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Implementing a material planning and control method for special nutrition in a Brazilian public hospital

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Abstract: This study aims to (i) propose a demand forecast model for special nutrition materials in the context of health services, and (ii) comparatively evaluate three inventory management and control systems (periodic review, continuous review and mixed) for special nutrition materials. For that, we carried out a case study in a Brazilian public teaching hospital where data and information collection were conducted over a span of 22 months (from January 2018

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and were consolidated until October 2019). A six-step approach was followed to propose the demand forecasting models and, later, evaluate the inventory control systems for special nutrition materials. Results indicate that if the organization implements the proposed inventory management method, there could be savings of up to 33% in the stock values managed by the healthcare organization. This research shows the planning and control of special nutrition materials in an integrated manner. Demand forecasting methods have been combined with inventory management to promote systemic improvements to healthcare organization.

Keywords: Healthcare, Materials Planning and Control, Special Nutrition, Demand Forecasting, Inventory Management.

1. Introduction

Health services have prioritized the efficiency of delivery and the optimization of resource allocation in order to improve the management of their processes and improve the quality provided to patients^{1, 2}. Health organizations need not only to guarantee the quality of procedures for the detection and diagnosis of diseases, but also to ensure the on-time availability and supply of the necessary materials, which can represent a critical factor for the proper treatment of patients^{3, 4}. Thus, frameworks frequently used in manufacturing, such as those related to the planning and control of materials, have been used to assist in the processes of health organizations⁵.

A structured material planning and control in a hospital reduces overall costs and results in better performance rates^{6, 7}. Dacosta-Claro⁸ and Volland et al.⁹ indicate that the cost related to materials corresponds to more than 40% of a hospital's budget. This is the case of special nutrition materials, such as supplement, infant formula, and enteral nutrition, which have a large share in these expenses¹⁰. In terms of its functionality, Nyswonger and Helmchen¹¹ reported that the use of enteral nutrition and nutritional supplements significantly reduce the length of

stay of patients, leading to a more effective metabolic improvement state. In addition, Waitzberg et al.¹² showed that about 40% of hospitalized patients have some degree of malnutrition requiring use of special nutrition materials, pointing out the relevance of adequate planning and control of these materials. However, studies which approach materials planning and control methods for supporting the flow of nutrition are scarce in the literature. The few existing studies addressed the use of different methods without exploring their integration^{13, 14}.

Demand forecasting aims at estimating future data based on statistical, mathematical, or subjective models to support organizations' decision-making^{15, 16}. Given that health services operate in an environment of capacity and financial constraints, demand forecasting can help to optimized capacity planning and resource allocation^{17, 18, 19}. However, the application of demand forecasting methods remains relatively underdeveloped in healthcare when compared to other sectors^{20, 21, 22}. Methods involving linear regression are commonly used as they provide reasonably accurate results, are easy to interpret and have wide applications in modeling^{23, 24, 25}.

Furthermore, the management of medical supplies has been a priority due to uncertainties in demand and risk of shortages that affect patient safety^{26, 27, 28}. Although health services are considered highly unique and complex, improvement opportunities are abundant, especially with regards to inventory management and control methods^{29, 30, 31}. Pan and Pokharel³² and Iannone³³, for example, used the periodic reviews to manage the inventory of medicines and medical consumables; while Rosales et al.³⁴ indicated that the periodic review exceeded the continuous review, being suitable to low-cost and non-critical hospital material storage areas.

Thus, the objectives of this work are: (i) to propose a demand forecast model for special nutrition materials in the context of health services; and (ii) comparatively evaluate three inventory management and control systems (i.e., periodic review, continuous review and mixed) for special nutrition materials. A case study was carried out in a Brazilian public

teaching hospital following a six-step approach. The analysis of the data allowed the proposition of demand forecasting models and, later, the evaluation of inventory control systems for special nutrition materials.

2. Method

In this research, we adopted a case study approach, as it allows an in-depth and detailed examination of a particular case within a real-world context. Although we performed a single case, we included many observations from the same case study which enhances the internal validity of our findings. It is also worth mentioning that the methodology followed the STROBE (strengthening the reporting of observational studies in epidemiology) checklist for a case-control study. In this sense, we carefully considered the study design, setting, participants, variables, data sources and bias, study size and variables, and statistical procedures. Overall, the proposed method was comprised by six steps: (i) selection of the health organization and hospital sector (ii) identification of product families; (iii) data collection and preparation; (iv) testing demand forecasting models; (v) classification of materials; and (vi) determining the inventory management system.

Step (i) consisted of selecting an appropriate healthcare organization for the development of the case study. For this, some conditions were desirable. First, the commitment of the organization's top management was fundamental to the conduct the research³⁵. Second, the sector associated with the study should have outstanding relevance within the healthcare organization, increasing the impact of the proposed improvements.

In step (ii), product families were identified. With the help of experts, products were grouped according to similar characteristics, such as internal clients, types of inpatient units, method of preparation, delivery procedures, or functional characteristics of the materials. The identification of product families contributed to a better accuracy of the materials planning and control methods³⁶.

Subsequently, in step (iii), the collection and preparation of quantitative and qualitative data related to the materials under study were performed. The collection of quantitative data occurred through access to files which contained the historical demand for such materials. A span of 22 months (from January 2018 and were consolidated until October 2019) was used as dataset. Additional hospital data that could be correlated with the demand of the materials was collected. As for qualitative information, we used semi-structured interviews and non-participatory observation to capture them.

In step (iv), the demand forecast models were tested. For that, the variables suggested by the team of experts during step (iii) were used as independent variables in the causal models used for demand forecasting. For each product family, a demand forecasting model was determined using linear regression. It is worth mentioning that, prior to the linear regression analysis, the premises related to normality, linearity and homoscedasticity were all verified for each model³⁷. The residues were analyzed to confirm the normal distribution of the error. Linearity was verified with regression graphs for each model. Homoscedasticity was assessed by plotting standardized residues in relation to the predicted values and visually examining. All checks confirmed the requirements for a linear regression analysis.

Subsequently, results were analyzed according to their accuracy. The mean absolute percentage error (MAPE) was considered to verify the accuracy of the demand forecasting models due to its advantages of scale independence and interpretability³⁸ (see Equation 1). To avoid overfitting, 80% of the data was separated for the preparation of the demand forecasting model (training data) and 20% for the performance of accuracy tests³⁹. Baihaqi et al.⁴⁰ suggested that MAPE values below 10% are ideal and up to 15% are satisfactory.

$$MAPE = \frac{100\%}{n} \sum_{t=1}^n \left| \frac{D_t - M_t}{D_t} \right| \quad (1)$$

Where:

n = Total number of demand observations

D_t = Real demand value at time t

M_t = Calculated demand value by the model at time t

In step (v), each product family was classified according to two categories: ABC and VED (Vital-Essential-Desirable) classification. The ABC classification is a material classification widely used to list the main products according to the volume of demand. In this classification, three categories are defined as a function of volume, considering that products that added up 80% of the total volume were categorized as 'A', between 80% and 95% were denoted as 'B', between 95% and 100% were referred to as 'C'. The VED classification was carried out in a qualitative way, with the support of the experts from the hospital sector under study.

Then, we established a matrix in which the ABC classification was arranged in the rows and the VED in the columns, allowing the identification of the importance of the items both in terms of volume and criticality for the patient⁴¹. From the analysis of these two classifications, the desired service level for each group was identified (see Table 1). Service levels were divided into three: level I, given by the combination of 'A' and 'V' products; level II, given by the combination between 'A' and 'E', or 'B' and 'V'; and level III, representing the combination between 'A' and 'D', 'B' and 'E', 'B' and 'D', 'C' and 'V', 'C' and 'E', or 'C' and 'D'. For each one of three levels, experts determined the expected service level.

Table 1 – Classification ABC x VED and respective service level

Step (vi) examined the inventory management and control policies, analyzing the impact of their implementation. The main inventory review policies tested were continuous review and periodic review, in addition to a hybrid combination of the two. The mixed combination applied continuous review for the AV, BV and AE groups, and periodic review for the remaining groups in the classification matrix. Safety stocks, cyclical stocks and total stocks were calculated for each material with its respective service level. Equations 2, 3, 4 and 5 were used for the continuous review system. Equations 6, 7, 8 and 9 were applied for the periodic review system.

$$SS = \sigma_L \cdot Z \quad (2)$$

$$CS = D \cdot L \quad (3)$$

$$\sigma_L = \sigma_D \cdot \sqrt{L} \quad (4)$$

$$I_{Total} = SS + CS \quad (5)$$

$$SS = \sigma_{L+T} \cdot Z \quad (6)$$

$$\sigma_{L+T} = \sigma_D \cdot \sqrt{L + T} \quad (7)$$

$$CS = D \cdot (L + T) \quad (8)$$

$$I_{Total} = SS + CS \quad (9)$$

Where:

SS = Safety Stock

CS = Cyclical Stock

Z = Tabulated value for service level

I_{Total} = Total Inventory

L = Lead Time

D = Average Demand

T = Review period

$\sigma_{(L+T)}$ = Standard deviation of demand during the period $L + T$

σ_L = Standard deviation of demand

3. Results

3.1. Case study and data collection

The selected healthcare organization was a public teaching hospital located in southern Brazil. The organization's top management is currently involved in the implementation of continuous improvement processes. Together with the healthcare organization's nutrition sector managers, we chose the special nutrition materials to be analyzed. The choice was made because of the on-time availability needed for the patient, perishability, and financial relevance (the average cost per patient was around US\$ 52.00⁴²). Special nutrition included enteral diets, supplements, and infant formulas. The relevance of special nutrition in the patient discharge process stood out since they are often substituting (or complementing) traditional food⁴². It is noteworthy that the research was carried out with the approval of the ethics committee of the healthcare organization

The work involved not only senior management and nutritionists but also employees from other areas, such as nurses, storekeepers, and administrative assistants, totaling 14 employees working directly in the study. It should be noted that the special nutrition purchasing system, being a public organization, occurs through a public bidding process under Law 86.666/1993⁴⁴,

in which the forecast was made for the next 15 months with a 10% tolerance in the number of materials. To determine this forecast, historical averages were used. There was no formal inventory control review process or clear policies for their sizing, depending on the experience and decision of the personnel and technicians involved.

Semi-structured interviews were conducted between May and July 2018, with an average duration of 90 minutes with employees of the hospital. The main comment of semi-structured interviews are summarized in Table 2. Complementarily, non-participatory observation and visits were made to learn about the processes and capture information that was not explained during the interviews

Table 2 – Main comments of semi-structured interviews

3.2. Data collection and demand forecasting models

The collection of demand data was made using historical data. Usage records were made through daily follow-ups, which presented the information on the products prescribed to each patient, as well as the daily quantity and frequency. These accompaniments were made by nutritionists, and divided into four families: supplement, enteral, syringes (infant formulas intended for the neonatal intensive care unit - ICU) and baby bottles (infant formulas intended for pediatrics). As the daily maps were not digitally kept, the work of compiling the data was performed manually. These were available from January 2018 and were consolidated until October 2019, resulting in 22 months of demand information. The last four demand data (approximately 20% of the data) were used to perform accuracy tests of the demand forecasting models by calculating the MAPE, and the previous one as training data for the models. When using models involving time series, it is recommended to have at least 50 historical data points, allowing the verification of periodicity, seasonality, trend, etc⁴⁵. As we did not have this sample

size, we used the linear regression model. Additional data from the healthcare organization was collected to verify possible correlations with the demand of special nutrition.

Experts mentioned that the ‘patient-days’ of each hospitalization unit was the most used variable for planning purposes and the one with the greatest affinity with the demand for special nutrition materials. ‘Patient-days’ is the total number of days a patient stays in the hospital unit during a calendar month⁴⁶. In other words, if a patient stays two days hospitalized, it is considered two patient-days. Other variables were also mentioned in the interviews, such as disease history and age. However, historical data from those variables were not available. Before determining the ‘patient-days’ for supplements, enteral, baby bottles and syringes, sources and units of demand for each group were analyzed.

In the case of the supplements, 95% of the materials were destined to the following inpatient units: clinical medicine (CM), clinical surgery (CS) and ICU. Therefore, the variable inputted into the forecasting model was the value for patient-days of these three inpatient units. For the enteral family, 99% of the materials were destined to CM, CS, and ICU, which led to the independent variable. All baby bottles were sent to the pediatric unit (PU), so we used the number of patient-days from this unit as independent variable. Finally, for the syringes, 99% of their destination was for the neonatal ICU (ICU-Neo), hence, we used the patient-days from this unit in the forecasting model. The independent variables for each family were tested in the regression models, whose results are displayed in Table 3.

Table 3 – Models description for each family

3.3. Materials classification

Table 4 shows the classification of items from each product family. Items from the supplement family were denoted as s_i ($i = 1, \dots, 10$). Items related to baby bottles were referred as b_j ($j = 1, \dots, 9$). Items from enteral and syringes families were represented as e_k ($k = 1, \dots, 7$) and sy_m ($m = 1, \dots, 6$), respectively. Thus, 47% of the items were classified as ‘A’ and 37.5% as ‘V’. Half of the items were grouped in the relevant categories (i.e., AV, BV and AE), indicating that the most critical items are also highly demanded.

Table 4 – Items distribution per classification ABC x VED

3.4. Inventory management system

With the support of experts, three service levels were determined: 90%, 85% and 80%. The safety stock, cyclical stock and total stock were calculated using a continuous, periodic and mixed review policies. In the case of the cyclical stock, the forecasting models were used to predict the demands from January until October 2019. Subsequently, using the recipe of each nutrition family, the demand values were transformed into purchasing units to calculate their cost (e.g., powder products that are used in bottles and syringes converted to cans using the dilution units provided by the organization). As bottles and syringes have some materials in common, after the inventory calculations they were added and regrouped in a new family called infant formulas. From the total stock, the costs of materials in inventory were calculated to allow the comparison with the actual stock, for the months between January and October 2019. For the continuous review system, the supplier lead time of 25 days was considered, which was equivalent to the average time elapsed from the order request until its arrival at the healthcare organization. For the periodic review system, in addition to the lead time of 25 days, the review time of 7 days was considered.

Figure 1 presents the inventory comparison for the supplements considering each inventory review policy and the actual inventory at that time. At the beginning of 2019, the values were very high and over the months, and the stocks were reducing and getting closer to the proposed policies, suggesting flaws in the planning and control of this product family. According to results shown in Table 5, the periodic review did not show a huge reduction in inventory (13%). When considering the continuous review, a 29% reduction was observed. A similar result was evidenced for the mixed review policy, from which only two items (s_7 and s_9) would undergo a continuous review as they were classified as AE. The remaining items (s_1 , s_2 , s_3 , s_4 , s_5 , s_6 , s_8 , s_{10}) would undergo a periodic review, reducing the inventory by 22% on average (approximately US\$ 1,000.00 per month). The mixed review policy was the most suitable for this family because, although the reduction was moderate, only two products would be under the logic of continuous review. The pure application of continuous review requires real-time monitoring of the inventory levels, which adds complexity and involves additional costs^{47, 48}. On the other hand, the application of pure periodic review policies can be restrictive and incur higher inventory costs, in addition to the risk of unexpected shortage of items. Therefore, the mixed policy showed financial advantages associated with operational benefits consistent with the reality of the studied hospital³⁴.

Figure 1 – Inventory comparison for Supplement

Figure 2 shows the results for the enteral family. Real stock values varied from US\$ 9,900.00 (March 2018) to US\$ 6,300.00 (September 2019). Analogously to supplements, there was a large gap between the real values and the proposed inventory policies, especially in the initial months of 2019. Although the materials planning was carried out annually, there seems to be an unequal distribution of stock values, suggesting that current policies are not clear or robust

enough and allowing such variation. The proposed inventory policy with the lowest inventory reduction corresponded to the periodic review (12%). The continuous review inventory policy yielded a reduction of 28%, very close to the mixed review policy (26%). This minimal difference between the continuous and mixed reviews can be explained due to the criticality of this family, whose items were mostly classified in categories AV, AE, and BV. Hence, the adoption of a continuous review for all items is recommended^{49, 51}, despite the efforts required for continuously controlling and monitoring this inventory. This could save approximately US\$ 2,200.00 per month in inventory.

Figure 2 – Inventory comparison for Enteral

Figure 3 illustrates the results for infant formula. All proposed policies indicated a relevant inventory reduction, saving between 62% and 68% when compared to the actual numbers. As the difference among inventory review policies was low, the periodic review policy was suggested due to its ease of managing. This inventory policy could save up to US\$ 2,300.00 per month and provide managers the more effective ways to plan the replenishment of items, such as reduction in the need of multiple request orders for various items⁵². Although the periodic review system has larger safety stock⁵³, the overall savings compensate it.

Figure 31 – Inventory comparison for Infant Formula

Table 5 - Possible savings in inventory

4. Discussion

We now discuss the main findings from our study. When analyzing at all product families, the continuous review policy was suggested for 9 items, while the remaining 19 were allocated to the periodic review system with an average total reduction equivalent to US\$ 5,500.00 per month (33%). In addition to the financial benefits, the establishment of clear inventory policies standardizes the order quantities and reorder points, allowing a more effective purchasing of materials and preventing from the variability inherent to employees' judgement. The coordination between the healthcare organization and suppliers may also be improved, as uncertainties are reduced⁴⁹. However, the implementation of these inventory policies might require investments in information technology and training, impairing their adoption especially in a public hospital located in an emerging economy (Brazil)⁵⁰.

Further, the purchasing of materials is done once a year through a public bidding process, providing materials for the subsequent 15 months. This planning is currently done by replicating past consumption averages to forecast future demands, without using any sophisticated statistical support nor corrective measures. The proposed forecasting models and inventory review policies enable a more proactive management, replacing the current unstructured planning in which demand is treated as being equally distributed over the time.

It is worth highlighting some comparisons with previous works related to the topic. Setyaningsih and Basri¹⁴ propose demand forecasting models for enteral nutrition materials only by time series. The current work proposes that independent variables influence the demand for nutrition materials, generating linear regression models and bringing additional insights. Likewise, Setyaningsih and Basri¹³ propose an inventory management model with periodic review but without connection with demand forecasting models resulting in an average saving of 77% in inventory values. Ardani and Simatupang⁵⁴ compared the exponential smoothing model with the linear regression model for prediction of nutrition materials and obtained better

parameters for the first method. In addition, the authors used the periodic review system to manage inventory for all materials.

5. Conclusions

The proposed objectives of this work were (i) to propose a demand forecast model for special nutrition materials in the context of health services, and (ii) to comparatively evaluate three inventory review policies (periodic review, continuous review and mixed) for special nutrition materials. We conducted a case study in the nutrition sector of a Brazilian public teaching hospital. Our findings contribute to both theory and practice.

From a theoretical perspective, this work has combined demand forecasting methods with inventory management policies. The proposed method brings a different perspective to analyze the materials planning and control in healthcare organization, with especial attention to nutrition materials. Thus, our research contributes to the body of knowledge in the area since we are not aware of similar studies. Regarding practical contributions, this study provided more assertive and consistent means for managerial decision-making related to materials planning and control in hospitals. Besides the evidenced financial benefits, the proposed method allows all employees to apply the same parameters and follow a structured approach to control inventories. This also enables the verification of deviations, ensuring a faster response in the occurrence of problems.

Some limitations of the study should be highlighted. First, the work is limited by the availability of data in the studied healthcare organization. A lot of data was obtained manually, which can cause loss of relevant information. This undermines the utilization of other demand forecasting methods, such as time series and neural network. Thus, future studies could involve a larger data collection. Second, the independent variables inputted into the forecasting models feature

another limitation. Larger datasets could raise complementary variables that could result in a higher prediction capacity of the demand. Third, regarding inventory management, the study disregarded possible discounts and negotiation related to suppliers' deliveries. These aspects may present a relevant impact on the inventory policies, overcoming our indications. Finally, additional considered service levels could be explored, making the inventory analysis more sensitive to different scenarios.

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Table 1 – Classification ABC x VED and respective service level

	V	E	D
A	AV (level I)	AE (level II)	AD (level III)
B	BV (level II)	BE (level III)	BD (level III)
C	CV (level III)	CE (level III)	CD (level III)

Note: V = vital; E = essential; D = desirable.

Table 2 – Main comments of semi-structured interviews

Aspect	Main comments
Inventory management	"The inventory of special nutrition materials is located in the hospital warehouse. The arrival and departure control is done manually daily, where the product that is closest to expiration is released to the sectors. When the end of the month approaches, I inform the nutritionist the remaining quantity of each material"
Materials planning	"The biggest difficulty is not having a defined material planning system. Our system depends on the experience of a nutritionist. In addition, many materials are donated as the expiration date approaches, which represents a loss for the hospital."
Purchasing process	"The purchase is made through a bidding process. The public hospital requests three budgets from different suppliers and the choice is given by the lowest value. This process takes place annually. Thus, the hospital's budget is destined for this purpose during the year, and each month new orders are placed."
Demand forecasting	"The demand for special nutrition materials depends on several reasons, such as: the patient's nutritional status, the type of procedure performed and age. The "patient-day" variable of each hospitalization unit has great affinity with the demand for special nutrition materials."
Materials Prescription	"Everyday the nutritionists visit inpatients to check their nutritional status. From this, the prescriptions of the respective material and delivery time are made."

Table 3 – Models' description for each product family

Units considered in the forecasting model	Supplements (CM+CS+ICU)	Enterals (CM+CS+ICU)	Baby Bottles (PU)	Syringes (ICU-Neonatal)
Constant	270.33*	349.31*	53.42	-42.25
Patient-days	0.188*	0.036*	5.06*	8.52*
F-value	40.68*	18.44*	77.83*	30.23*
R ²	0.717	0.586	0.829	0.683
Adjusted R ²	0.701	0.554	0.818	0.661
MAPE	11.65%	7.08%	7.29%	12.81%

Note: *p-value < 0.01; CM = clinical medicine; CS = clinical surgery; ICU = intensive care unit; PU = pediatric unit.

Table 4 – Items distribution per classification ABC x VED

	V	E	D	% itens
A	e ₅ , b ₁ , sy ₂ , sy ₃	s ₇ , s ₉ , e ₂ , e ₄ , e ₆ , b ₄ , sy ₁	s ₁ , s ₄ , b ₂ , b ₃	47%
B	e ₃ , b ₅ , b ₆ , b ₇ , sy ₄		s ₃ , s ₆ , s ₈	25%
C	e ₇ , b ₈ , sy ₅	e ₁	s ₂ , s ₅ , s ₁₀ , b ₉ , sy ₆	28%
% itens	37.5%	25.0%	37.5%	

Note: V = vital; E = essential; D = desirable; s_i = supplements; b_j = baby bottles; e_k = enteral; sy_m = syringes.

Table 5 - Possible savings in inventory

Family	Periodic Review	Continuous Review	Mixed Review
Supplements	13%	29%	22%
Enteral	12%	28%	26%
Infant Formula	62%	68%	63%





