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Combined tools for Surgical Case Packages contents and cost optimization: a preliminary study

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Abstract

This paper presents a solution proposal based on mathematical and statistical tools to optimize Surgical Case Packages of an Operating Room (OR) in a Portuguese public hospital that it is the most complex environment in a hospital. In this particular hospital, more than 27000 surgeries/year are performed, employing, sometimes, misadjusted composition of standard surgical packages and non-optimized grouping of surgical instruments. Problem consequences are, among others, high transport of various surgical cases packages; high number of open cases and delays in surgical times following surgery. These type of problems are waste that do not add value to the service in the context of Lean Healthcare and must be eliminated using the most suitable tools. After the analysis, different tools were used: combinatorial analysis to optimize surgical cases composition and statistical analysis to identify the instruments usage and surgical basic case patterns. An optimization model was developed which produced a sterilizing initial solution of 135.24€. By identifying the most commonly employed instruments, it was concluded that some instruments have never been used and others rarely and some patterns were identified. The results achieved were based on minor sample and in a form of data collection that needs some adjustments.

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1. Introduction

In the context of the National Health for Patients Safety¹ the safety assurance increase is a strategic objective and a world concern. The World Organization of Health estimate that, at least, half of the incidents deriving from the health care occur during the surgical act. Also, estimates, that 50% of the practice associated complications are avoidable¹. The operating room (OR), where the surgical acts occurs, is considered one of the most complex environment in the health care services units because it implies sophisticated technology and multidisciplinary teams¹. Additionally, the work conditions and team communication are fundamental for the service quality. Beyond the sophisticated technology also exist the surgical instruments smaller and simpler, most kept and transported in boxes, used in the surgical acts but which cut quality and sterilization must be assured as well their delivery after the surgical acts.

It was in this context that a Portuguese public hospital presents its objectives to an academic multidisciplinary team that was joined for a week in the framework of a European initiative called “European Study Group with Industry”. The objectives were to analyze the instruments usage pattern of the surgical cases: 1) grouping of surgical instruments comprising each case taking into account the maximum advantage of the available equipment and 2) minimization of material sterilization cycles. Additionally, they also wanted to identify groups of materials to be included in surgical packages or boxes: 1) minimum difference in usage profile (high internal consistency); 2) significant differences between different groups of boxes (high external heterogeneity, i.e. between groups of boxes).

The team formed was constituted by six members from different disciplinary areas: Mathematics; Statistics; Numerical Methods and Industrial Management that resorted to their knowledge and scientific (mathematical and statistical) tools to reach to a suitable solution for the objectives proposed. The data was provided by the hospital staff and were collected during a short time frame (March, 30 to May, 8) and only for 41 episodes of two types of processes: hernias reparation and laparoscopic (gallbladder reparation).

This paper is divided in five sections. After this first section, the second section presents the problem description, the third presents a brief literature review and the fourth the research methodology. In the fifth section the preliminary results are presented. Finally, the last section presents the conclusions and recommendations of the study.

2. Problem description

The problem presented was related with the basic surgical case packages that contents all instruments needed to all surgery types. Each basic case package should have in number and in type all instruments needed for surgeries types, e.g., for the general surgery exist 43 basic case packages. One of these surgical case package is the hernias and gallbladder reparation (laparoscopies) which have 19 different instruments in a total of 45 instruments. If there is a need for more and different instruments to a specific surgical procedure, surgery team opens a new case package or pick up an individual package material. When a new case package is open, all instruments must be sterilized which represents a high cost in OR that perform more than 27000 surgeries by year.

So, the misadjusted composition of standard surgical packages and the non-optimized grouping of surgical instruments that make up each box according to the surgical specialty brings consequences for the hospital, professionals and patients, referred as operational flaws: 1) transport of various surgical cases packages, probably avoidable; 2) high number of open cases, possibly preventable; 3) instrumental lack for other teams and surgery postponement risk; 4) early and excessive wear of the materials by successive decontamination/sterilization, possibly preventable; 5) difficulty in systematization of care provided with constant interruptions and material requests; 6) delays in surgical times following surgery, with the possibility of postponing surgery; 7) waiting for the surgical team, and loss of concentration for surgery; 8) successive occurrence of these situations, that may trigger anxiety to the different team elements, and suffering by anticipation; 9) physical & emotional fatigue/stress by the constant "search for materials"; 10) increased irritability/team voltage for failures.

3. Brief literature review

The healthcare environment is a peculiar environment that should be treated with particular attention. The proximity with life and death mix sentiments and, many times, it is difficult to separate the professional behavior from personal feelings. In spite of that, this environment is a production system that delivers a service and, like others systems, must be organized to achieve high efficiency and quality with reduced costs. To accomplish these objectives, the main healthcare units have been experienced different organization structures, being the most traditional “*the siloed, independent, and fragmented mentality of traditional health care culture*”² where functional units are organized, with each function organized around its specialist (e.g. cardiac care) and all resources are optimized to reduce costs. Nevertheless, this have been taking consequences for the main client: patients and their families³ since these resources are optimized but, many times, without thinking in them. Normally, they are optimized in a local instead of an integrated perspective². So, it is normal to find out that, for example, a unit intensive care director is more concerned with his/her “own” beds occupancy rate and less with patient health. It is important that all initiatives should be coordinated in an integrated way and use as much tools as needed to better serve the client. According to Kaplan et al.² healthcare organization must transition to “*..a culture of service excellence, an integrated approach with shared accountability in which physicians, employees, and patients treat one another with respect and as partners, and patient satisfaction and employee engagement are high.*”

Any initiative should have this focus: client satisfaction, reducing all wastes. Wastes are all activities that do not add value to the client (patient) in his/her perspective and that he/she is not willing to pay for. The operational flaws identified in section 2 above are considered wastes (*mudas*, in Japanese) in the Lean Healthcare context, a management methodology or an integrated socio-technical systems approach² rooted in the Toyota Production System that promoted Toyota Company to the great company it becomes⁴. Lean Healthcare⁵ is the application of Lean Thinking^{6,7} to the healthcare services meaning the costs reduction and productivity increase through wastes elimination. “*Doing more with less*” is the key idea of Lean that implies less human effort, less stock, less resources, less stress to obtain the same or even more without overburden people or increase the physical strain, just improving the system. Lean Thinking principles are five: 1) Value; 2) Value Stream; 3) Flow; 4) Pull Production and 5) Pursuit Perfection. In the healthcare context, value streams are the clinical value streams to map to improve patient healthcare. *A clinical value stream is broadly defined as the sequence of clinical processes required to provide integrated medical care to a patient diagnosed with a specific illness, including the diagnostic processes necessary to determine the requirements of the patient’s care plan and the clinical service-production processes by which the care plan is executed*⁸. To achieve a continuous flow for the patient, without losing this focus, and to solve the problems (e.g. the ones identified above in section 2) that, ultimately, result in serious injury or death, it is important to integrate and use all tools available (Lean, statistical, combinatorial,...) with interdisciplinary collaboration from the ones managing OR and inside the OR operation (e.g. surgeons, nurses,...) to pursuit continuous improvement^{2,9,10}.

4. Research methodology and methods

This section presents the methodology used to develop this research, presenting the form of data collection in first place and then methods and tools used.

4.1. Data collection

The data was collected between March, 30 and May, 8 by some internships of a University that works with the hospital. These internships were in the OR filling a form developed for this collection. Data filled was: episode, the surgery team, the surgery type (inpatient/outpatient) and the used instruments. Then, the data was launched in an Excel file. It was collected 41 surgery acts of hernias (15) and gallbladder reparation (26).

4.2. Methods and tools

Attending to the objectives and data analysis, it was decided using different methodologies: combinatorial analysis, statistical modeling (regression models for count data, considering the Poisson Log-Linear Model) and analysis of clusters (groups) using a clustering hierarchical method (Ward method). Mathematic Modeling Language

(AMPL) was the tool chosen for combinatorial analysis and Statistical Package for the Social Sciences (SPSS) for further analysis.

4.2.1. *Combinatorial analysis*

The combinatorial analysis was used to determine the number of instruments in the surgical cases packages that minimize waste when opening an additional package. This waste can be quantified in instruments that were not used in the open cases packages, but necessarily implying their sterilization. The approach used was dependent on the provided data. Nevertheless, it is possible to adapt the optimization models proposed to accommodate slight data modifications. The mathematical problem is formulated as an optimization problem (Eq. 1):

$$\max_{z_j \in Z^{(G)}} \sum_{j=1}^3 \left(\sum_{i=1}^{41} C_{i,abertasj}(z_j) \times (z_j) - C_{i,utilizadasj} \right) \times Custo \tag{1}$$

$$s.a \quad C_{i,abertasj}(z_j) \times (z_j) - C_{i,utilizadasj} \geq 0, \quad i = 1, \dots, 41, \quad j = 1, \dots, 3$$

where $C_{i,abertasj}$ correspond to the number of surgical case packages of type j open for the case i , i.e., $C_{i,abertasj} = \max_d \{ C_{i,utilizadasj} / (z_j)_d \}$ on what $C_{i,utilizadasj}$ is the case packages used of type j for the case i , $|C_j|$ is the number of elements (instruments) of case package j and z_j is the number of instruments of case package j .

This formulation consider that the waste occur only with the instruments from open case packages which were not used (defined by the “Custo” that means Cost), although the tools used also have a usage cost. Beyond the cost definition described above, the mathematical problem described in (1) has some assumptions. The most important is the number of considered cases packages. This number should be set after the cluster analysis, where the number of case packages and instruments contained is set. The number and composition of the case packages must take into account not only minimizing waste, but also the logistics required for the formation of the cases packages (where they are stored, a limited number of types of case packages to minimize the possibility of case packages exchanges, etc.).

In this preliminary study, it was considered the three case packages already used in the OR, defining for the problem (1) the number of instruments to put in the case package in order to minimize the waste. Due to the model complexity, it was selected the Mathematic Modeling Language (AMPL) to model the problem (1) that allowed to use the solver of the software for it resolution. However, and in spite of the intuitive formulation, it was not possible to obtain an optimal solution for the problem, because of the difficulty of solvers available. The difficulty came from the existence of a product of integer variables (number of instruments and number of open cases packages) in the objective function. To overcome this difficulty, it was modelled an optimization equivalent (in the sense that have the same solution) to the problem (1). For the costs calculation, it was considered a sterilization cost of 0,06€ (include others parcels) and of the imputation costs to the patient of 13,00€ (all parcels are imputed to the patients).

4.2.2. *Statistical analysis*

As a statistical tool was used the Poisson Log-linear¹¹ regression model that it is a generalized method in which the connection function is canonical. In this model the answer variable Y (or $\mu(x_i)$) is data of accounting, in which the connection function is a logarithmic function. So, for the Poisson Log-linear regression model were considered the following variables:

- Dependent variable: number of instruments for each episode;
- Independent or explicative variables: procedure (hernia/gallbladder) and surgery type (inpatient/outpatient).

Considering this, the Poisson Log-linear regression model is given by (Eq. 2):

$$\log(\mu(x_i)) = \beta_0 + \beta_1 x_{i1} + \dots + \beta_p x_{ip} \quad \text{and} \quad \mu(x_i) = \exp \{ \beta_0 + \beta_1 x_{i1} + \dots + \beta_p x_{ip} \} \tag{2}$$

In this model, the regression coefficients $\beta_j, j=0, 1, \dots, p$ (p is the number of explicative variables) represents the variation expected in the logarithm of the average by variation unit in the explicative variable $x_{ij}, i=1, \dots, n, j=1,$

..., p. So, the expected value of the response variable (or the average of the response variable) is given by $e^{\beta_0} e^{\beta_1 x_{i1}} \dots e^{\beta_p x_{ip}}$ ($i=1, \dots, n$).

4.2.3. Clustering analysis

The analysis of clusters¹² or groups is a process to produce ratings. Starting from a set of data relating to objects (which can be individuals or variables) of a collection, the aim is to build clusters so that objects within the same group are more similar than objects located in different groups, inducing in this way a classification in the initial collection. For the cluster analysis, it was considered as variable types of instruments (19 types of instruments base package) for each episode of surgery and objects or individuals to group or classify, the 41 episodes. So, group episodes (objects) were tried based on the number used in the process of each type of instrument. It was used a hierarchical clustering method with the clustering procedure (or algorithm). These algorithms operate from dissimilarities or distances, in this study was applied the Euclidian distance and a dendrogram was obtained by Ward method.

5. Preliminary results

Preliminary results are presented for the different approaches used showing the sterilization costs of improved solution, the instruments usage pattern and the episodes clustering identification.

5.1. Sterilization costs

The results obtained, using a similar formulation of the problem (1), indicate that the proposed approach for determining the optimal planning (which reduces waste) is possible and appropriate. Note, however, that the solution presented here is directly connected with the own waste definition and taking into account the data provided. The numerical solution is the construction of three surgical cases (as defined in the data supplied). The Gurobi solver was used to solve the obtained mathematical model where the final cost of 40,20€ was obtained, in opposition to the 135,24€ initial cost (previous to optimizing the surgical cases contents). Please note that the surgical instruments that are stored individually do not contribute to the objective function, but, in practice, to have all instruments stored individually has a storage cost which was not considered in the model.

5.2. Instruments usage pattern

It was set-up Log-linear Poisson regression models with the aim of analyzing the usage patterns of the instruments for registered episodes. The response variable was the number of instruments for each episode and the explicative variables were the type of surgery (hernia /gallbladder) and type of surgery (outpatient/inpatient). Thus they settled 19 models (one for each of the instruments 19 of the base box) of log-linear Poisson regression.

Statistical analysis of the outcome of the model showed a different pattern for the surgery episodes of gallbladder and hernias that has being used the same basic case package. For example, there are instruments that were never used in these surgeries: stiletto, cannula probe and lanquebeck. If the sample was significant could mean that these elements could be removed from the box and resort to the individual package for these cases. There are instruments that are only used in one of the surgeries: cable knife no. 24 and allis (not required for gallbladder) and clothing clip (not required for hernias). There are instruments whose reduction in the box is significant in some cases to go to half the number in the base package (e.g. from 3 to 6). The analysis of the results lead to the following result:

1. Basic case package for gallbladder with 14 different instruments in a total of 29 (inpatient) or 27 (outpatient);
2. Basic case package for hernia with 15 different instruments in a total of 25 (inpatient) and 30 (outpatient).

5.3. Episodes clustering identification

Cluster analysis was applied in order to classify the 41 episodes at the expense of the number and type of instruments used in each episode. A preliminary identification of patterns of instruments used by episode was performed, taking only the 19 instruments of the base box. This should be validated by practitioners since the

method provides the possibility to form different clusters (homogeneous groups), depending on where the cut is made. As an example, a cluster formed could lead to a base box 14 different instruments in a total of 26 if the mode was determined (statistical which represents the most frequent value) the use of instruments.

6. Conclusions and recommendations

To solve the problem presented by a Portuguese public hospital in the context of the European Study Group with Industry (ESGI), combined tools were used. This problem derived from the misadjusted composition of standard surgical packages and non-optimized grouping of surgical instruments that make up each case package according to the surgical specialty. Consequences of this problem are too many and considered as activities that do not add value (wastes) to the patient or to the professionals or to the hospital. Beyond the cost these imply, there is a higher cost, a cost never accounted: the patient safety and professionals' sanity. In a Lean Healthcare context this is the key cost to be reduced. In this context, it could be used simple tools or more sophisticated tools to eliminate wastes. In this particular case, combinatorial, statistical and clustering tools were viable tools and were used in order to optimize the composition of the surgical case packages. Some preliminary results were achieved.

A week time-frame for the study revealed short as the time-frame to collect data that resulted in a short sample and little representative with an error associated to the results of 25%, which is a high error. It is suggested a 5% of maximum error for a probability level of 95% that implies a sample dimension of 338 observations. Others recommendations to proceed with this study in a future work were: 1) to refine the current study (a better clustering analysis that needs a better study and costs association to the generated solutions); 2) to collect more observations to obtain more data about all the surgeries that use the same surgical case package; 3) to establish a sampling plan by surgery and for the total of used surgical case packages; 4) to improve the register form (some flaws were noticed: a unique identifier for the team must be used; outliers identification, ...); 5) to refine the calculus for the sterilization costs (0,06€) and of the imputation costs to the patient (13€) (all parcels are imputed to the patients) and 6) to establish the Log-linear Poisson regression models equations and to evaluate the models quality.

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