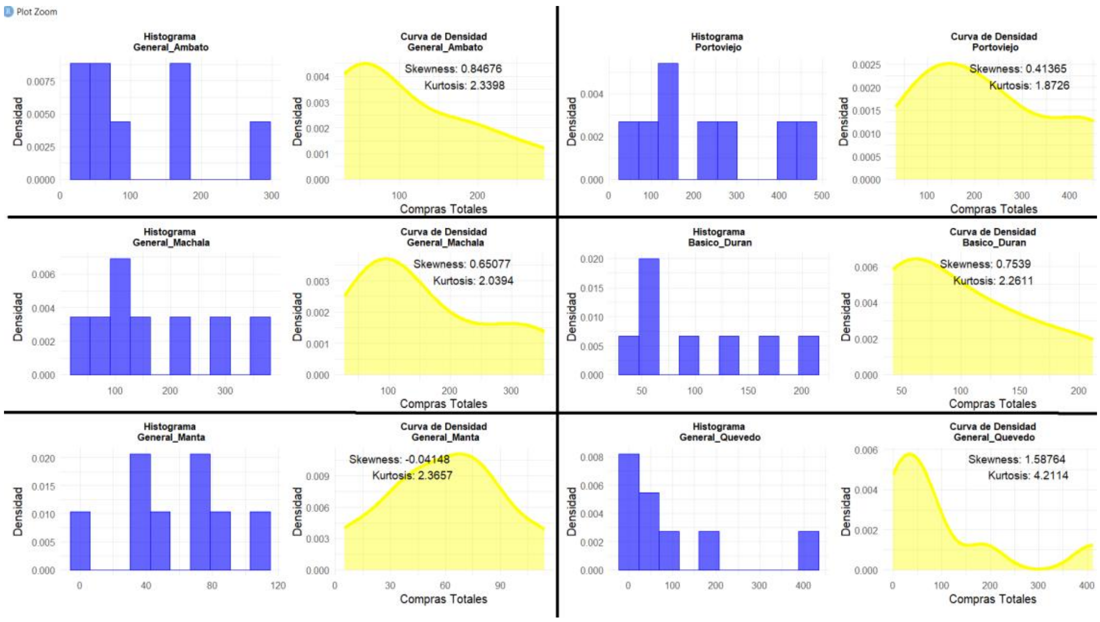


Figure 2. Density curve and histogram of the purchases of medicines and medical supplies (2017-2020), of the Ambato, Portoviejo, Machala, Básico Durán, General Manta and General Quevedo Hospitals.In original language Spanish

The Ambato IESS General Hospital shows a mean of 113.38 and a standard deviation of 91.66. Purchases range from 30 to 285 units, with a median of 71 units. The density curve can be visualized in Figure 12, which reveals a positively skewed distribution, with a concentration of purchases at the lower end of the range. Kurtosis (2.3398) suggests a distribution with more extreme values.

The Portoviejo IESS Hospital presents in table 2, great variability in purchases that is remarkable, with a range ranging from 33 to 450 units, a median of 203 units, a mean of 224.75 and a standard deviation of 149.44. The density curve suggests a slightly right-leaning distribution, indicating that there is more buying at the higher end of the range. Kurtosis (1.8726) indicates a distribution with fewer extreme values than a normal distribution.

At the Machala IESS General Hospital, the purchases in Table 2 vary from 28 to 354 units, with a median of 114.5, a mean of 160 and a standard deviation of 114.63. Figure 12 shows the density curve, where a positively skewed distribution is observed, indicating a concentration of purchases at the lower end of the range. Kurtosis (2.0394) suggests a distribution with more extreme values.

The Basic Hospital of Durán IESS shows in table 2 a mean purchase of 100.25 and a standard deviation of 61.20. In addition, purchases that range from 43 to 212 units, with a median of 81.5 units. The density curve reveals an almost symmetrical distribution, as shown in Figure 12, with a slight inclination to the right. Kurtosis (2.2611) indicates a distribution with more extreme values.

The Manta IESS General Hospital has a mean purchase of 59.75 and a standard deviation of 33.69. Purchases range from 5 to 114 units, with a median of 63 units. The density curve shows a slightly right-skewed distribution, suggesting that there is more buying at the lower end of the range. Kurtosis (2.3657) indicates a distribution with more extreme values.

The Quevedo IESS General Hospital shows in Table 2 a mean purchase of 101.25 and a standard deviation of 138.99. The variability in purchases ranges from 0 to 412 units, with a median of 56.5 units. The density curve suggests a positively skewed distribution, which can be seen in Figure 12, indicating that there is more buying at the lower end of the range. Skewness (1.5876) and kurtosis (4.2114) indicate a distribution with more extreme values and highly asymmetric to the right.

Detailed analysis of purchases made by these 12 hospitals reveals significant differences in the distribution and variability of purchasing data over the years 2017-2020. Box plots and density curves provide a clear view of distribution characteristics, including data skewness and concentration. This analysis is crucial for planning and decision-making in the field of hospital management and resource optimization. According to Doane and Seward (2011), a positive skewness indicates that the tail of the distribution extends to the right, while a negative skewness indicates that it extends to the left. On the other hand, high kurtosis suggests a distribution with heavier tails and a higher concentration of extreme values compared to the normal distribution.

4.3 Analysis of pie and box graph of purchases of medicines and supplies in IESS Hospitals (2017-2020)

The hospitals under study together carried out a total of 16,907 purchase orders in very small amounts, which can be seen in figure 3, during the years 2017 to 2020, of which 63.23% were allocated to medical supplies or 10,690 purchases, right there is where mathematical inventory models for important decision-making are most lacking. Medicines represent 36.77%, which would be 6,217.

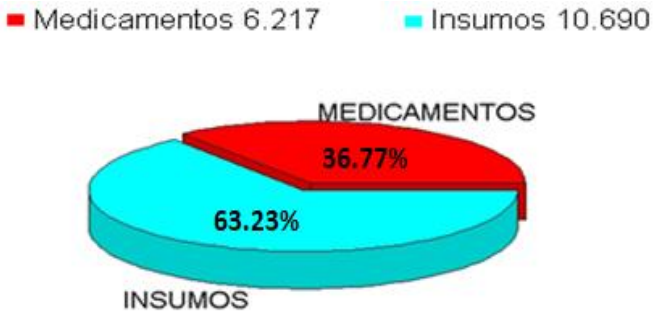


Figure 3. Purchasing (I.C.) Medicines and Supplies from 2017 to 2020.In original language Spanish

The research of Quiroga et al., (2015); Taha (2017), reported that, by having little inventory, it can incur an increase in the cost due to shortages, this is what practically happens in the IESS, because, when they run out of supplies in some medicines and supplies, they resort at the last minute to this type of purchase (I.F.) where they cannot obtain many discounts because it is an emergency purchase. An inventory system model, whether deterministic or stochastic, is very helpful in this problem. The recommendation that it is essential to analyze the turnover and the consumption cycle and the control of fundamental inventories, exclusively because it is one of the most important items that companies have, where a large amount of financial resources are invested.

In Figure 4, each boxplot shows the distribution of the quantities of purchases of medicines and supplies as a whole acquired in different years, allowing a comparison of both the medians and the variability between periods. Among the most important findings, we highlight the following:

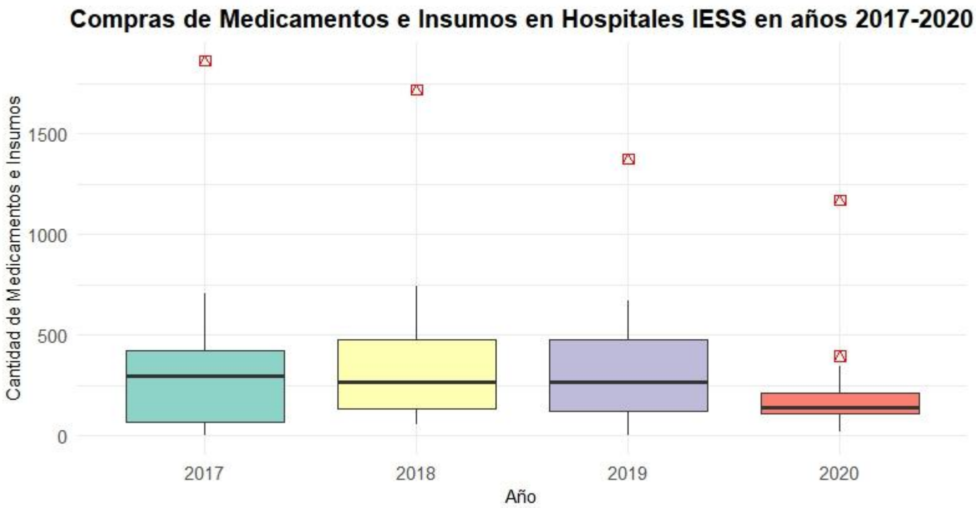


Figure 4. Box graph of total purchases of medicines and medical supplies in IESS hospitals during the years (2017-2020).In original language Spanish

In 2017, the median of purchases is around 300 units, with an IQR ranging from approximately 50 to 700 units, indicating a high variability in purchases between different hospitals. In addition, a significant outlier is observed from the Carlos Andrade Marín IESS Hospital with 1861 units, which reflects an exceptionally high demand compared to other hospitals.

For the year 2018 the median of purchases increases slightly to about 350 units, with an IQR that varies from 150 to 500 units. This year shows a more balanced distribution than 2017. High outliers such as 1716 from the Carlos Andrade Marín IESS Hospital and 744 from the Quito Sur IESS stand out, suggesting peaks in demand possibly related to specific events or specific needs.

During 2019 the median decreases to around 150 units, with an IQR that extends from 50 to 300 units, indicating a reduction in global purchases of medicines and medical supplies in that year. Again, outliers are observed, although less pronounced. The Teodoro Maldonado Carbo IESS Hospital with 457 units and the Carlos Andrade Marín IESS Hospital with 1373 units stand out as cases of high demand.

For the last study year 2020, the median stabilizes at around 110 units, with an IQR ranging from 50 to 200 units. This year shows the least variability among hospitals. Despite the lower variability, there are notable outliers, such as the 1168 of the Carlos Andrade Marín IESS Hospital and the 395 of the Teodoro Maldonado Carbo IESS, which reflect high specific demands.

It can be concluded that Figure 4 reveals several important trends:

a) Annual Variability: The variability in the purchases of medicines and supplies shows a tendency to decrease over the years, suggesting a possible improvement in the planning and distribution of resources.

b) Outliers: Recurrent outliers in specific hospitals, such as the Carlos Andrade Marín IESS, indicate the existence of exceptional demands that may be related to the capacity and volume of patients treated in these institutions.

c) Median trends: The median purchases show a gradual decrease from 2017 to 2020, which could reflect an optimization in the use of resources or changes in procurement policies.

The whisker charts in Figure 5 provide a clear view of trends and variations in the use of medicines and medical supplies in IESS hospitals over four years. The high initial variability and the presence of outliers highlight the disparity in resource management between different hospitals. However, the progressive reduction in dispersion and outliers from 2017 to 2020 suggests an improvement in the standardization and efficiency in the management of these resources.

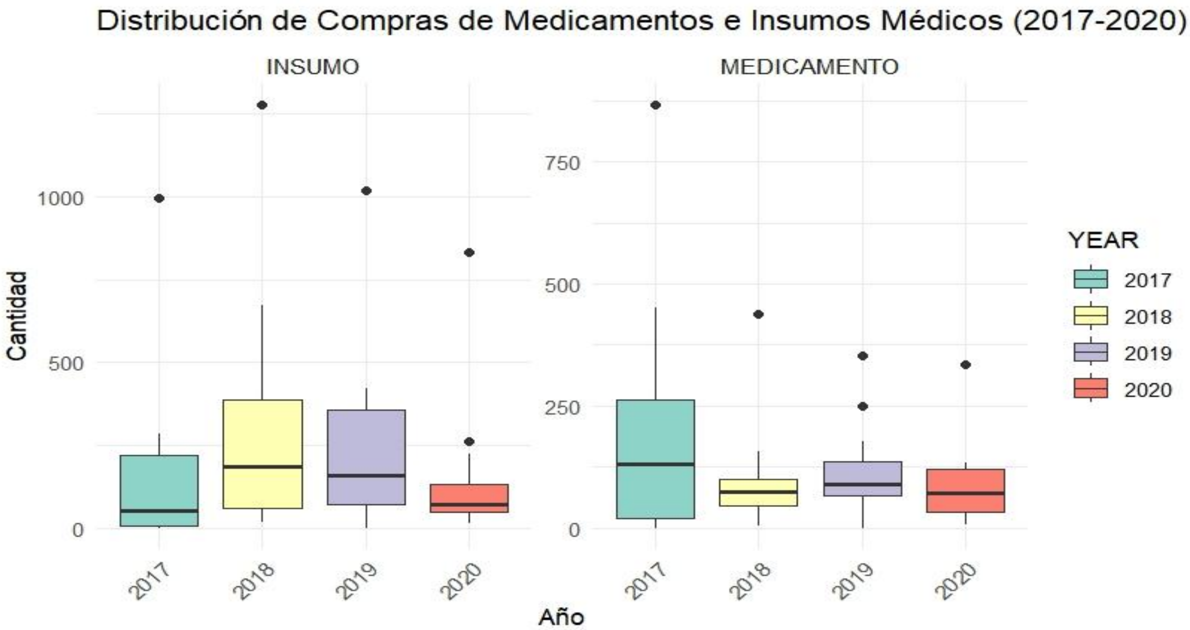


Figure 5. Box graph of purchases of medicines and medical supplies, during the years (2017 – 2020).In original language Spanish

There is high variability in the data for medicines and supplies, especially in 2017, with some hospitals showing exceptionally high values (outliers). Over time, the dispersion of data tends to decrease, indicating a possible stabilization in the expenditure of medicines and supplies. Carlos Andrade Marín's IESS outliers suggest that some hospitals have significantly different needs or consumption than the average, possibly due to their size, the number of patients served, or the diversity of services offered.

In 2017, a high dispersion in the quantity of medicines is observed, with a median of 130.5 units. The amount of inputs also shows a significant dispersion, with a median of 53.5 units. The data on medicines and supplies are mostly above the median, indicating intensive use in certain hospitals. Multiple outliers are observed among hospitals in terms of purchases. Specific values include 867 units of medicines and 994 of supplies at the "Carlos Andrade Marín IESS", with several hospitals reporting quantities of zero, which contributes to the high variability.

The year 2018 presents a median of 75 units for medicines and 185.5 units for supplies. The dispersion is lower compared to 2017, although significant outliers are still observed. Most input data are above the median, while drug data are more evenly distributed. Examples include 439 units of medicines in the "Carlos Andrade Marín IESS" and 1277 units of supplies in the same hospital.

In 2019, the median of medicines decreases to 88.5 units, and the median of supplies is 160 units. Variability is significantly reduced, especially in medicines, with fewer outliers. Most of the drug data are below the median, reflecting a more even distribution compared to previous years. For example, the "Carlos Andrade Marín IESS" reports 354 units of medicines and 1019 units of supplies.

The year 2020 shows a median of 70 units for medicines and 72.5 units for supplies. The dispersion remains smaller, with a reduction in the number of outliers. Data on medicines and supplies are mostly below the median, which could be associated with containment and inventory management policies during the COVID-19 pandemic. An example is the "Carlos Andrade Marín IESS" with 335 units of medicines and 833 units of supplies.

4.4 Analysis of the scatter chart of purchases of medicines and supplies in IESS Hospitals (2017-2020)

Figure 6 shows a wide dispersion in the data in 2017, with some hospitals registering extremely high quantities of medicines or supplies, suggesting considerable variability in their use, and a moderate positive relationship between the two. In 2018, the dispersion was more compact, indicating a possible improvement in consistency, and the positive relationship was slightly stronger. In 2019, the data showed greater consistency with a positive trend similar to that of 2018.

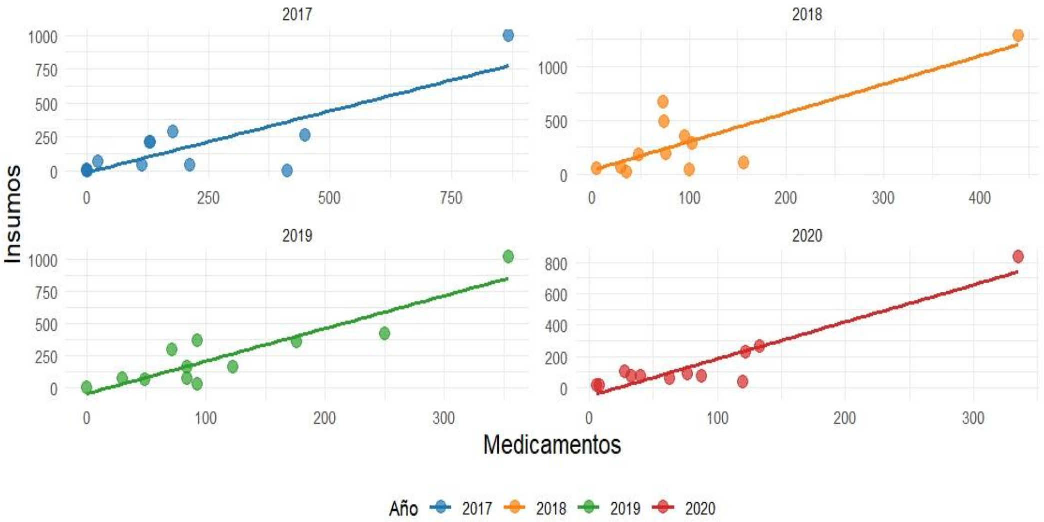


Figure 6. Scatter chart of purchases of Medicines and Medical Supplies (2017-2020).In original language Spanish

In 2020, there was greater variability in the amount of medicines and supplies, possibly due to the COVID-19 pandemic, maintaining a positive relationship, although with greater dispersion, reflecting the variable impact on hospitals. According to Anderson (2003), the presence of a strong relationship between two variables indicates that variations in one variable are consistently associated with variations in the other, while a weak relationship suggests a less consistent and more dispersed association.

4.5 Analysis of the Dispersion Matrix with a regression line, and correlation of purchases of Medicines vs Medical Supplies (2017-2020)

Correlations in the Main Diagonal

In the main diagonal of the scatter matrix in Figure 7, where purchases of medicines and supplies are compared with themselves over the years (2017-2020), significant positive correlations are observed. The correlation values for 2017 drug vs. 2018 drug, 2018 drug vs. 2019 drug, and so on, indicate a consistency in the quantities purchased year after year.

For example, the correlation between 2020 medicine and 2020 input is 0.933, which suggests a high positive relationship and consistency in medicine purchases between these two years.

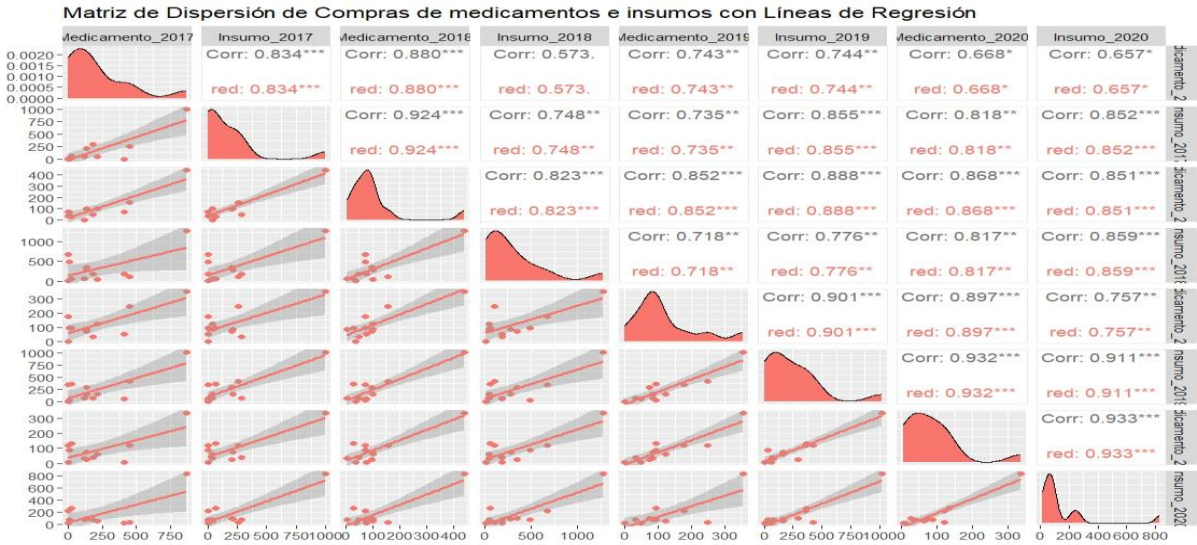


Figure 7. Matrix of dispersion of purchases of Medicines and Medical Supplies (2017-2020).In original language Spanish

Comparison between Years

When analyzing the purchases of medicines and supplies between different years, a gradual increase is generally observed. The correlation between 2017 input and 2018 input is 0.748, which suggests a moderately high positive relationship in input purchases between these two years, indicating that purchases tend to increase from one year to the next consistently.

Variability between Medicines and Supplies

When observing the dispersion of points outside the main diagonal, a variability in the purchases of medicines and supplies between different hospitals and years is noticed. Some pairs of variables show a closer and more consistent relationship, represented by denser clusters around the corresponding regression lines. When comparing the relationship between medicine 2017 and input 2017, it exhibits a moderate positive correlation of 0.83, which indicates a stable but not as strong relationship.

Outliers

Some points are identified that are far from the regression line, which indicates a high number of atypical purchases for certain hospitals in specific years.

In summary, the scatter matrix together with the calculation of correlations allows not only to visualize the relationships between the purchases of medicines and medical supplies in different hospital contexts, but also to quantify the strength and direction of these relationships.

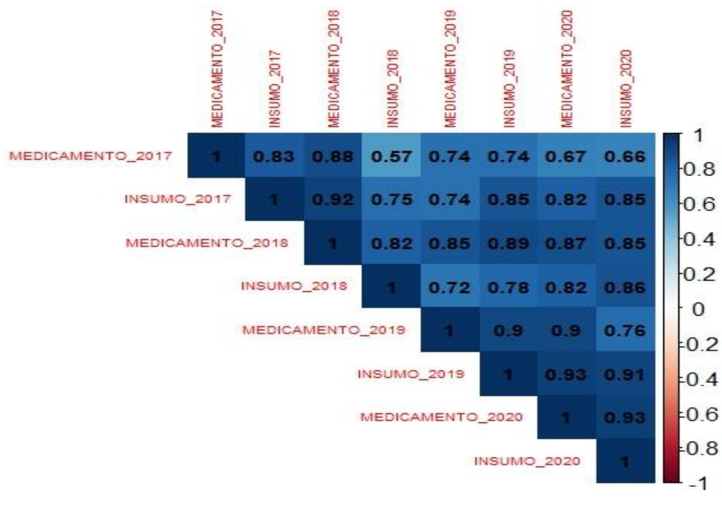


Figure 8. Correlation Matrix of Purchases of Medicines and Medical Supplies (2017-2020).In original language Spanish

Figure 8 of correlation is a similar interpretation to Figure 7, it provides a more direct visual representation of how the purchases of medicines and medical supplies are related throughout the years 2017, 2018, 2019 and 2020 in the different IESS hospitals under study. In the correlation matrix, the values range from -1 to 1, where:
a) A value close to 1 indicates a strong positive correlation, which means that the variables tend to increase or decrease together.
b) A value close to -1 indicates a strong negative correlation, which means that variables tend to move in opposite directions.
c) A value close to 0 indicates that there is no linear correlation between the variables.
Importantly, the strength of this correlation varies between years. For example, the correlation between purchases of medicines and supplies is strongest in 2019 and 2020, with correlation coefficients of 0.90 and 0.93 respectively, which coincide with Figure 17 in the scatter plot. This indicates a very strong relationship between the purchases of medicines and supplies in those years, suggesting that the purchases of these two types of products are very well aligned.
In contrast, the correlation is slightly weaker in the years 2018 and 2019, although it remains moderate. In 2018, the correlation coefficient is 0.72 between the inputs of that year vs. the 2019 drugs, and is 0.78 between the 2018 input vs. the 2017 inputs. These values still indicate a significant positive relationship, but not as strong as in the years that followed.
These results suggest that procurement and inventory management policies for medicines and supplies may have become more coordinated and aligned over time. Although the correlation between purchases of medicines and supplies is positive and significant in all the years considered, the strength of this correlation varies, being stronger in 2019 and 2020.
There is a very important detail in particular, where it is shown that most hospitals incur in the emerging purchases of the years 2017 to 2020, and are related to these variables, this being what must be corrected with the inventory models, so as not to incur in these purchases often, since this is not helping to optimize the costs in the purchases of medicines and medical supplies of the IESS hospitals.

4.6 Operation of inventory control software for pharmacies of IESS hospitals.
The inventory control software for pharmacies of the hospitals of the Ecuadorian Institute of Social Security (IESS), is designed to manage the inventory of medicines and medical supplies efficiently, allowing to record income and expenses, keep track of available stock, and generate detailed reports.
The construction of the software was developed using RStudio and its "shiny" package. it started with defining the user interface (UI) and server logic. The UI was designed to be intuitive, allowing data entry across various fields such as pharmacy, drug type, quantity, and supplier, among others. The "shiny" package made it easy to create an interactive web interface, allowing dynamic data updates. Server logic was implemented to manage the interaction between the UI "" and the data, ensuring that inventory inputs and outputs are recorded and updated correctly. In addition, functionalities for the generation of reports and graphs were added, allowing efficient inventory management. Using RStudio provided a powerful and flexible integrated development environment (IDE), making it easy to write, debug, and execute R code efficiently. Each tab of the software has specific functionalities that are described in detail below.

a) Income
The 'Revenue' tab allows the user to record the entry of new products into inventory. Figure 9 shows the fields available for the record include the following:
a) Pharmacy: Selection of the pharmacy where the product will be received.
b) Average Monthly Demand: Average monthly amount expected for the product.
c) Type of Item: Selection of the type of item (Medication or Medical Supply).
d) Inventory: Name of the product entered.
e) Quantity: Number of units received.
f) Price: Product cost per unit.
g) Supplier: Selection of the supplier of the product.
h) Date of Manufacture: Date of manufacture of the product.
i) Date of Purchase: Date on which the product was purchased.
j) Expiration Date: Expiration date of the product.
k) Batch: Batch number of the product.

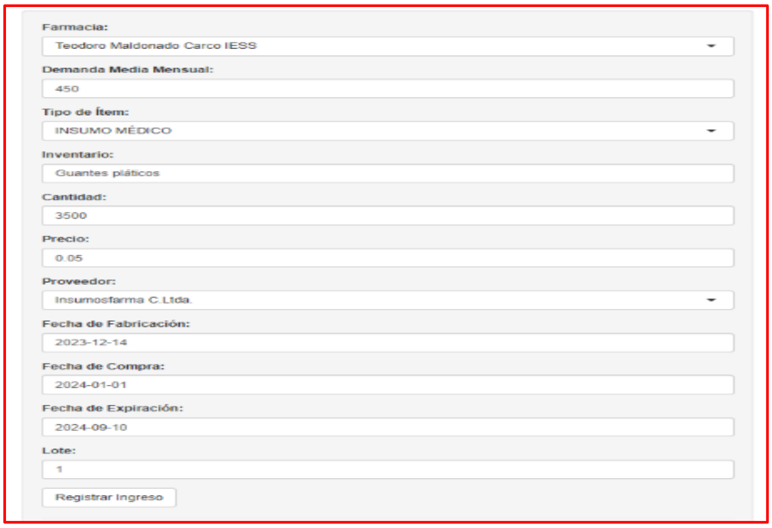
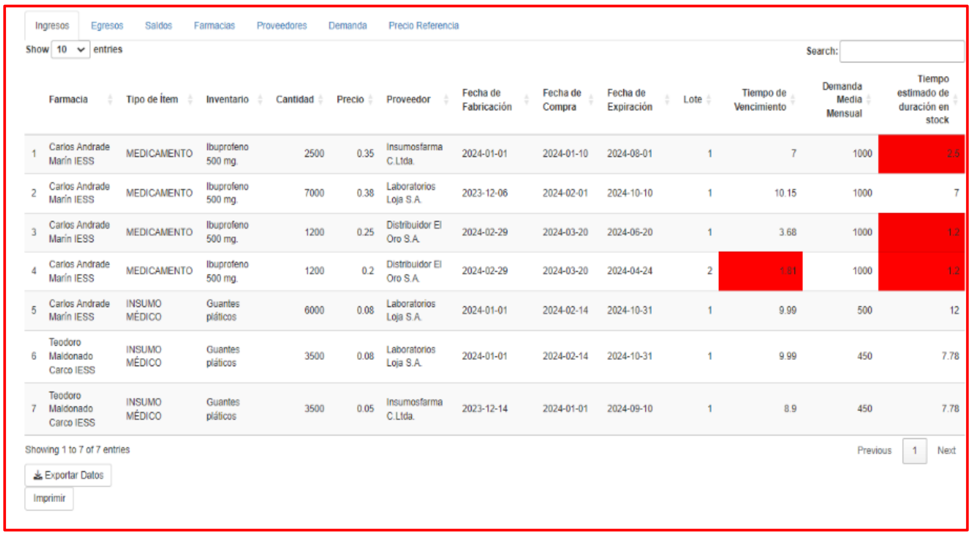


Figure 9. Software Interface, Revenue Record.In original language Spanish

Once these fields are completed, the user can press the 'Register Income' button to add the product to the inventory. The software will automatically calculate the expiration time and the estimated time of duration in stock in "months" based on the average monthly demand, in this example it was considered that the numbers less than 3 months in both columns are displayed in red, each hospital user can estimate their real need and filter in time needed. Look at Figure 10.



Ingresos | Egresos | Saldos | Farmacias | Proveedores | Demanda | Precio Referencia

Show 10 entries Search:

	Farmacia	Tipo de Ítem	Inventario	Cantidad	Precio	Proveedor	Fecha de Fabricación	Fecha de Compra	Fecha de Expiración	Lote	Tiempo de Vencimiento	Demanda Media Mensual	Tiempo estimado de duración en stock
1	Carlos Andrade Marín IESS	MEDICAMENTO	Ibuprofeno 500 mg.	2500	0.35	Insumosfarma C.Ltda.	2024-01-01	2024-01-10	2024-08-01	1	7	1000	2.5
2	Carlos Andrade Marín IESS	MEDICAMENTO	Ibuprofeno 500 mg.	7000	0.38	Laboratorios Loja S.A.	2023-12-06	2024-02-01	2024-10-10	1	10.15	1000	7
3	Carlos Andrade Marín IESS	MEDICAMENTO	Ibuprofeno 500 mg.	1200	0.25	Distribuidor El Oro S.A.	2024-02-29	2024-03-20	2024-06-20	1	3.68	1000	1.2
4	Carlos Andrade Marín IESS	MEDICAMENTO	Ibuprofeno 500 mg.	1200	0.2	Distribuidor El Oro S.A.	2024-02-29	2024-03-20	2024-04-24	2	1.81	1000	1.2
5	Carlos Andrade Marín IESS	INSUMO MÉDICO	Guantes pláticos	6000	0.08	Laboratorios Loja S.A.	2024-01-01	2024-02-14	2024-10-31	1	9.99	500	12
6	Teodoro Maldonado Carco IESS	INSUMO MÉDICO	Guantes pláticos	3500	0.08	Laboratorios Loja S.A.	2024-01-01	2024-02-14	2024-10-31	1	9.99	450	7.78
7	Teodoro Maldonado Carco IESS	INSUMO MÉDICO	Guantes pláticos	3500	0.05	Insumosfarma C.Ltda.	2023-12-14	2024-01-01	2024-09-10	1	8.9	450	7.78

Showing 1 to 7 of 7 entries Previous 1 Next

Exportar Datos

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Figure 10. Software interface, Revenue tab display.In original language Spanish

a) Expenses

The 'Expenditures' interface is intended to record the output of products from the inventory. Figure 36 shows the fields available for inventory posting to the system, including:

a) Pharmacy: Selection of the pharmacy from which the product will be shipped.
b) Inventory: Name of the product to be disbursed.
c) Quantity: Number of units shipped.
d) Supplier: Selection of the supplier of the product.
e) Batch: Batch number of the product.
f) Date of Manufacture: Date of manufacture of the product.
g) Check-In Date: Date on which the product is delivered.

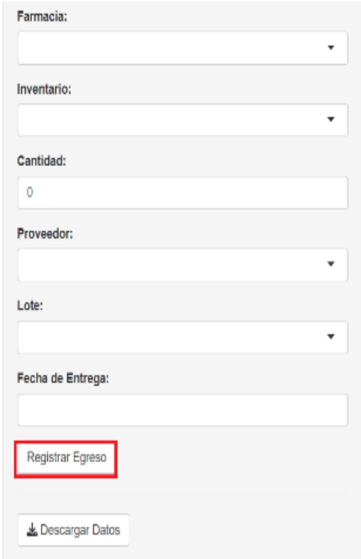
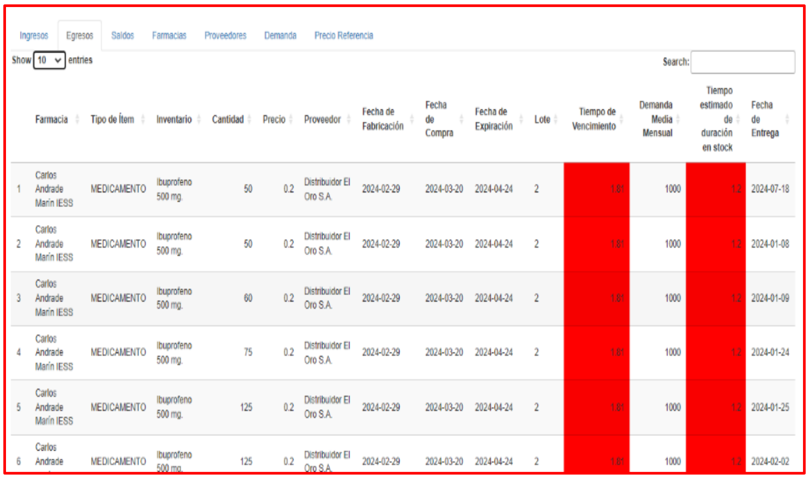


Figure 11. Software Interface, Exit Record.In original language Spanish

The user can register the output of products by pressing the 'Register Output' button. The software verifies that there is enough stock available before registering and automatically updates the inventory. If there is no availability of the product in the inventory, the system presents an alert through a message with the legend "Error" There is not enough quantity to deliver.



	Farmacia	Tipo de Ítem	Inventario	Cantidad	Precio	Proveedor	Fecha de Fabricación	Fecha de Compra	Fecha de Expiración	Lote	Tiempo de Vencimiento	Demanda Media Mensual	Tiempo estimado de duración en stock	Fecha de Entrega
1	Carlos Andrade Marín IESS	MEDICAMENTO	Ibuprofeno 500 mg.	50	0.2	Distribuidor El Oro S.A.	2024-02-29	2024-03-20	2024-04-24	2	1.81	1000	1.2	2024-07-18
2	Carlos Andrade Marín IESS	MEDICAMENTO	Ibuprofeno 500 mg.	50	0.2	Distribuidor El Oro S.A.	2024-02-29	2024-03-20	2024-04-24	2	1.81	1000	1.2	2024-01-08
3	Carlos Andrade Marín IESS	MEDICAMENTO	Ibuprofeno 500 mg.	60	0.2	Distribuidor El Oro S.A.	2024-02-29	2024-03-20	2024-04-24	2	1.81	1000	1.2	2024-01-09
4	Carlos Andrade Marín IESS	MEDICAMENTO	Ibuprofeno 500 mg.	75	0.2	Distribuidor El Oro S.A.	2024-02-29	2024-03-20	2024-04-24	2	1.81	1000	1.2	2024-01-24
5	Carlos Andrade Marín IESS	MEDICAMENTO	Ibuprofeno 500 mg.	125	0.2	Distribuidor El Oro S.A.	2024-02-29	2024-03-20	2024-04-24	2	1.81	1000	1.2	2024-01-25
6	Carlos Andrade	MEDICAMENTO	Ibuprofeno 500 mg.	125	0.2	Distribuidor El Oro S.A.	2024-02-29	2024-03-20	2024-04-24	2	1.81	1000	1.2	2024-02-02

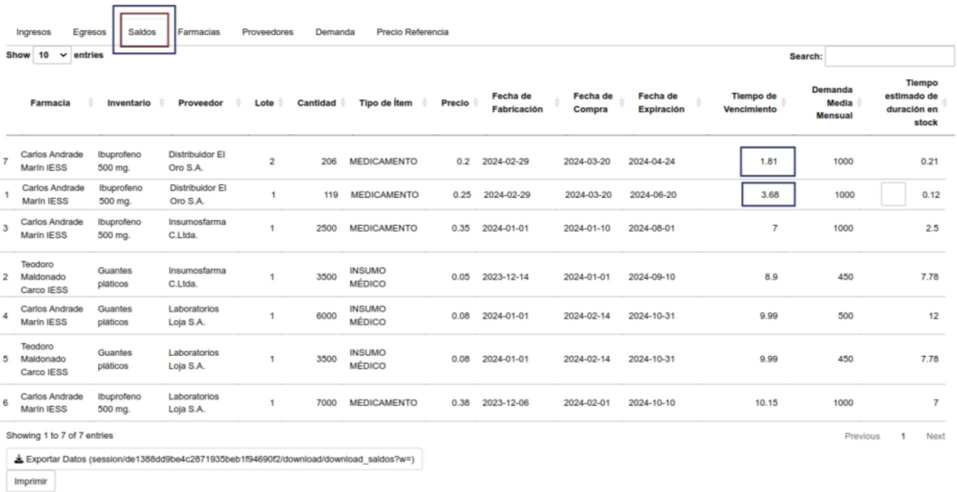
Figure 12. Software interface, Egress tab.In original language Spanish

Figure 12 shows a visualization of all the 'Expenditures' records, which is updated with each expenditure made from the inventory.

b) Balances

Figure 13 shows the interface of the 'Balances' tab, which is a summary of the current inventory. In this 'Balances' interface, the column that should be most distinguished for the users of each hospital is the column (estimated time of duration in stock) because it reflects an estimate of the time in which each product in the inventory will remain in stock based on the average monthly demand

On this Balances tab, it is also very important to filter the column (expiration time) by highlighting the products that are close to expiring. Here is the importance of applying the FIFO Inventory Model (first in – first out) allowing the user to take preventive actions, or for example to release products close to their expiration date less than 4 months as shown in figure 36, or the months that the user considers, according to the product turnover based on demand, and in turn carry out the respective procedures in the institution, to inform the laboratory and obtain the respective exchange of the new product. In this way, we avoid millionaire economic losses in the IESS hospitals, such as those detailed in this research.



	Farmacia	Inventario	Proveedor	Lote	Cantidad	Tipo de Ítem	Precio	Fecha de Fabricación	Fecha de Compra	Fecha de Expiración	Tiempo de Vencimiento	Demanda Media Mensual	Tiempo estimado de duración en stock
7	Carlos Andrade Marín IESS	Ibuprofeno 500 mg.	Distribuidor El Oro S.A.	2	206	MEDICAMENTO	0.2	2024-02-29	2024-03-20	2024-04-24	1.81	1000	0.21
1	Carlos Andrade Marín IESS	Ibuprofeno 500 mg.	Distribuidor El Oro S.A.	1	119	MEDICAMENTO	0.25	2024-02-29	2024-03-20	2024-06-20	3.68	1000	0.12
3	Carlos Andrade Marín IESS	Ibuprofeno 500 mg.	Insumosfarma C.Ltda.	1	2500	MEDICAMENTO	0.35	2024-01-01	2024-01-10	2024-08-01	7	1000	2.5
2	Teodoro Maldonado Carco IESS	Guantes pláticos	Insumosfarma C.Ltda.	1	3500	INSUMO MÉDICO	0.05	2023-12-14	2024-01-01	2024-09-10	8.9	450	7.78
4	Carlos Andrade Marín IESS	Guantes pláticos	Laboratorios Loja S.A.	1	6000	INSUMO MÉDICO	0.08	2024-01-01	2024-02-14	2024-10-31	9.99	500	12
5	Teodoro Maldonado Carco IESS	Guantes pláticos	Laboratorios Loja S.A.	1	3500	INSUMO MÉDICO	0.08	2024-01-01	2024-02-14	2024-10-31	9.99	450	7.78
6	Carlos Andrade Marín IESS	Ibuprofeno 500 mg.	Laboratorios Loja S.A.	1	7000	MEDICAMENTO	0.38	2023-12-06	2024-02-01	2024-10-10	10.15	1000	7

Figure 13. Software interface, Balances tab.In original language Spanish

In addition, a scenario has been proposed if there is a shortage for any reason, for example "the non-delivery of part of the supplier in the established times", the hospital in shortage would have the option of requesting emerging loans from other IESS hospitals until it is restocked in its inventory, observing in this section BALANCES the possible hospitals that maintain a stock of more than 5 or 6 months of duration, as long as you also consider the expiration date and give priority to the one that is closest to the expiration date, after receiving the inventory from the supplier, it is returned.

Analysis of Inventory Model Results
We analyze which model has the highest value for each of the parameters (Reorder Point (R), Safety Inventory (SS) and Total System Cost (TC)) and explain why this happens:

Reorder Point (R)

a. **Highest value**: EOQ Basic with 682.16 units.
b. **Reason**: The basic EOQ model does not consider variability in demand or lead time, so your reorder point is based solely on average demand during lead time. Without the inclusion of a safety inventory, the reorder point is simply demand during lead time.

Safety Inventory (SS)

a. **Highest value**: MP-RC-DV-TV with 41.55 units.
b. **Reason**: This model considers variability in both demand and lead time, resulting in the need for a higher safety inventory to guard against uncertainty in both factors. This ensures that an adequate level of service is maintained even with fluctuations in demand or delays in supply.

Total System Cost (TC)

a. **Mayor valor**: MP-RC-DV-TV con $432.31.
b. **Reason**: The total cost is higher in this model due to the additional safety inventory required to mitigate variability in demand and lead time. This extra cost reflects the investment required to reduce the risk of stockouts and ensure continuous product availability.

In the analysis of the inventory models, it is observed that the Total System Costs (TTU) are quite similar between the different approaches, with values ranging from $431.06 to $432.31. Although this difference may seem small at first glance, it is crucial to consider that the volumes of purchases of medicines and medical supplies are significantly large. In addition, since there are multiple items, a seemingly minimal variation in cost can accumulate and become a considerably significant amount. Therefore, even a slight difference in total costs can have a relevant impact on the financial and operational management of IESS hospitals, underscoring the importance of choosing the most appropriate inventory model to optimize both costs and product availability.

General Recommendation
If the organization can handle the additional complexity and has access to reliable data on demand and delivery times, **the MP-RC-DV-TV model** is generally the most suitable, as it provides the most flexibility and preparedness in the face of uncertainty.

However, if resources for inventory management are limited, or if demand and lead times are relatively stable, **the basic EOQ model** may be sufficient and easier to implement.
For IESS hospitals, minimizing the risk of stockouts and ensuring continuous product availability is crucial. For this reason, the software that has been developed is designed to efficiently manage inventories and address these challenges. Below is an assessment of the most appropriate inventory models for this situation:

Basic Deterministic EOQ

a. Advantages: It is simple to calculate and understand, and does not require data on demand variability or lead time.
b. Disadvantages: It does not consider uncertainties in demand or delivery times, which can lead to inadequate stock levels (overstocking or understocking).
c. Suitable for: Situations where demand is relatively stable and predictable, and delivery times are consistent and reliable.

MP-RC-DV-TC (Variable Demand, Constant Lead Time)

a. Advantages: It considers variability in demand, which allows for a more accurate calculation of safety inventory and can therefore reduce the risk of stock shortages.
b. Disadvantages: Requires additional data on demand variability and can be more complex to implement and manage.
c. Suitable for: Environments where demand is variable but delivery times are reliable and consistent.

MP-RC-DC-TV (Constant Demand, Variable Lead Time)

a. Advantages: It allows you to manage uncertainty in delivery times, adjusting the safety inventory to cover possible delays.
b. Disadvantages: Similar to the previous model, it can be more complex and requires accurate data on delivery times.
c. Suitable for: Situations where lead times are variable, but demand is relatively constant.

MP-RC-DV-TV (Variable Demand, Variable Delivery Time)

a. Advantages: It offers the greatest flexibility and robustness, considering both the variability in demand and delivery times.
b. Disadvantages: It is the most complex model to implement and manage, and requires detailed data on demand and delivery times.
c. Suitable for: Environments where both demand and delivery times are variable and unpredictable.

a) Tab Software Price Reference

The 'Reference Price' tab allows you to calculate the average purchase price of a product in a specific period. Availablefieldsinclude:

a) Inventory: Product selection.
b) Date of Entry From: Start date for the calculation of the average price.
c) Date of Entry To: End date for the calculation of the average price.

By pressing the 'Calculate Average Purchase Price' button, the software calculates and displays the average purchase price of the product in the specified period.

The software also includes the following additional functionalities:

a) Download Data: Allows the user to download data on inventory, income, expenses, balances, pharmacies and suppliers in CSV or Excel format.
b) Print: Function to print the data of each tab.
c) Dynamic Refresh: Drop-down lists for selecting pharmacies and inventories are dynamically updated based on the data entered.
d) Stock Verification: Before registering an egress, the software verifies that there is enough stock available.

The inventory control software for IESS pharmacies is a robust and efficient tool that allows you to manage the inventory of medicines and medical supplies effectively. Each tab of the software is designed to facilitate the management of each hospital's pharmacy, ensuring that users can record and monitor admissions and expenses, maintain accurate stock control, and generate detailed reports that help the authorities of each IESS hospital in decision-making.

4.7 Software and its contribution to inventory optimization, for the application of deterministic and stochastic models.

The software is enriched with the ability to provide critical data on the quantities of medicines and medical supplies that are close to running out or requiring return, along with reference prices obtained from other hospitals for specific products, and a control of average deterministic demand such as probabilistic, This flow of information is complemented by detailed market research and discount offers based on purchase quantities. By integrating this data, the software allows to efficiently provide information for the administrators of the IESS hospitals and to consider the best decisions in the application of inventory models in deterministic and stochastic scenarios, especially in the latter.

In addition, the expiring product alerts functionality allows users to take preventive actions, such as returning products to suppliers within the established deadlines or redistributing them to hospitals where they can be used before they expire. This proactive management capability reduces the risk of expiration and ensures that resources are used efficiently. The ability to manage interhospital loans also contributes to a more dynamic and collaborative inventory turnover, optimizing available resources and ensuring that hospitals can respond quickly to emerging medical supply needs, helping administrators make informed decisions about when and how much to order, as well as assess the duration of available inventory. This allows for more precise planning and better management of storage space.

Lead time is another critical factor that software can provide information through compliance histories by suppliers. By having data on delivery times, it helps administrators plan orders well in advance to ensure supplies arrive on time. This is especially important for critical medications and other important medical supplies in IESS affiliates.

Together, these features enable proactive and adaptive inventory management, which is essential for maintaining operability and service quality in the healthcare sector. The integration of deterministic and stochastic models, along with detailed analysis of pricing, lead times, ensures that hospitals can optimize their inventories efficiently and effectively. This comprehensive approach not only improves the availability and use of resources, but also supports the financial and operational sustainability of healthcare institutions, ensuring that they can fulfill their mission of providing quality healthcare.

Deterministic and stochastic inventory models are essential for efficient purchasing planning. These models benefit greatly from the accurate information provided by the software on the average monthly demand and its variability, delivery times, and reference price, facilitating the calculation of the optimal order quantity. The application of the software offers price monitoring, helping officials a good market study, to guarantee the purchase of medicines and medical supplies at fair prices, which is crucial and strengthens strategic decision-making. This software will significantly improve transparency and efficiency in the management of IESS hospital resources and its implementation represents a crucial step towards modernization.

5. CONCLUSION

1. Conclusion on the purchase of medicines in IESS hospitals:

The analysis of the results of the thesis, using tests and statistical tests such as ANOVA, identified significant fluctuations in the purchase of medicines in IESS hospitals during the years 2017-2020. In particular, 2018 showed a considerable increase in the demand for medicines, reflecting significant differences compared to other years. These results indicate inefficiencies in inventory management, manifested in substantial variations in the quantities purchased and in the absence of an effective planning system. The analysis also suggests that stability in some periods and variations in others could be due to inconsistent procurement policies and poor demand planning, resulting in stockouts and surstocks. These issues have negative consequences for patient care and operating costs.

2. Impact of Optimization Software on Inventory Management:

The optimization software developed and presented in this thesis is emerging as a fundamental tool for the improvement of inventory management in IESS hospitals. This software, designed to integrate and analyze data in real time, incorporates advanced mathematical models that make it possible to predict the demand for medicines and other medical supplies, facilitating more efficient procurement planning. Its ability to monitor inventory in detail, alert on expiring drugs or overstocks, and recommend adjustments to purchase orders, optimizes not only procurement and storage processes, but also coordination between different hospital departments. This reduces staff uptime, lowers operating costs, and improves the availability of essential products for patients.

3. Benefits of inventory control with optimization software:

The implementation of optimization software in IESS hospitals offers multiple advantages in inventory management, particularly in the prevention of shortages and excess stock. By minimising the number of expired products, the system helps to reduce significant economic losses resulting from the expiry of medicines. In addition, the software's price control feature helps mitigate volatility and high price speculation, which can negatively impact hospital management. More rigorous inventory control ensures efficient utilization of resources, avoiding both waste and shortages, which is crucial to maintaining a stable and reliable hospital operation.

4. Comprehensive and adaptive control of inventory models:

The proposed software allows exhaustive control of inventory models, both deterministic and probabilistic, through continuous iterations and adjustments based on real data. In the deterministic model, the software facilitates demand forecasting and order volume optimization, reducing maintenance costs and preventing stockouts. In the probabilistic model, the system incorporates uncertainty in demand and delivery times, adjusting inventory levels to minimize stock risks. These functionalities allow for more accurate and adaptive inventory management, significantly improving the operational efficiency and responsiveness of the hospital system to fluctuations in the demand and supply of medicines**.**

6. RECOMMENDATIONS

a) Recommendations for the implementation of optimization software:

Based on the findings of this research, the implementation of the software developed to optimize economic resources in all IESS hospitals in Ecuador is recommended. The training of officials is crucial to ensure an effective adaptation to the use of the software and its correct operation. This system, based on deterministic and probabilistic mathematical models, optimizes the procurement of medicines and medical supplies by establishing reorder points and determining optimal order quantities. In addition, the software includes a price monitoring module that helps prevent cost overruns, ensuring the purchase of inputs at fair prices and improving transparency in resource management.

b) Selection of inventory models according to hospital conditions:

If IESS hospitals can handle the additional complexity and have access to reliable data on demand and delivery times, the MP-RC-DV-TV model is generally the most suitable, as it offers greater flexibility and preparedness for uncertainty. However, if resources for inventory management are limited or if demand and lead times are relatively stable, the Basic EOQ model may be sufficient and easier to implement. The software developed is designed to facilitate the implementation of these models, supporting inventory management and informed decision-making in IESS hospitals.

c) Impact of the implementation of the software on hospital management:

The adoption of the software will significantly reduce the economic losses associated with expired medicines and stockouts, optimizing the use of resources and improving patient care. This technological innovation represents a crucial step towards the modernization of health systems in Ecuador, ensuring that IESS hospitals manage their inventories more efficiently and sustainably. In short, the software not only addresses critical issues such as lack of medicines and waste of supplies, but also strengthens strategic decision-making in hospital administration.

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