Decision Support System for the Application of Lean Healthcare in Stock Management in Health Facilities

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Abstract – The scarcity of consumables in health facilities has important implications for the quality of healthcare services, the user's well-being, and costs. The negative impacts associated with the lack of necessary products for the treatment of patients can be minimized by applying the Lean philosophy to stock management in healthcare facilities. Therefore, an easy-to-use virtual Kanban decision support system with low implementation costs was created. The quantitative model includes the calculation of maximum and minimum stocks for each item and makes it possible to determine the level of urgency for placing orders. This model presupposes the classification of items according to the level of demand, providing, depending on that classification, the quantity to be purchased. The inventory optimization system is described and then tested using the items of a first-aid kit.

Keywords- Inventory management, Decision support system, Lean healthcare, e-Kanban, Stock

I. INTRODUCTION

A report by the World Health Organization (WHO) states that the lack of medicines, vaccines and other consumables triggers the emergence of substitute products of lower quality. In addition, the shortage of proper consumables, in turn, can extend the condition of illness, as well as the associated inconveniences and risks and it can also generate waste of time and employee absenteeism [1].

"Lean Thinking" is based on the production philosophy developed by Toyota, which focuses on maximizing customer value by minimizing all forms of waste. According to the Just-in-Time (JIT) production system, one of the Lean tools, the goods must be available according to the customer's demand and in the required quantity[2].

The guiding principles of this philosophy are extended to the healthcare sector and its implementation has resulted in time-savings, timeliness of service, errors reduction, patient satisfaction and reduced mortality [2]. Nevertheless, the application of "Lean Thinking" in this sector needs some adaptations. While in an industrial context stockouts result in loss of profit, in a health facility it can cause the loss of a life. Therefore, it is necessary to establish a balance between the elimination of delays as well as stockouts and the minimization of overstocks [3].

Several models have been used to assist inventory management, including computerized and automated methods, such as automated warehousing, bar coding, Radio Frequency Identification (RFID) tags, among others. Nevertheless, the costs of these information technologies are too high for most state funded healthcare facilities [3].

In addition, Ref. [4], [5], and [6] present mathematical models for inventory management in health facilities. Other studies describe decision aid tools for inventory management, namely,[7], and [8].

However, there is a scarcity of references in the literature about the description of a decision support system (DSS) for inventory management in healthcare facilities, using lean thinking and, particularly, the Kanban tool, hence, the novelty and relevance of this work.

The Kanban system is one of the most used Lean tools in healthcare facilities. According to this system, the consumption of an article generates a replenishment order, which is signaled by the so-called Kanban cards. A study on the use of these cards in an outpatient pharmacy revealed that, due to space limitations, Kanban cards were frequently exchanged, or misused (for example, the card was not taken away when the order point was reached) [3].

Despite being a topic of interest for many researchers, the inventory management for healthcare supply chains has rarely been studied for many inventory specialists in the last decade [9].

Thus, the proposed methodology aims to minimize some problems detected in healthcare facilities regarding stock management, such as stock outages, overstocks, the lack of awareness by the medical staff of techniques to overcome some logistical problems and misuse of Kanban cards [3].

The purpose of this study is to develop a decision support system that applies Lean philosophy to the inventory management in healthcare facilities, using optimization techniques, and ensuring the availability of the required consumables, through the application of e-Kanban, which signals the need to replenish each item.

Thus, in this paper, the authors describe the development of an easy-to-use virtual Kanban DSS, which has low implementation costs, so that it can be affordable for most healthcare facilities. Furthermore, the DSS developed is a novel framework based on Lean Healthcare Thinking, more specifically, using the Kanban tool, that allows to determine when and in which quantity each item (depending on the level of demand) must be ordered.

II. Methodology

The proposed DSS allows to visually identify the need to place an order, through a computer system. An easy-to-use decision-making aid system was developed in the Microsoft Excel software. This system choice was motivated by its reduced implementation costs when compared to other computerized and automatic methods. Additionally, the wide use of this software can favour its implementation.

The proposed solution is an inventory management system with replenishment by levels, which requires a prior analysis of the products, as well as their classification according to the demand (high or low). The presented quantitative model allows the determination of the urgency, as well as the quantity of each item that must be ordered.

It also intends to facilitate the calculation of the ideal minimum and maximum levels of stock for each product, according to its own specifications in terms of characteristics such as demand, waiting time between order and delivery, and others.

In the study of [10], about the application of Six Sigma, more focus was given to the quality control rather than the quantity.

Although studies have been conducted in the healthcare inventories subject [11], with some publications even pointing out exactly what should be done to prevent years of expensive experimentation [12], none was found that would be as completed and calculate all the variables that are calculated in this paper.

This work provides a practical tool using the Lean Thinking in healthcare. This tool was also developed not only thinking about internal management (such as the ideal minimum and maximum stocks), but also having in sight the interactions with the suppliers. If, for some reason, the necessity of ordering a large quantity of a given item at once is verified, an immediate response from the supplier might be impossible. With that in mind, the sooner the user realizes the need and urgency of that order, the quicker the user will take the indicated decisions, preventing a possible product stockout.

All these characteristics make this study rather contributory for the healthcare industry, as if implemented, it will reduce the over-ordering of products, diminish the order's waiting time (because the order will be placed in time and users won't be able to feel the shortage), as well as making a much leaner facility.

This model applies, in a single DSS, various equations, in addition to adding a visual system to alert the user about a possible supply problem when large quantities are needed.

If applied in a large scale, the outcome could be a much more organized healthcare system, with less waste of time and resources, meaning, ultimately, a more improved treatment of the patients, which could result in a smaller mortality rate.

To test the DSS tool, a series of items used in first-aid boxes [14] was applied. Hence, the nature of the proposed tool allows it to be applied to other types of products in different healthcare environments, as the program will always consider factors such as quantity, rather than the type of item.

In the presentation sheet of the DSS, named "Help", the user can find information about the tool's functionalities, as well as the general instructions of its operation.

The second sheet, entitled "Data", presents a table in which the user must input the stock data. Information about the item identification code as well as its description and some statistical information, including the average demand for the item, replacement frequency, the frequency with which the inventory is present when requested, the amount of safety stock, standard deviation of daily demand and time between order and delivery must be inserted.

The user must collect the healthcare unit's statistical data (value and standard deviation) in advance, given that the developed DSS does not determine these values, but uses them as factors for some calculations.

In the "Stock Calculation" sheet, the information and the calculations from the "Data" sheet are automatically introduced, allowing the calculation of the maximum and minimum stocks, as well as the item's order quantity.

The ideal maximum and minimum stocks are calculated according to the item's data, through the Equations (1) and (2) [3][5], respectively.

$$Imax = \mu d * fr + Zp * \sigma d * \sqrt{\frac{7}{fr}} + S \quad (1)$$

$$Imin = Zp * \sigma d * \sqrt{\frac{7}{fr}} + S + \frac{\mu d}{24} * Tee \quad (2)$$

Therefore, μd represents the average demand, fr corresponds to the replacement frequency, Zp represents the relative frequency of an item's presence, when necessary, S represents the safety stock, σd corresponds to the standard deviation of demand and Tee comprises the time between the act of ordering and the actual delivery.

With the variables previously defined inputted by the user, and through the equations (1) and (2), the program can calculate and display the best maximum and minimum stocks for each product.

The DSS presents an item's division according to the demand level [3], with the order quantity being differently calculated, depending on the situation. So, when it comes to items whose demand is high, the order quantity will be given by Equation (3) [3]:

$$Qe = Imax - Ie \tag{3}$$

Where Qe represents the order quantity, $Imax$ refers to the maximum stock, and Ie to the existing stock. Since these products are more often replenished, the outstanding quantity is not considered.

When, however, the item's demand is considered low, the order quantity will be calculated using Equation (4) [3]:

$$Qe = Imax - Ie + Qp \tag{4}$$

Where Qe is the order quantity, $Imax$ is the maximum stock, Ie the existing stock, and Qp is the number of pending items.

The use of Equation (4), though, is only directed to situations where the existing stock is below the minimum level [3], meaning the program must take this event into account.

Once again, from the values previously inputted by the user (Ie and Qp) and the values formerly calculated by the system ($Imax$), the program will display, through the calculation of (3) or (4) depending on the case, the ideal order quantity.

The DSS was designed to, in addition to provide numerical data, give the user an easy perception of the stock's status. For this to be accomplished, and according to the results, some visual aids were added.

In the case of the existing stock, it was defined [3] that it would be worrying, in high demand products, the existing stock (Ie) to be equal to or below the optimal quantity (Qo) (5). Therefore, for the user to be alerted of such an occurrence, the tool will automatically fill in red the cell where this condition is verified, informing the user of the need to order that same product.

$$Ie \leq Qo \tag{5}$$

The economic order quantity (EOQ), in Equation (6), corresponds to the quantity that minimizes the cost [6]:

$$EOQ = \sqrt{\frac{2 \times k}{c_1}} \tag{6}$$

Where, k corresponds to the ordering cost and c_1 to the stock holding cost. Despite being an elemental formula, the economic order quantity reveals the integration of multiple strategic functions, including Tech SMED, through the inclusion of the fixed cost k [13].

Similar to the methodology applied in Equation (5), for low demand products, it is inadvisable [3] that the existing stock (Ie) is equal to or below the minimum stock ($Imin$) (7). The cell where this condition is verified will change its colour to red to advise the user. The cell colour will be green when this does not occur, advising that placing an order for this item is unnecessary.

$$Ie \leq Imin \tag{7}$$

The final value of the order quantity for a given product is accompanied by another visual system that makes it easier for the user to understand the supply's difficulty, according to the needed quantities.

The selected limits were as follows: when the order quantity varies between 0 and 25 units, the tool will activate the green flag, indicating that there should not be any problem in terms of supply. When the number is greater than 25, but less than 50, the yellow flag is shown to the user, drawing attention to the fact that it's already a considerable quantity to be ordered from the supplier. For orders that exceed 50 units of the same product, the system generates the appearance of a red flag, indicating the urgent nature of the order, since with these quantities, there may be problems in the immediate supply of the entire order.

This component of the model allows for a better understanding of the order's size, and the subsequent implications this may have on timely delivery.

Being a three-colour visual effect, the understanding of the flags' meanings is rather natural, as the chosen colours – green, yellow and red – are widely used in other aspects of life with the same connotation: green for no problems, yellow for attention must be payed and red for trouble.

That point brings a much-needed aspect, as because of its natural understanding, the user will not need to be checking the program's instructions to know what the displays mean.

The visual system with colours and flags allows the supply urgency's identification, which enables a much quicker detection if the required quantity is or not likely to cause supply problems.

Although the mentioned values are merely arbitrary, without complying with any study and/or rule, the quantities associated with potential supply problems must be fixed in an appropriate way, considering supply difficulties that the healthcare facility may have identified in the past.

III. Results

It was possible to verify that when the values were inserted in the "Data" sheet, they were correctly transferred to the "Stock Calculation" sheet. This allowed the program to properly calculate the optimal maximum and minimum stock quantities [15], as shown in Fig. 1.

Existing Stock
30
15
13
60
300
37
7
11
25
3

Fig. 1. Correct colouring of the cells corresponding to the amount of each product's existing stock, taking into account the value entered by the user, and equations (5) and (7).

The system was also able to, according to the values entered by the user in the "Data" sheet regarding the existing stock in the healthcare facilities, apply the inequalities (5) and (7) distinctly. As shown in Fig. 2, the correction in the coloured filling of the cells was verified, considering the results arising from the cell's value and the applied inequalities.

Order Quantity
50
70
0
40
0
0
7
28
0
80

Fig. 2. Correctly achieved display of flags with specific colours, relating to the order quantity.

In Fig. 3 is verified the correct appearance of the flags, which display different colours depending on the value ranges in which the order quantity falls.

The DSS correctly detected that in quantities ranging between 0 and 25 units, there should not be any supply problems. However, in quantities greater than 25 and less than 50 units of a given product, a yellow flag appears, indicating the need to pay some attention to this order. Once again, the system's correctness was verified, when in values greater than 50 units of the same item it showed a red flag, sign of the urgent nature of communication with the supplier, otherwise there would be problems in the immediate supply of the entire order.

It should be noted that in this type of calculation, again, different equations were used depending on whether the product was included in a high (3) or low demand (4) group.

Still, the tool displayed the flag with the correct colour in all studied scenarios.

In Fig. 4 is shown the table for the user to enter the data, present in the first sheet, called "Data". In the same way, Fig. 5 represents the tool that appears in the second sheet, "Stock Calculation", containing the entered data, the calculated results and the program's generated alerts, according to these same results.

	Item's Code	Item	Pm	Fr	Zp	Dp	S	Tee	Maximum Stock	Minimum Stock
High Demand	1520	Sterile Compress	5	15	0,8	12	3	15	85	13
	1532	Band-Aid	20	10	0,75	18	5	2	216	18
	1549	Surgical Adhesive Tape	3	1	1	0,7	3	24	8	8
	2248	Antiseptic Solution	50	5	0,9	2	25	24	277	77
	3062	Rubbing Alcohol 70%	80	5	1	1	7	16	408	62
Low Demand	8979	Saline Solution	5	7	1	2	3	5	40	6
	3547	Scissors	3	2	0,2	1,5	2	48	9	9
	9541	Clamp	7	2	0,8	1,5	6	14	22	12
	1985	Gloves	8	10	0,5	3	10	5	91	13
	3186	Non-elastic Bandage	10	5	1	4	8	6	63	15

Fig. 3. Calculation of maximum and minimum stock's ideal levels, through (1) and (2), with the user's entered data.

Item's Code	Item	Pm	Fr	Zp	Dp	S	Tee	Optimal Quantity	Existing Stock	Pending Quantity
1520	Sterile Compress	5	15	0,8	12,0	3	15	80	30	35
1532	Band-Aid	20	10	0,75	18,0	5	2	85	15	74
1549	Surgical Adhesive Tape	3	1	1	0,7	3	24	6	13	73
2248	Antiseptic Solution	50	5	0,9	2,0	25	24	100	60	38
3062	Rubbing Alcohol 70%	80	5	1	1,0	7	16	289	300	64
8979	Saline Solution	5	7	1	2,0	3	5	37	37	49
3547	Scissors	3	2	0,2	1,5	2	48	8	7	5
9541	Clamp	7	2	0,8	1,5	6	14	15	11	17
1985	Gloves	8	10	0,5	3,0	10	5	80	25	27
3186	Non-elastic Bandage	10	5	1	4,0	8	6	44	3	20

Fig. 4. Table presented to the user in the "Data" sheet for inputting data.

	Item's Code	Item	Pm	Fr	Zp	Dp	S	Tee	Maximum Stock	Minimum Stock	Existing Stock	Order Quantity
High Demand	1520	Sterile Compress	5	15	0,8	12	3	15	85	13	30	50
	1532	Band-Aid	20	10	0,75	18	5	2	216	18	15	70
	1549	Surgical Adhesive Tape	3	1	1	0,7	3	24	8	8	13	0
	2248	Antiseptic Solution	50	5	0,9	2	25	24	277	77	60	40
	3062	Rubbing Alcohol 70%	80	5	1	1	7	16	408	62	300	0
Low Demand	8979	Saline Solution	5	7	1	2	3	5	40	6	37	0
	3547	Scissors	3	2	0,2	1,5	2	48	9	9	7	7
	9541	Clamp	7	2	0,8	1,5	6	14	22	12	11	28
	1985	Gloves	8	10	0,5	3	10	5	91	13	25	0
	3186	Non-elastic Bandage	10	5	1	4	8	6	63	15	3	80

Fig. 5. Tool of the "Stock Calculation" sheet, which contains the entered data, the calculated results, and the program's generated alerts.

IV. CONCLUSION

As the data compiled through this article suggests, it was inferred that the development of a Lean-based philosophy algorithm was successful in all the proposed objectives. It was possible to demonstrate that this DSS managed to calculate with security, the necessary order quantities of the wide range of products that were chosen to test the proposed model. This way, it is possible to, at some point in the future, try to implement this same model in a practical, rather than a theoretical case study. However, it should be reported that this model works equally well with all the products used in this study, regardless of the eventual variations of its demand (high or low), as well as of their real, maximum, and minimum quantities. Notwithstanding these results, the main limitation of this DSS is the absence of real data. i.e., it was not possible to evaluate its efficiency and efficacy, neither quantify its real impact in cost reduction and improvements of productivity and quality of the services supplied to the patients of the healthcare facilities.

Having in consideration that stock maintenance is one of the costliest elements present in an organization, this tool could provide added value in the implementation of a Lean approach in healthcare management, allowing the user to identify the necessary order quantities correctly and easily from the different products in question, this way diminishing stock costs.

One of the key aspects of this algorithm is the availability in which it can be implemented in several different healthcare facilities, to solve similar logistical chain problems. Furthermore, another positive aspect of this DSS is the ease of use since it is based on one of the most common elements of informatics systems, the software Microsoft Excel, which also leads to being easily recognizable by eventual users.

For future research, it should be highlighted the inclusion of a prediction model for the calculation of the order quantities, as well as the optimum order time and the addition of an alert system of the incoming deadline of products.

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