APPLICATION OF THE DISCRETE EVENT SIMULATION INTEGRATED WITH LEAN CONCEPTS FOR IMPLEMENTING IMPROVEMENTS IN A MILITARY FIELD HOSPITAL

Aplicação da simulação de eventos discretos integrada com conceitos enxutos para a implementação de melhorias em um hospital militar de campo

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Abstract: Discrete Event Simulation (DES) and Lean applied in health services help the quality and efficiency of their services. The objective of this article is to use DES with the aid of Lean principles to analyze the structure of a military field hospital and to assess its ability to care for patients in case of environmental disasters. For this, the field hospital was simulated using FlexSim Healthcare® software and, with the aid of Design of Experiments (DoE), the optimal number of locations and resources was defined. The main measure of output was the total number of patients completely treated. Results showed that, as currently configured, the field hospital is unable to cope with the demand, as only 20.6% of patients (588 out of 2,855) were completely treated. However, after changing the decision variables, the percentage of fully treated patients increased to 93.6% (2673 out of 2,855), which means an increase of 355%. To achieve this result, the total number of locations increased by 162% (from 90 to 236), while the total number of human resources decreased by 52% (from 63 to 30).
Keywords: Discrete Event Simulation. Lean healthcare. Design of Experiments. Field hospital.

Resumo: A Simulação de Eventos Discretos (SED) e o *Lean* aplicados em serviços de saúde auxiliam na qualidade e na eficiência dos serviços prestados. Diante disso, o objetivo do artigo é utilizar a SED em conjunto com os princípios enxutos para analisar a estrutura de um hospital militar de campo e avaliar a capacidade desse hospital quanto ao atendimento de pacientes no caso de desastres ambientais. Para isso, o hospital de campo foi simulado no *software* FlexSim Healthcare® e, juntamente com o planejamento de experimentos (DoE), foi definido o número ideal de locais e de recursos. A principal medida de saída foi o número total de pacientes completamente tratados. Os resultados mostraram que, como está configurado atualmente, o hospital de campo não é capaz de lidar com a demanda, uma vez que apenas 20,6% dos pacientes (588 de 2.855) foram completamente tratados. No entanto, após alterar as variáveis de decisão, a porcentagem de pacientes completamente tratados aumentou para 93,6% (2.673 de 2.855), significando aumento de 355%. Para alcançar tal resultado, o número total de locais aumentou 162% (de 90 para 236), enquanto o número total de recursos humanos diminuiu 52% (de 63 para 30).
Palavras-chave: Simulação de Eventos Discretos. *Lean Healthcare*. Planejamento de experimentos. Hospital de campo.

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1. INTRODUCTION

Discrete Event Simulation (DES) is commonly used for studies and analysis of complex systems, such as manufacturing and transportation systems, banks and even hospitals (BANKS et al., 2010; SARGENT, 2013; LAW, 2015). DES has played an important role since the 1960s when it comes to health care (BRAILSFORD et al., 2009) and, not long ago, hospitals and health authorities became more aware of the potential of DES for improving the services provided (CHENG; DRIVE; RABE, 2016). Examples of studies that used DES in healthcare settings are found in the literature (HUSSEIN et al., 2017; BABASHOV et al., 2017; URIARTE et al., 2017). In addition, tools common to manufacturing can also be applied to healthcare. Lean Healthcare can be implemented in the solution and in the optimization of processes in these areas (GRABAN, 2013).

Lean applied in hospitals and health services can change very positively how these environments are organized and managed. The Lean Healthcare methodology provides hospitals with a shorter waiting time for patients, a reduction in errors made, and an increase in the quality of services provided (GRABAN, 2013). Furthermore, the DES stands out as a promising tool in predicting behaviors of stochastic processes that have processing times. This method brings dynamism to the current state map and the map of the future state of the process, allowing for the inference on how resources are being used and where is there waste (DOGAN; UNUTULMAZ, 2014).

Therefore, separately, DES and Lean have received increased attention in this area (ROBINSON et al., 2012). Filser, Silva and Oliveira (2017) identified more than 300 studies on Lean in the health area, 99% of which were published from 2002. Brailsford et al. (2009) estimate that there are about 44,000 articles on simulation in health care, more than 80% published from the 1990s. However, when integrated, Lean and DES build a synergistic relationship, leveraging its benefits. The possibility of evaluating the results of the proposed improvements in advance should be highlighted among the benefits of this integration for Lean, without the need to try them in the real system (BHAT; GIJO; JNANESH, 2014; BARIL et al., 2017; WANG et al., 2015; HADDAD et al., 2016). For DES, integration allows focusing on efficiency gains by eliminating waste, using Lean concepts and techniques (RAGHAVAN et al., 2010; BHAT; GIJO; JNANESH, 2014; YANG et al., 2015; HUANG ; KLASSEN; 2016).

With regard to healthcare environments, there are different types of hospitals, each designed to meet specific demands. Designed and managed by the United States Army, field hospitals (FH) are designed to serve people when natural disasters occur, as several hurricanes have hit the North American continent in recent years. FH need to provide immediate care to patients, and thus they need to be well designed so that they can efficiently cope with the demand of patients. Hurricane-stricken areas often lose their sources of electricity and access to clean water, communication, transportation, and distribution of food and medicine. Many of these distribution channels remained inert and inoperable for several days after the disaster. For this reason, every community must be prepared to provide immediate and lasting medical assistance to the populations affected by these events.

In this context, the objectives of this study were to analyze the structure of an FH and to evaluate its capacity and care of patients in the event of environmental disasters. In addition, the objective was also to evaluate and define the ideal number of resources and equipment needed, as well as the most appropriate layout for efficient service. Furthermore, the scope of the project aimed to enable the assistance of the largest possible number of patients without the resources being idle. For this, the scope of the study object was defined and the tools Lean Healthcare, DES and Design of Experiments (DoE) were applied together, to assess the current scenario and possible improvements for future scenarios of the studied hospital.

The article is divided as follows: section 1 presents the introduction and contextualization of the problem. Section 2 presents a literature review, defining DES and Lean Healthcare concepts and integration of these tools. Then, section 3 presents the methodology used, defined by Montevechi et al. (2007) and applied to the object of study, which is explained in section 4. Finally, in section 5, the conclusions of the work are presented.

2. BIBLIOGRAPHIC REVIEW

2.1. LEAN HEALTHCARE

According to Ohno (1997), the focus of Lean production is the elimination or minimization of waste, that is, eliminating any activity that does not add value to customers or users, but that adds cost to the product, whether in production or commercialization. Thus, activities can be divided into three groups: activities that add value, activities that do not add value, and activities that do not add value, but are necessary. Within the principles of Lean, Ohno (1997) classifies seven major wastes, being: overproduction, stock, waiting, transportation, handling, inefficient or unnecessary process, and defective processes.

These are the concepts of Lean Manufacturing, which when applied to healthcare systems are called Lean Healthcare. The aforementioned wastes are adapted for hospital environments (BERTRANI, 2012; GRABAN, 2013) and are explained according to Chart 1:

2.2. DISCRETE EVENT SIMULATION - DES

The simulation can be considered the imitation of a real system, which is modeled on a computer for carrying out later experiments to evaluate and improve the performance of this system (HARRELL et al., 2012). It can also be understood as the creation and observation of a real or hypothetical system to generate inferences regarding it (BANKS et al., 2010). This technique is extremely versatile and can be used to investigate any type of stochastic system. Such versatility has made simulation the most used operational research

Chart 1. Comparison between Lean Manufacturing and Lean Healthcare.

Waste	Manufacturing	Health services
Overproduction	Production above demand consumption capacity. It occurs by quantity or by anticipation.	Excessive monitoring in a patient who does not demand such care.
Storage	Excessive storage of goods. It harms customer service, causing waiting for information and products. May present transport and storage costs and material damage.	Exam results awaiting processing, patients waiting in line for care, expired materials and drugs that must be discarded.
Waiting	Long periods of inactivity, such as waiting for process, batch or operator, resulting in long lead times.	Waiting of the patient for release of the bed, result of exams, treatments or hospital discharge.
Transportation	Unnecessary and/or excess transport of goods and/or information, resulting in increased costs, time and efforts.	Excessive transportation of exams, medications and patients that can be caused by improper layout.
Movement	Excessive and/or unnecessary movements of employees in the system. Include physical efforts during the manufacturing process.	Excessive movement of doctors, nurses and assistants, due to poorly organized jobs.
Inefficient or unnecessary process	Procedures performed incorrectly; do not add value to the customer.	Inefficient use of medication, surgical cart with missing item, ordering tests that are not needed.
Defective processes	Generate products outside the customer's specification, either in product quality or delivery performance.	Inadequate examinations, time/date data posted on forms, but never used.

Source: adapted from Bertrani (2012) and Graban (2013).

technique for studies dealing with random systems (HILLIER; LIEBERMAN, 2001). For Law (2015) and Bloomfield et al. (2012), simulation is an alternative to direct experimentation in the real system, thus avoiding costs due to experimentation and interrupting the flow of activities in the real system.

Among the advantages of the simulation, the following stand out: the decision rules and the possibility to explore the information flows and the organizational procedures explored without interrupting the real system; to test physical layouts and transportation systems without compromising resources; to test the hypotheses as to the feasibility of implementation; to expand or compress the time for the investigation of phenomena; to study the importance of variables for system performance and answer "what-if" questions (BANKS et al., 2010). That is, in addition to providing a complete view of the system, the simulation allows decision makers to view the results even before their implementation (LAW, 2015).

2.3. LEAN HEALTHCARE AND DISCRETE EVENT SIMULATION

The integration of DES with Lean in health services assists in implementing Lean concepts on three major fronts: assess, facilitate and teach (ROBINSON et al., 2012). Thus, the use of simulation and Lean Healthcare in hospital environments can bring more safety, quality, and efficiency for both patients and managers (GABA, 2004). In addition, this use can optimize the flow of patients and serve as a motivational factor for employees (SALAM; KHAN, 2016). Swick et al. (2012) state that hospitals that integrate the two tools offer an efficient method of strategic planning and provide employees with a privileged view of how to reduce waste and add value. Still, it is possible to decrease the waiting time for patients, reducing the workload of employees and promoting the reallocation of resources (BHAT; GIJO; JNANESH, 2014; HADDAD et al., 2016).

3. METHOD

Modeling and Simulation, a technique used in the study, can be divided into three major phases: Conception, Implementation and Analysis (MONTEVECHI et al., 2007). In the first big phase, that is, the Conception, the first step to be carried out is the formulation of the problem. At this stage, the process to be modeled is defined, so that the actions and objectives can be specified (BALCI, 2011). The second stage is the construction and documentation of the conceptual model, followed by the validation of the model. Many techniques can be used for documentation, however, choosing a technique focused on simulation is ideal (MONTEVECHI et al., 2007). The last stage of the Conception is the modeling of the input data, which can be time, cost, percentages, capacities, among others, varying according to the objective of each study (BANKS et al., 2010; MONTEVECHI et al., 2007).

The second major phase, called Implementation, covers the stages of construction, verification, and validation of the computational model. The construction of the computational model must be performed in software with which the modeler is familiar. Then, verification is necessary, which will ensure that the programming of the computational model corresponds to the conceptual one (SARGENT, 2013). Finally, the validation of the computational model can be performed through hypothesis tests, confidence intervals, comparison charts, among others (SARGENT, 2013).

The last major phase, called Analysis, begins with the planning, construction and analysis of the experiments. In this phase, possible scenarios are elaborated, in addition to using experiment planning (DoE) and statistical tests (MONTGOMERY; RUNGER, 2018). After the experiments, the scenarios are analyzed, thus obtaining the conclusions and answers to the problem defined in the Conception stage.

4. RESULTS AND DISCUSSION

4.1. CASE STUDY

The current FH consists of 12 tent units, which are coupled together, forming the structure of the hospital. It is estimated that the FH is capable of treating between 300 and 500 patients per day. In order to provide care, it is necessary to pay attention to the different types of patients, who can remain in the hospital for up to 48 hours. Thus, it is assumed that patients receive first care at the FH facilities and, as soon as possible, are referred to the nearest health units.

Each patient who arrives at the FH goes straight into the Screening area. There, patients are assessed for their initial condition and registered at the hospital. Patients are classified according to the severity of their injuries and then referred to specific areas. If the patient's severity is considered low, he is referred to the emergency room (ER) for superficial care, followed by discharged. If the patient's severity is considered medium and there is a need for specific treatment, such as sutures, plaster, among others, they are sent to the ER, and then taken to the appropriate sector. Finally, if the patient's severity is high, they are directed to the specific care area, which will depend on the type of care needed.

High severity patients can be referred to different areas. If the patient is suffering from a heart attack or other situation that requires immediate care and monitoring, the patient will be accompanied to the cardiac unit (CU) or to the extreme care ward (ECW). Women in labor are referred to the maternity (MA) ward. Patients in need of surgical care are directed to the pre-surgical sector (PS) and after surgery, taken to the postoperative sector (PO) for recovery. Patients who need specialized doctors are referred to the minimal care (MCW) and intermediate care (ICW) wards. In these cases, patients belonging to MCW are discharged after 24 hours, while those belonging to ICW are discharged after 48 hours of observation. Finally, patients who are considered critical, but who do not fit the cases described, are referred to the ER.

It is worth mentioning that all patients who are in the specific care areas must be duly registered. If there are inconsistencies in the record, the admission and discharge team (AD) is responsible for regularizing such record in the bed itself; also, laboratory tests are performed. The flow of each specific service area for cases of patients considered critical is described below:

- CU and ECW: the patient, after arriving at the CU or the ECW, receives an initial assessment made by the group of nurses, then undergoes regular assessment by nursing technicians until they are transferred to a health unit with more resources. Such transfer is performed with air support, depending on the risks to which the patient in this condition is exposed;
- ICW: the flow of the patient in this case is similar to the flow of the CU and the ECW; however, the patient is referred to the nearest health unit after 24 hours, with the help of an ambulance;
- MCW: in this case, the flow is also similar to that of the ICW; however, the patient can be referred to the nearest health facility after 48 hours, with the help of an ambulance (15% of cases), or receives discharge and return home (85% of cases);
- MA: the woman in labor is referred to an available bed, where she will undergo laboratory tests and the baby's information will also be recorded. After the pre-delivery time, the woman is taken to the delivery room and, after delivery, returns to the bed to recover, while the baby goes to the crib and waits for the mother's recovery time to be taken to her.
- PS and PO: before surgery, the patient is submitted to laboratory exams and X-rays, then waits until the time of surgery in the PS area. Then, the patient goes into the operating room (OR), where the procedure is performed. At the end of the procedure, they are directed to the PO area to recover. After this period, the patient can be referred to the MCW (50.16% of the cases), the ICW (37.84% of the cases), and the ICU (12% of the cases);
- ER: patients, upon arriving at the ER, wait in a waiting chair until a medical assessment of their condition is carried out. After evaluation, they can be directed to the suture area (about 10% of cases), where they are discharged after the procedure. Patients can also be directed to the malaise (55% of cases) or to the infection treatment areas (20% of cases), where they are then directed to the MCW. Finally, patients can be referred to a psychological treatment area (3% of cases) or to a fracture area (12% of cases), and subsequently taken to the ICW.

4.2. CONCEPTION

The study aimed to analyze the structure of a FH and to evaluate the capacity of that hospital regarding the care of patients in the case of environmental disasters. Other issues to be resolved are: the ideal number of employees and equipment, the most appropriate layout, and the improvement of patient care according to the capacity of human resources. The construction and documentation of the process that patients go through (described in section 4.1) was performed using IDEF-SIM (LEAL, 2008; MONTEVECHI et al., 2007). Figure 1 shows the conceptual model of the system.

The validation of the conceptual modeling was done through face-to-face validation, in which the specialists verify if the model in fact matches the real system. The collection and modeling of the data were made according to other natural disasters that occurred on the continent. Historical data has undergone data processing, in which the best statistical distributions have been linked.

4.3. IMPLEMENTATION

The computational model was built using the FlexSim Healthcare® software. This package was used due to its interface and ease of programming in relation to health services. The model was verified by specialists. For validation, the model was simulated and validated using historical data. Figure 2 presents the screen of the current state of the computational model.

4.4. ANALYSIS

After the model was validated and simulated for a week, it was possible to obtain the metrics for the first analyses. Therefore, it can be said that the hospital is unable to meet the expected demand. Thus, the results obtained were:

- On average, 2,855 patients arrived at the model;
- On average, 588 (20.6%) patients completed their treatments;
- About 2,202 patients (77.01%) have not even been screened;
- 65 patients (2.9%) started treatment, but did not finish it.

After a few executions, it was noted that human resources were significantly idle, indicating that they may not be a limiting feature. What can also be said for the layout characteristics

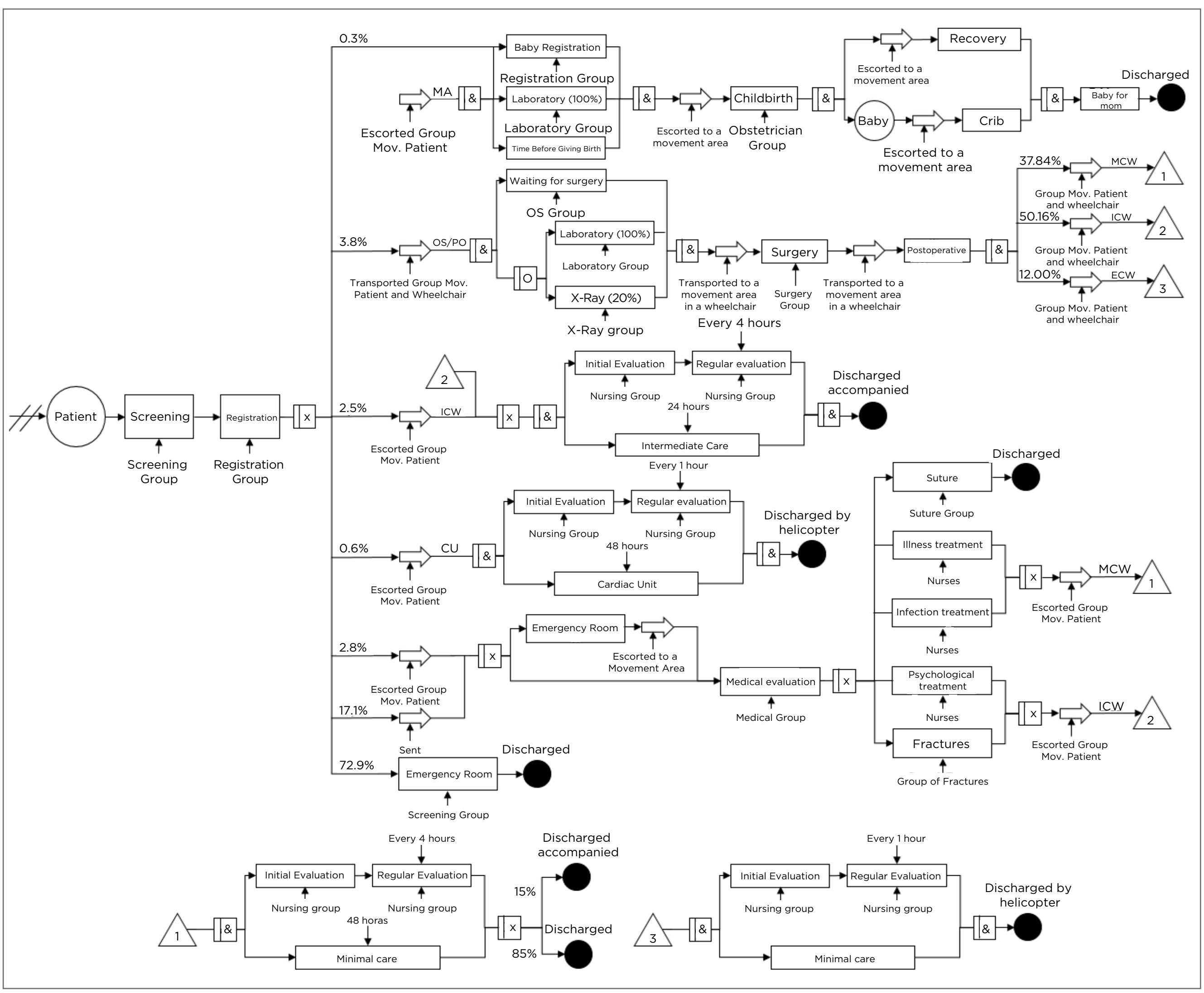

Figure 1. Conceptual modeling of the simulated process.

and transport times. On the other hand, the MCW, OR, and screening areas were occupied most of the time. In addition, it was identified that there is a long wait for assistance in the areas mentioned

However, investigating the reasons why patients wait for care, a possible relationship between the areas was noted. Thus, when fully occupied, the MCW blocks the predecessor areas, causing a sequential effect that returns to screening. In fact, the number of MCW beds (19) is insufficient in the current state. On average, 67.3 patients require these beds per day, and each patient remains there for approximately 48 hours. Thus, about 135 beds are needed to satisfy the demand for this type of patient. However, this calculation considers only the mean estimate, which does not include the variability of the model

4.4.1. Analysis and experiments for locations

DoE techniques were used to explore the variables related to the number of places (beds, tables, and chairs) in each area, since human resources and layout were not identified as the limiting characteristics. The chosen variables are shown in Table 1.

The numbers of required locations were determined in a deterministic manner in relation to the demand for each area using Equation 1. The results were rounded up to the next whole value and are also shown in Table 1.

$$Qi = \frac{P_i * t_i}{24h} \tag{1}$$

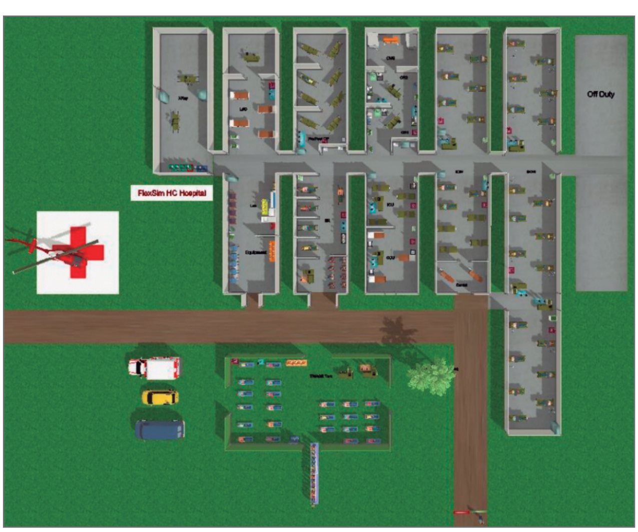

Figure 2. Screen of the computational model: current state

Where:
Qi = Number of sites in area *i*;
Pi = Mean daily number of patients arriving in area *i*;
ti = Time (in hours) that the patient remains in area *i*.

Based on the results presented in Table 1, the variables OR, CU and beds for labor from the DoE were chosen to be excluded, since the ideal number needed for these locations is similar to the current scenario. Thus, the variables were redefined as shown in Table 2. The central points were defined according to the ideal number for each location (Table 1). A margin of 20% of the central points was used to define "level -" and "level +". The results were rounded up and down, respectively. The minimum number of locations was established as one and the need for human resources in these experiments was eliminated, since they were idle in the first executions.

A fractional factorial arrangement (fraction 1/8, resolution IV) was performed to screen the significant variables, resulting in 32 experiments. According to Figure 1, there are seven types of patients who follow seven different flows. Thus, the number of patients seen by each flow was used as a parameter for the DoE. After the analysis and based on the Pareto graphs generated for each DoE, variables B, F and G were eliminated, since they were not significant for the model.

Table 1. Variables related to the locations in each area.

Variables	Current	Necessary
Beds (MCW)	19	135
Beds (ICW)	13	28
Beds (OR)	2	2
Beds (ECW)	4	2
Beds (CU)	3	2
Beds (PS)	8	3
Beds (ER)	5	2
Waiting room (ER)	8	16
Recovery beds (MA)	4	1
Beds for labor	1	1
Beds (Screening)	23	5
Total	90	197

A response surface was defined using the centered face experiment (CFC) arrangement, in which the numbers of locations have a minimum, maximum and a central point. Using this arrangement, it was possible to obtain 10 central points and 10 axial ones, which resulted in another 20 experiments. It was decided to use this methodology to test the midpoints of each factor. Figure 3 shows one of the surfaces analyzed, which corresponds to decision variables D (PS beds) and E (ER beds) and the answer for the patient who needs intermediate care. In this case, it was observed that there is a curvature, indicating an optimum point.

For optimization, a multiobjective approach was adopted by using the metamodels obtained in the DoE. These metamodels were combined using global criteria (RAO, 2009). The weights of each function were established using the canonical mixing polynomials method (TORRES et al., 2016). The optimal values of the variables and the results of the optimization for the one-week simulation are shown in Tables 3. The values of variables B, F, and G were defined as "level-", since they were not considered significant after the analysis of the DoE.

After defining the ideal number of locations, the results obtained were:

- On average, 2,855 patients arrived at the model;
- On average, 2,674 (93.7%) patients completed their treatment;
- All patients (100.0%) underwent screening;
- 181 patients (6.3%) started treatment, but did not finish it.

Despite the improvements observed after the experiment, it is noted that patients still wait a long time for care, especially in the OR, PS, ER, and screening areas. Therefore, it was decided to increase the number of sites in these areas. In addition, other final adjustments were made, for which it was decided to change the variables referring to the beds of ICW, ECW, MA, and CU, according to Table 4.

4.4.2. Analysis and experiments for resources

Based on the results obtained after the adjustments, human resources were tested, as defined in the current scenario. However, even after increasing the number of locations, employees still found themselves stranded. Thus, it was decided to analyze the impact of these resources by reducing these groups through new simulation rounds. The changes were made based on the resource occupation rate. One type of resource was analyzed at a time, starting with the most specialized. After a few cycles, the changes were summarized and are shown in Table 5.

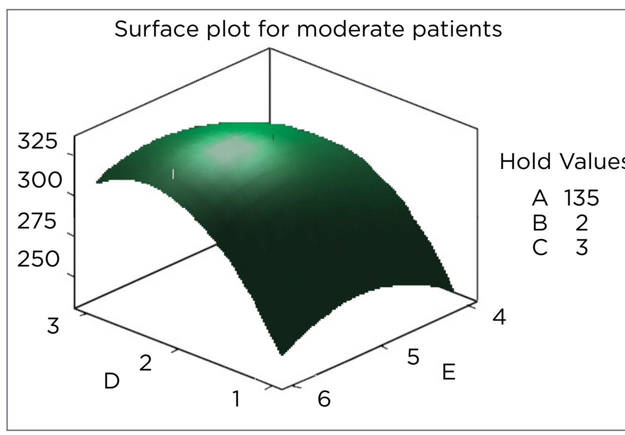

Figure 3. Response surface.

Table 2. Levels of design of experiment (DoE) variables for locations.

Variables	Description	Level -	Central point	Level +
A	Beds (MCW)	108	135	162
B	Beds (ICW)	22	28	34
C	Beds (ECW)	1	2	3
D	Beds (PS)	2	3	4
E	Beds (ER)	1	2	3
F	Waiting chairs (ER)	12	16	20
G	Recovery beds (MA)	1	2	3
H	Beds (Screening)	4	5	6

After defining the ideal number of resources and the model's being simulated again for a week, it can be observed that:

- On average, 2,855 patients arrived at the model;
- On average, 2,673 (93.6%) patients completed their treatment;
- All patients (100.0%) underwent screening;
- 182 patients (6.3%) started treatment, but did not finish it.

4.4.3. Confirmation experiments

To confirm the proposed modifications, the model was simulated 30 times over a week. According to the data observed in Table 4, the total number of locations increased by 162.0%, but, as shown in Table 5, the total number of human resources was reduced by 52.4%.

According to the simulation results, an increase in waiting necessary in the ER (50.0%) and beds in the OR (50.0%), in the CU (66.7%), in the ICW (153.8%), and in MCW (700.0%). However, there was a need to reduce beds in screening, in MA, ER and PS by 34.8, 50, 20, and 37.5%, respectively. Regarding the ECW, there was no need for changes. As for human resources, changes were not required for assistants, surgical technicians, and administrative technicians. For the other resources, there was a reduction of 20.0% for doctors, 42.3% for nurses, 91.6% for nursing technicians, 50.0% for X-ray technicians, 66.7% for laboratory technicians, and 87.5% for support technicians.

For the final comparison between the current and the future state, in addition to the previously mentioned metrics, the waiting time for each type of patient was included. Table 6 presents the results of both the current and the future scenario, illustrating that there was a reduction in the patient's length of stay during the procedure (min).

Figure 4 shows the layout for the future state of the FH.

Table 3. Optimal values for the location variables.

Variables	Description	Optimal value
A	Beds (MCW)	152
B	Beds (ICW)	22
C	Beds (ECW)	3
D	Beds (PS)	3
E	Beds (ER)	2
F	Waiting chairs (ER)	12
G	Recovery beds (MA)	1
H	Beds (Screening)	5

Table 4. Number of locations in the current scenario and in the future.

Beds and chairs	Scenarios	
	Current	Future
Beds (Screening)	23	15
Recovery beds (MA)	4	2
Waiting chairs (ER)	8	12
Beds (ER)	5	4
Beds (PS)	8	5
Beds (OR)	2	3
Beds (ECW)	4	4
Beds (CU)	3	5
Beds (ICW)	13	33
Beds (MCW)	19	152
Total	90	236

Table 5. Number of human resources in the current and future scenarios.

Human resources	Scenarios	
	Current	Future
Doctors	5	4
Assistants	2	2
Nurses	26	15
Nursing technicians	12	1
Surgical technicians	2	2
X-ray technicians	2	1
Laboratory technicians	3	1
Support technicians	8	1
Administrative technicians	3	3
Total	63	30

5. CONCLUSION

The present work aimed to use the integration of DES with lean concepts in a hospital environment. For this, the object of study chosen was a FH, which aimed to analyze the structure and to evaluate the capacity of this hospital regarding the care of patients in the case of environmental disasters.

The Discrete Event Simulation methodology defined by Montevechi et al. (2007) was used in the study, which was divided into three major phases: Conception, Implementation, and Analysis. In the Conception phase, the objectives were defined, namely: ideal number of employees and equipment; more appropriate layout and improvement of patient care according to the capacity of human resources. The conceptual model was built using the IDEF-SIM modeling technique, and the input data was obtained using historical data from other situations in which a FH was needed. In the Implementation phase, the model was simulated in the FlexSim Healthcare® software and also validated through historical data.

For the Analysis phase, the DoE was used to verify the variables that were most influenced in the expanding locations. Experiments were used to determine the ideal number of human resources. Thus, it can be said that the model in its current state does not have the capacity to meet the required demand. Despite this, the proposed model provides adequate support for this need, since it has improved the service to demand from 20.6 to 93.6%. All the questions proposed in the objective were answered and, using Lean principles, there was a significant improvement in the studied process.

Regarding the limitations of this study, difficulties were found in the execution of the replicas due to the computational effort required. For this reason, only one replica was performed in the current state model. In addition, the length of stay of patients was chosen as a measure of FH performance, since it is the most critical metric from the patient's

Figure 4. Screen of the computational model: future state.

Table 6. Outputs for the current and future scenarios.

Outputs	Scenarios	
	Current	Future
Length of stay of pregnant women (MA)	0.2	13.1
Length of stay for surgical patients (PO)	5023.6	77
Length of stay for patients with minimal severity (MCW)	2073.4	22.9
Length of stay for cardiac patients (CU)	3140.5	12.5
Length of stay for patients with high severity (ECW)	5019.2	58.3
Length of stay for patients with intermediate severity (ICW)	5525.2	58.2
Length of stay of patients in the emergency room (ER)	2431.2	2.8
Total patients attended	588	2673
Total locations	90	236
Total human resources	63	30

point of view. However, having a high outflow of patients does not necessarily mean that they are being treated properly. This is because the arrival of patients is irregular and the waiting time can be long.

Finally, for future work, it is suggested that different layouts are tested in order to assess the displacement of patients, human resources, and equipment. In addition, it is suggested to use the design of experiments to assess and optimize the amount of human resources and to assess whether there is an influence on the interactions of these resources with the different changes to be made.

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REFERENCES

BABASHOV, V.; AIVAS, I.; BEGEN, M.A.; CAO, J.Q.; RODRIGUES, G.; D'SOUZA, D.; LOCK, M.; ZARIC, G. S. Reducing Patient Waiting Times for Radiation Therapy and Improving the Treatment Planning Process: a Discrete-event Simulation Model (Radiation Treatment Planning). *Clinical Oncology*, v. 29, n. 6, p. 385-391, 2017. https://doi.org/10.1016/j.clon.2017.01.039

BALCI, O. How to successfully conduct large-scale modeling and simulation projects. *In*: WINTER SIMULATION CONFERENCE, 2011. *Anais* [...]. Phoenix, 2011.

BANKS, J.; CARSON II, J.S.; NELSON, B.L.; NICOL, D.M. *Discrete-event Simulation*. 5. ed. Nova Jersey: Pearson Prentice-Hall, 2010. 622 p.

BARIL, C.; GASCON, V.; MILER, J.; BOUNHOL, C. The importance of considering resource's tasks when modeling healthcare services with discrete-event simulation: An approach using work sampling method. *Journal of Simulation*, v. 11, n. 2, p. 103-114, 2017. https://doi.org/10.1057/jos.2016.6

BERTRANI, T.M. *Lean Healthcare: recommendations for implementations of the concepts of Lean Production in hospital environments*. 166f. Tese (Doutorado) – Escola de Engenharia de São Carlos, Universidade de São Paulo, São Carlos, 2012.

BHAT, S.; GIJO, E.V.; JNANESH, N.A. Application of Lean Six Sigma methodology in the registration process of a hospital. *International Journal of Productivity and Performance Management*, v. 63, n. 5, p. 613-643, 2014. https://dx.doi.org/10.1108/IJPPM-11-2013-0191

BLOOMFIELD, R.; MAZHARI, E.; HAWKINS, J.; SON, Y.J. Interoperability of manufacturing applications using the Core Manufacturing Simulation Data (CMSD) standard information model. *Computer & Industrial Engineering*, v. 62, n. 4, p. 1065-1079, 2012. https://doi.org/10.1016/j.cie.2011.12.034

BRAILSFORD, S.C.; HARPER, P.R.; PATEL, B.; PITT, M. An analysis of the academic literature on simulation and modelling in health care. *Journal of Simulation*, v. 3, n. 3, p. 130-140, 2009. https://doi.org/10.1057/jos.2009.10

CHENG, R.; DRIVE, E.; RABE, M. Simulation: the Past 10 Years and the Next 10 Years. *In*: WINTER SIMULATION CONFERENCE, 2016. *Anais* [...]. Washington, D.C., 2016.

DOGAN, N.O.; UNUTULMAZ, O. Lean production in healthcare: a simulation-based value stream mapping in the physical therapy and rehabilitation department of a public hospital. *Total Quality Management & Business Excellence*, v. 27, n. 1-2, p. 64-80, 2014. https://doi.org/10.1080/14783363.2014.945312

FILSER, L.D.; SILVA, F.F.; OLIVEIRA, O.J. State of research and future research tendencies in lean healthcare: a bibliometric analysis. *Scientometrics*, v. 112, n. 2, p. 799-816, 2017. https://doi.org/10.1007/s11192-017-2409-8

GABA, D. The future vision of simulation in health care. *Quality and Safety in Health Care*, v. 13, Supl. 1, p. 2-10, 2004. https://doi.org/10.1136/qhc.13.suppl_1.i2

GRABAN, M. *Hospitais Lean:* melhorando a qualidade, a segurança dos pacientes e o envolvimento dos funcionários. 2. ed. Porto Alegre: Bookman, 2010. 312 p.

HADDAD, M.G.; ZOUEIN, P.P.; SALEM, J.; OTAYEK, R. Case Study of Lean in Hospital Admissions to Inspire Culture Change. *Engineering Management Journal*, v. 28, n. 4, p. 209-223, 2016. https://doi.org/10.1080/10429247.2016.1234896

HARRELL, C.; GHOSH, B.K.; BOWDEN, R. *Simulation using ProModel*. 3. ed. Nova York: McGraw-Hill Education, 2012. 704 p.

HILLIER, F.S.; LIEBERMAN, G.J. *Introduction to operations research*. 7. ed. Nova York: McGraw-Hill, 2001. 976 p.

HUANG, Y.; KLASSEN, K.J. Using six sigma, lean, and simulation to improve the phlebotomy process. *Quality Management Journal*, v. 23, n. 2, p. 6-21, 2016. https://doi.org/10.1080/10686967.2016.11918468

HUSSEIN, N.A.; ABDELMAGUID, T.F.; TAWFIK, B.S.; AHMED, N.G.S. Mitigating overcrowding in emergency departments using Six Sigma and simulation: A case study in Egypt. *Operations Research for Health Care*, v. 15, p. 1-12, 2017. https://doi.org/10.1016/j.orhc.2017.06.003

LAW, A. *Simulation modeling and analysis*. 5. ed. Boston: McGraw-Hill Education, 2015. 804 p.

LEAL, F. *Análise do efeito de falhas em processos de manufatura através de projeto de experimentos simulados*. 237f. Tese (Doutorado em Engenharia de Produção) – Universidade Estadual Paulista "Júlio de Mesquita Filho", Guaratinguetá, 2008.

MONTEVECHI, J.A.B.; PINHO, A.F.; LEAL, F.; MARINS, F.A.S. Application of design of experiments on the simulation of a process in an automotive industry. *In*: WINTER SIMULATION CONFERENCE, 2007. *Anais* [...], Washington, D.C., 2007.

MONTGOMERY, D.C.; RUNGER, G.C. *Applied Statistics and Probability for Engineers*. 7. ed. Hoboken: Wiley, 2018. 976 p.

OHNO, T. *O Sistema Toyota de Produção:* Além da produção em massa. Porto Alegre: Bookman, 1997. 150 p.

RAGHAVAN, V.A.; VENKATADRI, V.; KESAVAKUMARAN, V.; WANG S.; KHASAWNEH, M.; SRIHARI, K. Reengineering the Cardiac Catheterization Lab processes: A lean approach. *Journal of Healthcare Engineering*, v. 1, n. 1, p. 45-65, 2010.

RAO, S.S. *Engineering Optimization:* Theory and Practice. 4. ed. Nova Jersey: John Wiley, 2009. 813 p.

ROBINSON, S.; RADNOR, Z.J.; BURGESS, N.; WORTHINGTON, C. SimLean: Utilising Simulation in the Implementation of Lean in Healthcare. *European Journal of Operational Research*, v. 219, n. 1, p. 188-197, 2012. https://doi.org/10.1016/j.ejor.2011.12.029

SALAM, M.A.; KHAN, S.A. Value creation through lean management: a case study of healthcare service operations. *International Journal of Services and Operations Management*, v. 25, n. 3, p. 275-293, 2016. https://doi.org/10.1504/IJSOM.2016.10000239

SARGENT, R.G. Verification and validation of simulation models. *Journal of Simulation*, v. 7, n. 1, p. 12-24, 2013. https://doi.org/10.1057/jos.2012.20

SWICK, M.; DOULAVERIS, P.; BAGNALL, T.; WOMACK, D. Application of Simulation Technology to Enhance the Role of the Professional Nurse. *The Journal of Nursing Administration*, v. 42, n. 2, p. 95-102, 2012. https://doi.org/10.1097/NNA.0b013e3182433706

TORRES, A.F.; GOMES, J.H.F.; CAMPOS, P.; PAIVA, A.P. Otimização multiobjetivo com identificação de pesos ótimos: aplicação em um processo de torneamento de aço endurecido. *In*: SIMPÓSIO BRASILEIRO DE PESQUISA OPERACIONAL, 48., 2016. *Anais* [...]. Vitória, 2016.

URIARTE, A.G.; ZÚÑIGA, E.R.; MORIS, M.U.; NG, A.H.C. How can decision makers be supported in the improvement of an emergency department? A simulation, optimization and data mining approach. *Operations Research for Health Care*, v. 15, p. 102-122, 2017. https://doi.org/10.1016/j.orhc.2017.10.003

WANG, T.; YANG, T.; YANG, C.; CHAN, F.T.S. Lean principles and simulation optimization for emergency department layout design. *Industrial Management and Data Systems*, v. 115, n. 4, p. 678-699, 2015. https://doi.org/10.1108/IMDS-10-2014-0296

YANG, T.; WANG, T.; LI, V.C.; SU, C.L. The Optimization of Total Laboratory Automation by Simulation of a Pull-Strategy. *Journal of Medical Systems*, v. 39, n. 1, p. 162, 2015. https://doi.org/10.1007/s10916-014-0162-6