

## Supporting Management of Medical Equipment for Inpatient Service in Public Hospitals: A Case Study\*

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**Abstract**— This work presents a study of medical equipment availability in the short and long term. The work is divided in two parts. The first part is an analysis of the medical equipment inventory for the institution of study. We consider the replacement, maintenance, and reinforcement of the available medical equipment by considering local guidelines and surveying clinical personnel appreciation. The resulting recommendation is to upgrade the current equipment inventory if necessary. The second part considered a demand analysis in the short and medium term. We predicted the future demand with a 5-year horizon using Holt-Winters models. Inventory analysis showed that 27% of the medical equipment in stock was not functional. Due to this poor performance result we suggested that the hospital gradually addresses this situation by replacing 29 non-functional equipment items, reinforcing stock with 40 new items, and adding 11 items not available in the inventory but suggested by the national guidelines. The results suggest that general medicine inpatient demand has a tendency to increase within the time e.g. for general medicine inpatient service the highest increment is obtained by respiratory (12%, RMSE=8%) and genitourinary diseases (20%, RMSE=9%). This increment did not involve any further upgrading of the proposed inventory.

### I. INTRODUCTION

Quality of care is a priority goal for most health authorities in developing countries. Although many health investment plans have focused on buying capital assets and improving physical infrastructure, access to medical equipment is still poor due to inappropriate or lack of hospital management and maintenance plans [1, 2].

In the words of the World Health Organization (WHO): “Medical devices in particular are crucial in the prevention, diagnosis, and treatment of illness and disease, as well as patient rehabilitation [3]. Thus, designing plans for managing medical devices is one way of strengthening health care services [4].

In many developing countries the management of medical devices in the public sector continues to be very poor and sometimes no national guidelines are available. Previous literature warns that in developing countries medical equipment is not always operational for various reasons [2, 4]. This is still the case for at least public hospitals where medical devices are not always available for use even if in stock. Reasons can range from lack of appropriate technical

service or maintenance to insufficient personnel knowledge and skills in how to operate the device. For instance, in 2008, Dr. Dasanayaka analyzed the situation of health devices in the public sector of Sri Lanka; he concludes from his research that 42% of healthcare equipment was not functional [5].

Health administrators have to face the challenges of designing plans with limited financial resources to assure the best medical equipment acquisition strategy. They also have to keep the available equipment functional to satisfy patient demands and meet expectations.

In Chile, especially in the public sector, there is a need to update the available data, develop demand models, and improve knowledge on medical equipment management in order to develop appropriate guidelines [6]. Around 80% of the Chilean population benefits from public health care plans [7]. For this reason the government is making investments plans for infrastructure including medical devices as a way to improve access and health care quality.

There are few guidelines on medical equipment allocation for developing countries [8]. In this study we rely on the Chilean guidelines on basic requirements for medium complexity establishments [9]. This guideline states the basic requirements in infrastructure, communications, security, medical equipment, human resources, and others needed by a hospital. We will also consider guidelines proposed by the Mexican national center of health technologies [10]. The guidelines have recommendations on medical equipment for inpatient services with different number of beds and also about the proportion of medical equipment per number of beds, e.g. one suction pump for every ten beds.

This study was conducted at the San Jose’s Hospital in Coronel which is a medium complexity establishment with 142 beds. It has four main inpatient services: general medicine inpatient service, surgery, maternity and pediatric service. In Chile most of the hospitals are in the process of applying for the government certification process to provide health services. San Jose’s hospital does not have a formal medical equipment management plan. There is a proposal plan but it is still on revision. Having an inventory management and control plan is a requirement to obtain the government certification. While they are waiting to implement an inventory management plan they are reviewing the current situation and hospital processes. In this context they wanted to perform an analysis of the current medical equipment inventory situation for the inpatient service. They also wanted to know if the current amount of available medical equipment would allow them to satisfy the patient demand for this service.

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The aim of this study is to update and analyze the current inventory to obtain medical equipment performance and failure percentages and to recommend inventory upgrades according to the current situation of the inpatient service. We will forecast the inpatient demand by disease to indirectly validate the inventory proposed. This method will help to support future decisions in medical equipment management. Although the study was tailored to the specific situation of the general medicine inpatient service, we believe the methodology can be generalized to other health services within the same hospital or other hospitals.

## II. METHODS

As a way to determine the amount of functional medical equipment and provide recommendations, this work is divided in two parts: a short term and a medium term analysis.

### A. Short term analysis

In this stage of the work we focused on updating inventory data and recommending upgrades to medical equipment. We collected information and analyzed the situation of the 4 inpatient services of the San Jose' hospital.

The last inventory update was done in 2010. In order to have information about the current stock of the hospital and be able to compute performance rates, we gathered data per medical service on functional items, items waiting for technical service and items ready to be discarded. From this information we computed the operational rate and the availability and failure rate in order to measure performance. Additionally, we also conducted a volunteer survey to hospital personnel to have their opinion about the current equipment availability. For each medical equipment in the inventory list, we asked the clinical personnel to answer two questions: Is the available amount of equipment X sufficient for you to perform your work? (Yes/No). If no, how many would you consider sufficient?. The results of the survey were averaged using the statistical mode.

We analyzed the current stock of medical equipment considering the rate between amounts of medical equipment per number of beds proposed in [10]. We customized this recommendation to the current situation of the San Jose's Hospital by using the current hospital inventory, the current number of beds, and the survey results to determine if it was necessary to upgrade the current number of available equipment.

### B. Evaluation of the recommended upgrading plan in the medium term.

In order to know if the proposed inventory will need any further upgrade in the medium term, we evaluated the validity of our recommendations by predicting population epidemiology based on inpatient demand and also considered the equipment lifetime. The horizon of this study is 5 years. We believe that significant changes in epidemiology should also involve upgrades to the available medical equipment to be able to fulfill patient needs [11]. For this reason, we used the same principle of the inventory proportionality method [11] to reflect the changes in medical equipment stock.

As our dataset for the predictive model, we used discharge patient's statistics from 2001-2012 of the general inpatient service provided by the hospital. This dataset contains the number of patients discharged per day grouped by primary diagnostics coded with ICD-10<sup>1</sup>. We grouped the available data per trimesters and per disease category. The final dataset has 46 pairs of points (x,y) where x is the number of patients discharged in the trimester y. With the purpose of linking this data to the population epidemiology, we also grouped the data in 10 disease categories that include the most frequent diagnostics registered by the hospital's general medicine inpatient service (diseases from circulatory, digestive, blood, nervous and respiratory system, infectious diseases, neoplasm, among others).

We built predictive models to predict inpatient demand for the general medicine inpatient service and also inpatient demand per disease from the same service.

The available data is considered to be time series data. Forecasts for time series make use of historical data to predict future data. Time series data in health care usually presents trends, seasonality—e.g. that respiratory diseases are more frequent in winter—and sometimes cycles. For this reason, we selected the Holt-Winters method to model inpatient demand [12, 13]. We built the model using the first 36 trimesters. To assess generalization error, we evaluated the resulting model using the remaining 10 trimesters and calculated the root mean square error (RMSE).

We will compare the predicted inpatient demand in 2017 (5 year horizon) to the inpatient demand in 2011 (obtained from real data). The adjustment in equipment inventory will be proportional to the increment in patient demand.

## III. RESULTS

In this section we provide the results obtained in the current performance analysis of medical equipment and patient demand forecast, we conducted at the San Jose's hospital.

From the medical equipment information gathered (see Table I), we counted a total of 114 available equipment items. The new inventory now includes suction pumps, vital signs monitors, defibrillators, refrigerators, infusion pumps, electrocardiograph machines, humidifiers, ultrasound machines, and baby incubators among others. Table I shows a summary of the medical equipment inventory. We observe that only 72% of the equipment is functional while 28% is not functional due to maintenance or disposal. Maternity is the inpatient clinical service that has the lowest rate of non-functional equipment (19%) while general medicine is the clinical service with the lowest functional rate.

Table II shows an example of the survey results for the general medicine and surgery inpatient services. A total of 5 people per service answered the survey. The recommended amount by personnel was computed as the mode between the five surveys.

<sup>1</sup> International Statistical Classification of Diseases and Related Health Problems 10th Revision available from:www.who.int

TABLE I. SUMMARY OF THE AVAILABLE EQUIPMENT (INPATIENT SERVICE).

Inpatient Service	Medical Equipment to 2012			
	Total	Functional (%)	In maintenance (%)	Beyond repair (%)
General Medicine	19	68	0	32
Maternity	31	81	3	16
Pediatrics	46	69	0	31
Surgery	18	72	11	17
Total	114	72	3	25

The resultant amount of equipment to be purchased (shown below in Table III as *survey results*) can be calculated from Table II by subtracting the *recommended amount by personnel* to the current *total* of medical equipments.

TABLE II. EXAMPLE SURVEY APPLIED TO THE CLINICAL PERSONNEL (INPATIENT SERVICE).

Equipment	Total <sup>a</sup>	Sufficient (%)	Insufficient (%)	Recommended amount by personnel
E1	1	0	100	4
E2	2	20	80	4
E3	1	100	0	1
...	...	...	...	...

a. This total includes functional, in maintenance, and out of service equipment.

TABLE III. MEDICAL EQUIPMENT UPGRADING RECOMMENDATIONS.

	General Medicine	Maternity	Pediatrics	Surgery
Current Total	19	31	46	18
Beyond repair	6	5	15	3
Survey results <sup>a</sup>	8	6	18	8
Additional non in stock <sup>b</sup>	2	5	4	0
Total to purchase per service <sup>c</sup>	16	16	37	11

a. Total number of equipment suggested by personnel

b. Additional equipment not currently in stock but recommended by guidelines

c. Total equipment to purchase per service = Beyond repair + Survey results + Additional non in stock

Table III shows the upgrading recommendations, after we analyzed the updated inventory, surveys, and added relevant equipment indicated by literature but currently not present in the hospital [8-10].

We recommended to purchase a total of 51 equipment items. We also recommended the hospital to gradually replace the 29 items that are completely non-functional and beyond repair

Fig1 shows the resulting model and the predictions. The graphical inspection tells us that the chosen model captures most of the variations in the dataset. We observe that the general medicine inpatient demand has a slight tendency to

increase for actual and predicted data. In fact the number of discharged patients in the general medicine inpatient service in 2011 was 2,044 while the predicted number for 2017 is 2,146. This number is obtained by adding the predicted inpatient demand of the 4 last trimesters on Fig.1.

Table IV compares current inpatient demand in 2012 to the predicted inpatient demand for 2017. We observe that respiratory diseases present the higher increment followed by the Genitourinary diseases. RMSE values for the predictive model are in average 9.4% with a minimum of 7.9% and a maximum of 11.16%. Respiratory and Genitourinary diseases are the ones with highest increments for inpatient admissions in 2017. Using the proportional inventory method we observed that the new stock may not suffer any further increment in the medium term.

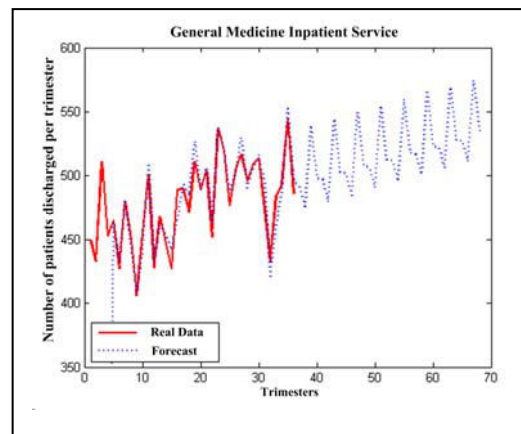


Figure 1. Number of patients discharged per trimester.

TABLE IV. SUMMARY FORECASTS BY DISEASE CATEGORY

Category	General Medicine Inpatient demand		
	2011	2017	RMSE (%)
Circulatory	286	289	8,76
Digestive	230	241	8,80
Endocrine	62	39	7,91
Genitourinary	310	370	9,19
Infectious	166	159	9,96
Respiratory	585	658	8,63
Blood	56	63	11,16
Nervous System	21	10	10,14
Trauma	82	91	8,66
Neoplasm	49	73	10,46

#### IV. DISCUSSION AND CONCLUSION

In this work we analyze the current medical equipment inventory of the inpatient service and also present a simple but effective methodology to address the problems found in medical equipment inventory. We updated the medical equipment inventory and provided recommendations on

equipment upgrade according to the appreciation of the clinical personnel and international guidelines. From the inventory analysis we conducted with data from the inpatient service, we found that 28% of the medical equipment was out of service. From that percentage only 10% is waiting for technical service, the other 90% correspond to non-functional equipment. The poorest performances are found in the general medicine and pediatric services with more than 30% of non-functional equipment. Although that may not be a critical number, it may become critical if the equipment is left unattended or the institution does design management plans. We recommended the hospital to gradually address this problem by repairing the still useful equipment and replacing the non-functional items. According to the number of beds the updated inventory followed the Mexican guidelines in medical equipment allocation except for 11 missing equipment items. We used the personnel survey results to customize the bed ration and improve the model. Survey results suggested that the available amount for some equipment items was not sufficient to attend patient needs. Thus we suggested to gradually purchase in the medium term 51 equipment items; 40 to reinforce the current stock and 11 new items suggested by guidelines, reviewed in the survey by personnel but not present in current inventory.

In the second part of this project we predicted general medicine inpatient demand in the medium term with a horizon of 5 years. The results suggest that general medicine inpatient demand has a tendency to increase within the time. In terms of epidemiology and the demand for general medicine inpatient service the highest increment is obtained by respiratory (12%, RMSE=8%) and genitourinary diseases (20%, RMSE=9%). We revised the proposed inventory according inventory proportionality. The idea of inventory proportionality is to have enough products to satisfy customer demand. Predicting the population epidemiology in the medium term will support the hospital managers in the decision of purchase new equipment to fulfill patient needs. From the results of the direct relationship between patient demands and medical equipment, we found that only one suction pump needs to be purchased. We believed the rest of the items from the upgraded inventory may be sufficient to satisfy patient demand in the medium term.

This methodology is simple and it answer the hospital managers concerns about the current equipment inventory. We believe this model can be applied to the other medical services from the same institution or even to other health care centers. At the moment we did this study we only had available patient discharge statistics, but an improvement to the method can be to use admission statistics together with length of stay to predict the inpatient demand, and also use the actual demand for medical equipment if available.

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