

Inventory management models in a hospital environment

Pedro Araujo Villarinho

⁽¹⁾Pontifícia Universidade Católica do Rio de Janeiro (PUC-Rio)

- R. Marquês de São Vicente, 225 - Gávea, Rio de Janeiro - RJ, 22451-900 -Departamento de Engenharia Industrial (DEI)
villarinhopedro@gmail.com

Amanda de Araujo Batista da Silva

⁽¹⁾Pontifícia Universidade Católica do Rio de Janeiro (PUC-Rio)

- R. Marquês de São Vicente, 225 - Gávea, Rio de Janeiro - RJ, 22451-900 -Departamento de Engenharia Industrial (DEI)
a.mandabatista@hotmail.com

Antônio Marcio Tavares Thome

⁽¹⁾Pontifícia Universidade Católica do Rio de Janeiro (PUC-Rio)

- R. Marquês de São Vicente, 225 - Gávea, Rio de Janeiro - RJ, 22451-900 -Departamento de Engenharia Industrial (DEI)
mt@puc-rio.br

ABSTRACT

Inventory control of hospital supplies is a challenge for healthcare organizations, not only due to the fact that expenditures with materials account for a large share of total hospital expenditures, but more importantly because the lack of such materials may compromise, at times irreversibly, a patient's health. This work entails an approach to purchase policies based on material management and control to assist the decision-making process determining the amount of financial resources which will be needed to meet the demand. Batch heuristics, well-knowns in the state of the art, were applied in real data from a Brazilian public hospital and the Monte Carlo simulation was used to simulate the variable demand. Replenishment plans generated through dynamic programming revealed that the lot for lot method always represents the worst purchase method and the Wagner-Whitin presents the lowest total cost.

KEYWORDS. Inventory management, Purchase process, Medical supplies.

Paper topics: SA (PO na Área de Saúde), AD&GP (PO na Administração e Gestão da Produção)

1. Introduction

Efficient management and resource control are vital to organizational sustainability. In a hospital context, that statement continues to hold true. The correct allocation of resources, being them financial or materials, allows high-quality care and entails adequate service delivery.

Supplies have a fundamental role in the assistance and treatment of a patient. However, in the case of a stock out, not only will the professional's performance be interrupted, but this may also compromise the patient's health, causing incalculable losses. Thus, efficient stock management in a hospital environment becomes fundamental, since it financially impacts its operations and clinical outcomes (Iannone et al., 2013).

The surgical center is the main cost-provoker of a hospital, representing 40 % to 60% of the total expenditure on supplies in a health-care unit (Moons et al., 2019). Materials are the second major cause of an increase in the expenses of a hospital, losing only to human resources (Paschoal e Castilho, 2010).

Although appropriate management is crucial in the health sector, especially regarding the surgical center, specialist's discussions are delayed and little importance devoted to this research topic (Volland et al., 2017). While other sectors present advanced studies related to supply chain, Beier (1995) has already highlighted which hospitals are challenged by the intrinsic complexity of logistic networks and the indirect relationship with its end activity. This scenario poses a paradox between the importance given to the management of materials in a hospital and its impact on the different contexts of the organization.

Thus, this work seeks to advance on the discussions about inventory management in the process of purchasing hospital materials. The batch size models were applied to real data from the surgical center of a public hospital located in the city of Rio de Janeiro, in order to analyze their effectiveness when used for planning the replacement of materials in operating rooms.

Simulation techniques were applied to treat the uncertainty of the demand for material present in the surgeries, as well as to evaluate the impact of this variation on the purchasing process and in the financial planning of the health unit. Therefore, this research main aim is to assist decision-makers in the process of determining the amount of financial resources required that it should include in its budget in order to meet a surgical center demand.

This paper is structured as follows. After this introduction, Section 2 offers the theoretical background focusing on the methods used for inventory control in this study. Section 3 presents the methodology used to classify and analyze data. Section 4 shows the results and Section 5 offers final consideration regarding practical applications and directions for futures works.

2. Theoretical Background

2.1. Monte Carlo Simulation

According to Niederreiter (1992), Monte Carlo Simulation can be defined as a numerical method based on random sampling. This method was developed in the United States during the Manhattan project at the time of World War II to simulate atomic collisions (Júnior et al., 2011), being used today to solve problems in several areas of study for example: Mathematics and Engineering (Osais, 2018).

The first step in the Monte Carlo simulation is to define the probability distribution that is going to be used as a source to the inputs parameters for the model. Then, random samples, which represent the values of these inputs variables, are taken off from this distribution with the same probability. For a set of input parameters, a set of output parameters is generated, which represent the result of a particular simulated scenario.(Raychaudhuri, 2008).

2.2. Shapiro-Wilk test

As stated by Leotti et al. (2005) Shapiro-Wilk test was shown to be a superior alternative when compared to other alternatives for the analysis of adherence to normality.

As discussed in de Mesquita Lopes et al. (2013) the Shapiro-Wilk test is based on p-value, which seeks to evaluate the degree of concordance between the data and the null-hypothesis H_0 , which in the case corresponds to the Normal distribution. The lower the p-value, the lower the consistency between the data and a hypothesis (de Mesquita Lopes et al., 2013).

With this, the hypothetical test H_0 : if $p\text{-value} \leq \alpha$, then the null hypothesis is rejected, i.e., it cannot be admitted that the data in question follows a normal distribution, and If $p\text{-Value} \geq \alpha$, then the null hypothesis is accepted, i.e., it can be admit that the data in question follows a normal distribution.

2.3. Ordering polity

In the following section are presented the inventory models: Lot-for-lot, Economic Order Quantity, Least Unit Cost, Least Total Cost, Period Order Quantity, Silver-Meal and Wagner-Whitin. Being all of them well-known models in the literature having the aim of minimize the total inventory cost.

2.3.1. Lot-for-lot

The lot-for-lot method has the purpose of meeting the demand in the exact amount requested, i.e. is produced exactly what is necessary for meeting the demand of the period. As a consequence, no item is allocated in the inventory. Therefore, the total costs of this model are associated only with the purchasing process, making the method not cost-effective when the fixed costs are significant (Silver et al., 2016).

2.3.2. Economic order quantity

Proposed by Harris (1915) this method is the basis of modern inventory models (Khan et al., 2011).

The EOQ is based on constant demand without any deterioration function (Sarkar, 2012) and seek to an optimum amount that minimizes the cost of holding an item in stock and their purchase cost (Kumar e Suresh, 2006).

2.3.3. Least Unit Cost

As stated by Nahmias e Cheng (2005) this method is similar to the Silver- Meal method and seek to minimize the cost per unit of demand.

On each period the ratio between the total cost of the period by the total number of units demanded thought the period is continuously calculated until the stop condition is reached, i.e., the ratio between the cost of setup and holding costs by the total number of units are continuous calculated until the first increase of this ratio happen. When this happens, the batch size to be ordered is found. The method restart from the period in which this increase has to happen and is executed until all demands are met.

2.3.4. Least Total Cost

This method aims at finding the batch size that should be ordered so that the number of periods covered by the replenishment has the total carrying costs as close as possible to the setup cost (Silver et al., 2016).

2.3.5. Period order quantity

This method proposes that requests are made at time intervals, which are calculated from the ratio between the EOQ and the average demand of the period and rounded to the nearest integer number, i.e, an order, which is large enough to cover exactly the demand of this integer number of periods (Silver et al., 2016).

2.3.6. Silver-Meal

Proposed by Silver e Meal (1973), this heuristic is forward method (Nahmias e Cheng, 2005) that aims to find the batch size responsible for minimizing the total cost per period (Alfares e Turnadi, 2018).

To do it, on each period the average of the total cost, i.e, cost of setup and holding costs, are continuously calculated until a stop condition, a first increase of the average, happen. When this happens, the batch size to be ordered is found. The method restart from the period in which this increase has to happen and is executed until all demands are met.

2.3.7. Wagner - Within

Proposed by Wagner e Whitin (1958), this heuristic aims at obtaining optimal solutions and minimizing costs in problems with a known demand, a single-item and a single-machine with no capacity constraints.

However, due to the complex nature of the algorithm, the need of well-defined ending point for the demand and the need of assumptions that replacement could only be made in discrete intervals made the dynamic programming model not be widely accepted in practice (Silver et al., 2016).

3. Methodology

The proposed method aims to assist hospital managers in the decision-making process in budget matters. To this end, this experiment aimed to analyze the behavior of the costs resulting from the hybridization between the lot sizing heuristics covered in Section 2.3 and Monte Carlo Simulation in four items of high importance for the operation of this health care unit.

This analysis aims to assist the budget planning of a health unit, while the same should be financially able to make purchases of supplies in order to attend an expected level of demand. In order to quantify and analyze the costs associated with the hospital stock management process, the inventory models: Lot-for-Lot (L4L) , Least Unit Cost (LUC), Economic Order Quantity (EOQ), Least Total Cost (LTC), Period Order Quantity (POQ), Silver - Meal (S.Meal) and Wagner - Within (WW) were implemented in Visual Basic.

Those models deal with idle resources as workforce, machines, money, and materials and seek to support the decision-maker in two decisions: how much to order and when to order with the aim of minimize the total cost (Kumar e Suresh, 2006).

3.1. Data Collection

Real data from the surgical ward of a public Brazilian hospital were collected from the hospital's corporate system and through interviews with those responsible for the management and purchase of the materials . They were extracted in the form of spreadsheets, in which the information: number of patients admitted to the surgical center, hospital supplies purchased and hospital materials requested by the examined sector, are available, comprising the historical period of six months, from May to October 2018.

The software Excel and R Studio version 3.5.3 were used for the structuring of information and implementation of the algorithms described in Section 2.

3.2. ABC classification

To find the items with the greatest impact on the financial planning of the hospital unit, an ABC classification was performed.

According to Oliveira (2011) from the use of this approach, it becomes possible to treat the items appropriately as to their importance, which, inspired on the Pareto principle, is based on the quantities, values or even degree of importance of the products (Eleodoro et al., 2013).

All the materials present in the surgical center were considered and classified according to their quantity and financial importance for the health care unit. Items of group A represented 70% of total cost consumed and 10% or more of the total amount of items, items of group B accounted for a large part of the remaining monetary value, and items in group C correspond to 10 % of the total value and 70 % of the quantity of items, as depicted in Table 1.

Based on the unit value of each item and quantity requested in the period in question, the ABC classification of the inventory presented in Table 1 was obtained. It is noteworthy that, unlike other approaches, in this analysis, we opted for the accounting of requested items, not consumed, since the demand for the materials is not always met.

Moreover, it was considered that the use of the aforementioned materials may vary according to the professional and the type of treatment the patient is subjected to. Therefore, the supplies considered for analysis were based on procedures performed in a standardized way. The materials selected for analysis were: (i) Bifurcated IV Extension Set; (ii) Aspirator Bottle 2000ml; (iii) Adult Bacterial and Viral Filter; (iv) Aspirator Bottle 1000ml.

Classification	A	B	C	Total
Total consumption (%)	70	20	10	100
Value of consumption (R\$)	94.479,94	26.994,27	13.497,13	134.971,35
Number of items	17	13	44	74
Number as percentage (%)	23	18	59	100

Table 1: ABC Classification

3.3. Assumptions

The study is based on the following assumptions:

1. The lead time in each period is zero.
2. The procurement cost is the cost of purchasing the item.
3. The ordering cost for any item is constant.
4. There will be no capacity increase or new hires of staff during the period of analysis.

4. Results

From the classifications performed in Section 3.2, 4 materials were selected to evaluate the impact on the financial planning of this hospital unit.

Demand data is illustrated in Table 2, the batch-size policies described in Section 2.3 were implemented, with the aim of conducting an analysis of the total costs resulting from their application in the deterministic environment.

Material	Demand (Units)					
Bifurcated IV Extension Set	90	149	85	145	160	130
Aspirator Bottle 2000ml	65	42	40	58	55	70
Adult Bacterial and Viral Filter	73	140	119	110	105	111
Aspirator Bottle 1000ml	10	34	16	2	21	18

Table 2: Demand of the 4 items selected in the deterministic environment

To calculate the costs resulting from the application of the batch-size heuristics, the parameters of the purchase cost (A), the maintenance cost of inventory (r) considered by the hospital as holding cost, and the unit value of each product (v) were determined. Those parameters were obtained by means of reports extracted from the hospital system and are listed by the type of material in Table 3.

Material	A (R\$)	r (R\$ / R\$ / year)	v (R\$)
Bifurcated IV Extension Set	50	0.03	8.34
Aspirator Bottle 2000ml	40	0.03	18.28
Adult Bacterial and Viral Filter	40	0.03	7.09
Aspirator Bottle 1000ml	40	0.03	15.97

Table 3: Parameter values of the batch-size heuristics

The costs obtained from the application of the batch-size heuristics in the selected items are illustrated in Table 4.

As expected and consistent with Silver et al. (2016) the Wagner-Whitin method is responsible for minimizing the total costs in all of the items analyzed. Making this a promising method for efficient and effective management of a hospital budget.

Material	L4L	LUC	EOQ	LTC	POQ	S.Meal	WW
Bifurcated IV Extension Set	300.00	256.03	392.04	256.03	284.81	269.79	253.77
Aspirator Bottle 2000ml	240.00	213.20	507.02	213.20	213.20	213.20	212.08
Adult Bacterial and Viral Filter	240.00	196.78	368.88	196.78	229.95	196.78	196.78
Aspirator Bottle 1000ml	240.00	138.92	206.71	123.11	123.11	123.11	123.11

Table 4: Batch-size heuristics results

In order to consider the uncertainty in the demand for materials, a new study was conducted to ascertain the amount of budget required to meet an expected level of service, i.e., the financial amount that should be considered in the budget that allows the purchase of materials in sufficient quantity to attendance of uncertain demand, using Monte Carlo Simulation.

To this end, the Monte Carlo simulation technique was used to represent the uncertainty in the demand for materials in the health care unit. Since there is a restriction of storage capacity and total surgeries performed, it is possible to infer the future demand through historical data obtained. Hence, a study regarding the behavior of the demand was elaborated. To this end, the Shapiro-Wilk (Shapiro e Wilk, 1965) test was performed in order to verify whether the data follow a normal probability distribution.

In this experiment, a significance level of 95%, i.e. , a value of α equal to 5 % was used. Table 5 exposes the values found from the Shapiro-Wilk test. For all materials analyzed the hypothesis that the data follow a normal distribution is accepted.

Material	P-Value
Bifurcated IV Extension Set	0.217
Aspirator Bottle 2000ml	0.575
Adult Bacterial and Viral Filter	0.610
Aspirator Bottle 1000ml	0.944

Table 5: P-value from Shapiro-Wilk test

From the results obtained in the Shapiro-Wilk (Shapiro e Wilk, 1965) test, it was considered that the demand follows a Normal distribution ($N(\mu, \sigma^2)$), with averages equal to the averages of the demands of each of the materials and the variance equal to the variances of the demands of each of the material.

In this experiment, 1.000 Monte Carlo Simulations were carried out. For each of the selected materials, without considering any lack of materials, 100 samples were resampled with a replacement of 7 possible demand scenarios, thus seeking to evaluate different possible horizons of demand.

For each of the 100 possible horizons of demand were calculated the batch size policies. From the results found, the upper and lower confidence intervals were calculated, using a confidence level equal to 95 %.

For the purpose of financial planning of the company, managers need scenarios for decision making, since it involves variables of strategic, operational and financial order. The evaluation of cost scenarios involving probabilistic variations in demand becomes a valuable tool for decision makers to communicate about possible impacts on the organization, as well as greater adherence to the proposed goals.

Thus, in addition to deterministic calculations, the planning areas have in hand cost scenarios calculated by means of a Monte Carlo Simulation with lower and upper limits within a confidence interval equal to 95 % as is illustrated in Table 6. The proposal generates inferences about possible scenarios according to the demands, as well as safeguards due to changes in the demand itself. The decision maker will be responsible for the final word on resource allocation, but there is the communication of contingencies or provisioning of resources, which, by chance, will be requested in high demand environments.

Consequently, from this approach, the communication of ideas within teams, discussions of perceptions, possible impacts of a contingency becomes possible, making this tool useful in an environment of uncertainty.

According to the results found in Table 6 depending on the purchasing policy adopted by the health care unit, a significant variance is observed on the total costs. For all items analyzed in the probabilistic scenario, the maximum costs are derived from the adoption of the L4L heuristic, and the minimum costs as expected are derived from the adoption of the WW heuristic.

According to Table 6, it is noted that the purchase of the Adult Bacterial and Viral Filter for adult respirator, the hospital unit tends to have a maximum cost of R\$ 280.00 by adopting the Lot-for-Lot and a minimum cost of R\$ 202.92 policy by adopting the Wagner-Whitin method considering the uncertainty in demand.

In the process of ordering the Aspirator Bottle 1000ML, the hospital unit tends to have a maximum cost of R\$ 280.00 by adopting the Lot-for-Lot and a minimum cost R\$ 140.65 policy by

adopting the Wagner-Whitin method considering the uncertainty in demand as it illustrated in Table 6.

The hospital unit tends to have a maximum cost of R\$ 990.74 by adopting the Lot-for-Lot and a minimum cost of R\$ 753.85 policy by adopting the Wagner-Whitin method considering the uncertainty in demand as it shown in Table 6 in process of ordering the Aspirator Bottle 2000ml.

Lastly, it can be observed in Table 6, the health care unit tends to have a maximum cost of R\$ 964.66 by adopting the Lot-for-Lot and a minimum cost of R\$ 600.45 policy by adopting the Wagner-Whitin method considering the uncertainty in demand of Bifurcated IV Extension Set.

Material	Confidence Interval	L4L	LUC	LEC	LTC	POQ	S.Meal	WW
Adult Bacterial and Viral Filter	Upper Limit	280.00	226.80	398.18	220.31	238.71	213.61	208.83
	Mean	280.00	223.50	383.33	216.83	234.82	210.23	205.87
	Lower Limit	280.00	220.21	368.48	213.35	230.94	206.85	202.92
Aspirator Bottle 1000ml	Upper Limit	280.00	165.11	268.05	156.67	160.92	154.83	147.73
	Mean	280.00	161.40	255.56	152.85	157.40	151.08	144.19
	Lower Limit	280.00	157.70	243.08	149.03	153.88	147.33	140.65
Aspirator Bottle 2000ml	Upper Limit	990.74	828.45	940.96	804.45	844.30	819.56	762.74
	Mean	986.61	820.50	927.15	794.97	840.21	810.10	758.30
	Lower Limit	982.49	812.55	913.34	785.50	836.13	800.64	753.85
Bifurcated IV Extension Set	Upper Limit	964.66	732.80	906.95	686.29	770.70	677.78	610.14
	Mean	955.10	716.11	875.87	670.40	761.13	662.09	605.30
	Lower Limit	945.54	699.42	844.79	654.50	751.57	646.40	600.45

Table 6: Batch-size heuristic results

5. Conclusion

The current study presented an analysis of inventory management in the process of purchasing hospital materials. In this regard, the database from the hospital located in the city of Rio de Janeiro was analyzed to understand the behavior of demand and requests of material to supply the operating rooms.

The ABC classification was used to select the four items with the highest cost and pattern amount dispensed per patient. Subsequently, the batch-size policies Lot-for-Lot (L4L), Least Unit Cost (LUC), Economic Order Quantity (EOQ), Least Total Cost (LTC), Period Order Quantity (POQ), Silver - Meal (S.Meal) and Wagner - Within (WW) were applied to the observed demand.

The second investigation contemplated the variability of material consumption in surgical procedures that were treated with the Monte Carlo simulation technique. The same batch heuristics were used to identify the better purchase policy.

As expected, the Wagner-Whitin method provided the lowest cost for both analyzes. Thus, the mean, upper limit and the lower limit were exposed to each method to support the decision maker in evaluating the amount to be reserved from his budget for the purchase of the materials, considering the average, optimistic or pessimistic case. With that is recommended the use of confidence intervals in the control of hospital expenditures by health unit managers.

The application of the method for other class A items present in the surgical center is suggested as future research, as well as in each section of the hospital. In addition, the association of proposed batch policies with demand forecasting techniques to assist in future purchases and

the develop of an automatic system for cost calculation and control that would be used-friendly for physicians and other hospital managers, less acquainted with statistic and computing techniques.

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References

- Alfares, H. K. e Turnadi, R. (2018). Lot sizing and supplier selection with multiple items, multiple periods, quantity discounts, and backordering. *Computers & Industrial Engineering*, 116:59–71.
- Beier, F. J. (1995). The management of the supply chain for hospital pharmacies: a focus on inventory management practices. *Journal of Business Logistics*, 16(2):153.
- de Mesquita Lopes, M., Branco, V. T. F. C., e Soares, J. B. (2013). Utilização dos testes estatísticos de kolmogorov-smirnov e shapiro-wilk para verificação da normalidade para materiais de pavimentação. *Transportes*, 21(1):59–66.
- Eleodoro, L. S., CHAVES, L. d. C., BORTHOLIN, R. d. C., COTIAN, L., e CINTRA, S. (2013). Cálculo do lote econômico de compra de matérias-primas utilizadas no processo de tratamento de água considerando os estoques de segurança e o lead time dos fornecedores. *Anais do XXXIII ENEGEP*.
- Harris, F. (1915). What quantity to make at once. *The library of factory management*, 5:47–52.
- Iannone, R., Lambiase, A., Miranda, S., Riemma, S., e Sarno, D. (2013). Modelling hospital materials management processes. *International Journal of Engineering Business Management*, 5 (Godište 2013):5–15.
- Júnior, A. F. S., de Mesquita Tabosa, C., e da Costa, R. P. (2011). Simulação de monte carlo aplicada à análise econômica de pedido. *Production*, 21(1):149–164.
- Khan, M., Jaber, M., Guiffrida, A., e Zolfaghari, S. (2011). A review of the extensions of a modified eoq model for imperfect quality items. *International Journal of Production Economics*, 132(1): 1–12.
- Kumar, S. A. e Suresh, N. (2006). *Production and operations management*. New Age International.
- Leotti, V. B., Birck, A. R., e Riboldi, J. (2005). Comparação dos testes de aderência à normalidade kolmogorov-smirnov, anderson-darling, cramer-von mises e shapiro-wilk por simulação. *Simpósio de Estatística Aplicada à Experimentação Agronômica*, 11:192.
- Moons, K., Waeyenbergh, G., e Pintelon, L. (2019). Measuring the logistics performance of internal hospital supply chains—a literature study. *Omega*, 82:205–217.
- Nahmias, S. e Cheng, Y. (2005). *Production and operations analysis*, volume 6. McGraw-hill New York.
- Niederreiter, H. (1992). *Random number generation and quasi-Monte Carlo methods*, volume 63. Siam.

- Oliveira, C. d. (2011). Curva abc na gestão de estoque. *Encontro Científico e Simpósio de Educação Unisalesiano*, 3.
- Osais, Y. E. (2018). *Computer Simulation: A Foundational Approach Using Python*. Chapman and Hall/CRC.
- Paschoal, M. L. H. e Castilho, V. (2010). Use of medical supplies in surgical center after implementation of an automated management system. *Revista brasileira de enfermagem*, 63(6):887–893.
- Raychaudhuri, S. (2008). Introduction to monte carlo simulation. In *2008 Winter simulation conference*, p. 91–100. IEEE.
- Sarkar, B. (2012). An eoq model with delay in payments and time varying deterioration rate. *Mathematical and Computer Modelling*, 55(3-4):367–377.
- Shapiro, S. S. e Wilk, M. B. (1965). An analysis of variance test for normality (complete samples). *Biometrika*, 52(3/4):591–611.
- Silver, E. e Meal, H. (1973). A heuristic for selecting lot size requirements for the case of a deterministic time varying demand rate and discrete opportunities for replenishment. *Production and Inventory Management Journal*, 14(2):64–74.
- Silver, E. A., Pyke, D. F., e Thomas, D. J. (2016). *Inventory and production management in supply chains*. CRC Press.
- Volland, J., Fügener, A., Schoenfelder, J., e Brunner, J. O. (2017). Material logistics in hospitals: a literature review. *Omega*, 69:82–101.
- Wagner, H. M. e Whitin, T. M. (1958). Dynamic version of the economic lot size model. *Management science*, 5(1):89–96.