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SIMULATION AS A HOSPITAL MANAGEMENT SUPPORT TOOL

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ABSTRACT

This study aims to demonstrate the use of the discrete event simulation technique as a hospital management support tool, as well as all complex processes existing in a health unit. There must be an analysis of the system as a whole from the perspective of service level provided to patients regarding waiting times. The role of this technique is to show the behavior of a given system. Data were collected from employees of a public Polyclinic, located in a city of the greater São Paulo, by means of interviews which questions were prepared to determine the time spent in the processes of the service system. Such data were inserted in the software Arena in flowchart format for analysis and identification of the problem. Since the person responsible for the screening process was overloaded, thus causing longer waiting times for patients submitted for screening, some changes were made in the model in order to propose an improvement, to balance the occupancy levels of the health unit's staff and, at the same time, reach a shorter withdrawal period of patients throughout the system. Results showed a significant improvement in the performance of the Polyclinic's system, as well as a subsequent improvement in the level of service provided to patients. Based on this study, one can note that simulation allows for evaluating scenarios and projecting changes that will impact the behavior of a certain system with no physical changes, thus preventing the lack of scientific basis when making management decisions and allowing for improvements.

Keywords: Operations Research; Simulation; Software Arena; Hospital Management.

1. INTRODUCTION

In every organization, it is fundamental to improve processes, service levels, and operation efficiency on a continuous basis. However, it may be difficult to do so when the manager lacks a clear and holistic view of the organization's operations. At this point, Operations Research (OP) may play an important supportive role through quantitative techniques and tools for the analysis of processes implemented by organizations, allowing for improvements that may not be very clear at first sight.

In the last few years, there has been increased interest in OP-based techniques, especially because of recent software developments that help with the calculation process of many optimization methods. This is not enough though, since one of the biggest challenges is lack of knowledge in the field, mainly when it comes to simulation techniques. This study shows the implementation of simulation in a public polyclinic. In addition to showing its implementation, this study aims at showing how significant this technique is for the analysis of scenarios and improvements in the service process of a basic healthcare system selected due to its importance for the society in general.

The first part of this article addresses the theoretical grounding of Operations Research, as well as the basis for this simulation, which was selected for this study from a number of OP techniques. Next, there will be an approach to some of the many simulation software applications created in the past few years, with special emphasis on Arena. Following, there will be a brief approach to hospital management by virtue of the methodology used, i.e., the case study of a health unit.

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Following the study of the current situation of the unit's system and the identification of the bottleneck, i.e., the most overloaded employee (including which queue has longer waiting times), system improvements will be proposed in order to remove such bottleneck and balance the occupancy levels of resources available at the Polyclinic, while a greater service level is provided to patients.

2. THEORETICAL GROUNDING

2.1. Operations Research

Looking for improvements in the processes of a system is no easy task for managers. The greater the complexity of a problem, the more responsibility the decision requires. Operations Research is an applied quantitative science that can be useful in such a difficult task. As the name suggests, it studies operations, providing optimization tools and techniques based on mathematical models for a clearer and more objective view of the scenario at matter, thus providing a more solid basis for making decisions that require great responsibility.

This science is widely used by governments, industries, service companies, and business companies. With systemic focus on study issues, it attempts to find the optimal solution using a teamwork methodology that comprises Engineering, Statistics, Mathematics, Computing, and Economics (MARINS, 2011).

> Operations Research as we know it came into being during World War II, as a result of studies carried out by interdisciplinary teams of scientists hired to solve military issues of strategic and tactical nature (SILVA et al., 1998, p.11)

As mentioned before, OP uses models that enable the analysis of decisions, meaning that a decision can be tested and evaluated before being implemented, thus reducing the risks of possible losses because of decisions made by the manager. It is worth to emphasize that the progress of Operations Research in recent years is because the evolution of computers made it possible to design software applications that significantly help with the calculations of many techniques provided by this science due to its data processing and storage abilities (REZENDE FILHO, 2006).

Among the many OP-based techniques, one can mention linear programming in issues relating to production line optimization, production scale, transportation, maximum flow, shorter path, etc. All these problems have direct impact on

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calculations (maximizing or minimizing), and the result provides managers with the optimal solution, i.e., the best distribution of resources available based on system demands and characteristics, in order to meet the study goal (LACHTERMARCHER, 2009).

Accordingly, this work will show exactly the significance of implementing one of the OP-based techniques with the help of one of the many software applications created in the last few years.

2.2. Discrete Events Simulation

Discrete events simulation is a technique not as objective as linear programming. It is originated from an old theory within Operations Research: the queueing theory.

"This theory addresses system queueing issues, which main characteristic is the presence of 'customers' requesting 'services' somehow" (ANDRADE, 2009).

"In the context of the queueing theory, when one uses the word 'queue', one is referring to the set of customers that will be waiting for the service [...], in addition to that one who is being served" (CAIXETA-FILHO, 2004).

> *Queueing theory* is the study of waiting in various guises. It uses *queueing models* to represent the various types of *queueing systems* (systems that involve queues of some kind) that arise in practice. Formulas for each model indicate how the corresponding queueing system should perform, including the average amount of waiting that will occur, under a variety of circumstances (HILLIER; LIEBERMAN, 2010, p. 1)

Queues can be observed in a series of situations. Not only in people's everyday lives, clinical offices, banks, dental offices, etc., but also in the industry, such as productive systems, facilities planning, inventories, work force, etc. Discrete events simulation helps one to consider these scenarios by showing in a clear, objective, and quantitative manner the study system behavior, the occupancy percentage of resources used, the size of queues, waiting times, number attended, average and maximum travel time within the system, and many additional information that is important for managers.

Simulation is used mainly when system changes are too expensive or difficult to be implemented. This technique allows one to test many changes in the study system model, as well as to analyze which combinations render the best results. Subsequently, one can observe all the effects of these changes over the system

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without taking any unwanted cost-related risks, which would mean a loss (SILVA et al., 1998).

2.3. Simulation Software

According to Prado (2009), the study of system simulation has two stages. First, the analyst should build a model, feed data into it, and collect other data that are identical to the ones of the study system. The second stage consists of changing the model so that, based on the results obtained, one can perform analyses that will yield recommendations and a conclusion.

Arena is a graphic simulation and animation software created by Rockwell and distributed by Paragon.

According to Prado (1999), SIMAN is a simulation language, which, in 1983, gave name to the first simulation program for personal computers (PCs). Created in 1984, CINEMA was the first PC simulation animation program. This set was continually improved. In 1993, the programs were combined into a single software application: Arena.

Arena is an integrated graphics simulation environment with a number of modeling, animation, statistical analysis, and result analysis tools (LAW; KELTON, 2000).

> One of Arena's differentials is the ability of creating templates, i.e., a collection of modeling objects/tools, through which users can describe the behavior of the process in analysis based on answers to questions prepared in advance, with no programming, in a visual and interactive manner. Through the use of templates (customization), Arena can easily transform into a specific simulator to be used for reengineering, natural gas transportation, manufacturing, mining purposes, etc (PARAGON, 2016).

2.4. Hospital Management

The healthcare area is fundamental to society by nature. At a certain point, everyone needs medical attention, and this service must be performed with a high level of efficiency, unlike any other segment. The smallest mistake can mean losing a life, even if it is not an emergency. Any delay or procedure error can worsen the patient's condition, subsequently impairing the unit's service level, which is not good for the population. The manager is responsible for managing in a way that efficiently and effectively provides balance to the whole service process.

By virtue of their high service level, many times, issues that are incumbent on the unit's manager, which issues, if not resolved, can result in low service quality, challenge the mission of health units (DA SILVA; SILVA, 2008).

3. METHODOLOGY

A case study approach was used with the aim of studying a Polyclinic located in a city of the state of São Paulo, in order to show the significance of implementing the technique in hospital management. The study was selected due to its important role in management decisions. The first step of this process was to collect data in a regular workday of the health unit, including available resources (equipment and employees), service time in the different stages of the unit's system, patient arrival interval, and average percentage of patients rated in four priority levels.

Modeling came next, i.e., the data from the health unit's system were handled with the help of Arena in order to evaluate and identify the process with the longer waiting time and the most overloaded/idlest employees, so that service and operational level improvements could be proposed. It is worth emphasizing that discrete events simulation provides a number of possibilities of changes in the study system, which is made evident throughout the case study.

4. CASE STUDY

As previously mentioned, the object of the study was a Polyclinic where the exponential average patient arrival interval is six minutes. These patients have to fill out a form, which time in minutes follows a triangular distribution (TRIA) of (2, 3, 5), meaning minimum, average, and maximum times, respectively. The form is applied by 1 of 2 attendants of the health unit.

Based on these forms, 20% of the patients arriving are returning patients with no need to go through the screening process, but are still rated as "priority", while usually 1% is "urgent" and 9% "slightly urgent". The screening process is performed by a nurse in a TRIA of (5, 7, 9) minutes. Graph 1 represents the average percentage of patients rated in four different priority levels.

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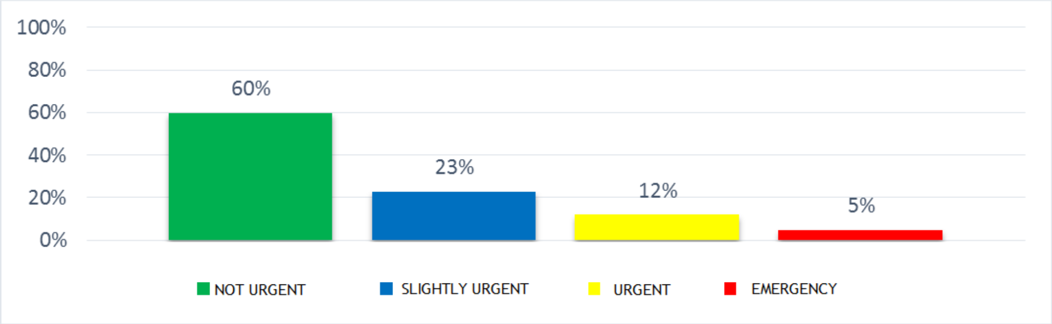

Graph 1: Priority Percentage
Source: Prepared by the Authors (2016).

From 5% of the patients rated as “emergency”, 80% are transferred to another hospital, due to the Polyclinic’s structure and medical service capacity. For the medical service, the unit relies on 2 professionals that see new patients in a TRIA of (5, 11, 13) minutes and returning patients in another TRIA of (4, 7, 10) minutes.

Typically, 24% of the new patients require X-ray examination, that is performed by a technician in a TRIA of (10, 15, 23) minutes and takes 30 minutes, other 37% are submitted for laboratory examination, performed by 2 nurses designated exclusively for this procedure, with a TRIA of (6, 8, 13) minutes to obtain the samples, plus 240 minutes to complete the examination.

The other 8% of the new patients are submitted for ECG, which takes a TRIA of (30, 45, 60) minutes to be completed by another specialized nurse. The remaining 31% of the new patients require no examinations. From all examined patients, 53% return on the same day to see the doctor, while the other 47% return on another date.

Most of the times, only 1% of the patients require no drug at the unit. However, 19% require inhalation procedure, which is prepared by a nurse from the drug room in a TRIA of (0.5, 1.5, 2.5) minutes. Next, these patients are transferred to a room with six places for them to receive the drug in another TRIA of (8, 10, 13) minutes.

30% of the new patients are submitted for intramuscular drug, given by the nurse in a TRIA of (3, 3.5, 5) minutes, the other 50% receive intravenous drug prepared by the same nurse in a TRIA of (0.5, 1.5, 2.5) minutes, and then they are addressed to another room with ten places, where they receive their drugs in a TRIA of (40, 70, 120) minutes.

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In general, 60% of the new patients have to return. The other 40% are discharged. 2% of the returning patients require new examinations, 20% receive the drug, and 78% are discharged.

4.1. System Simulation

Based on the data collected, the health unit's system was simulated in Arena. After the simulation, the software generated a number of reports, including occupancy level of resources, waiting time of each process, size of queues, among others.

Before proposing any kind of improvement, some report results were compared to the information provided by the Polyclinic's management in order to check if the simulation was actually representative of the study system. The first report shows the number of patients seen in average. This study resulted in 194 patients, while according to the unit's management, the average number is 190, i.e., a minimum difference.

Another analysis was carried out to find the most occupied and the idlest employees. According to the management, the screening nurse is usually the most occupied professional, while the idlest employees were the attendants and the drug room nurse. Figure 1 shows the report of occupancy levels of the health unit's attendants and resources.

Resource

Usage

Instantaneous Utilization	Average	HalfWidt	Minimu Value	Maximu Value
Attendants	0.2638	0,039263656	0.00	1.0000
Lab Examination Nurse	0.3443	(Insufficient)	0.00	1.0000
Screening Nurse	0.8530	(Insufficient)	0.00	1.0000
ECG Nurse	0.2273	(Insufficient)	0.00	1.0000
Nurse	0.05802839	(Insufficient)	0.00	1.0000
Inhalation	0.00	(Insufficient)	0.00	0.00
Inhalation Place	0.1409	(Insufficient)	0.00	1.0000
Intravenous Places	0.1552	(Insufficient)	0.00	0.4000
Intravenous Medications	0.00	(Insufficient)	0.00	0.00
Physician	0.7692	(Insufficient)	0.00	1.0000
Technician	0.4589	(Insufficient)	0.00	1.0000

Figure 1: Occupancy Level
Source: Prepared by the Authors (2016).

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One can see from Figure 1 that the employee with the highest occupancy level is exactly the screening nurse, as pointed out by the management, and that the idlest ones are the attendants and the nurse. It is worth emphasizing that Arena allows no special characters, such as accents in words.

Another important detail is the unit of value of results in Figure 1, which are expressed as decimals. Therefore, the nurse has an occupancy level of 85.30%, while the nurse has only 5.8% approximately; in the case of the 2 attendants, the number 26.38% accounts for the average occupancy between them both. Figure 2 shows the report of waiting times in the health unit's different processes.

Queue

Time

Waiting Time	Averag	Half Widt	Minimu Value	Maximu Value
Doctor's Office 1 for New Patients.Queue	1.7762	(Insufficient)	0.00	10.4165
Doctor's Office 2 for Returning Patients.Queue	2.2005	(Insufficient)	0.00	20.6210
ECG.Queue	3.4616	(Insufficient)	0.00	27.6927
Laboratory-Based.Queue	0.4370	(Insufficient)	0.00	5.6466
Intramuscular Medication.Queue	0.00	(Insufficient)	0.00	0.00
Inhalation Medication.Queue	0.05594736	(Insufficient)	0.00	1.1189
Intravenous Medication.Queue	0.00	(Insufficient)	0.00	0.00
Form Completion.Queue	0.1095	(Insufficient)	0.00	2.9510
Inhalation Preparation.Queue	0.00	(Insufficient)	0.00	0.00
Intravenous Medication Preparation.Queue	0.00	(Insufficient)	0.00	0.00
X-Ray.Queue	2.0109	(Insufficient)	0.00	12.1050
Screening.Queue	16.2031	(Insufficient)	0.00	65.2909

Figure 2: Waiting Times in Queues
Source: Prepared by the Authors (2016).

The values in this report are expressed as minutes. Again, the simulation matches the information provided by the management, since the process with the longest waiting time is the screening one, with approximately 16 minutes in average.

4.2. Proposed Improvements

Based on the analysis of the results reported in Arena, the proposed improvements aim at balancing the occupancy levels of the screening nurse and the drug room nurse, in order to make better use of their qualifications without overloading anyone and to test a potential change in the number of attendants.

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Subsequently, a new simulation was carried out, where the nurse had to administer the drugs and also support the screening nurse. There was a change in the number of attendants throughout the day. In the first 12 hours, the simulation took into account 1 attendant, while in the other 12 hours, 2 employees were taken into account. The inverse was tested as well, i.e., 2 in the first 12 hours, and 1 in the other 12. Figure 3 shows the occupancy levels with the proposed improvements.

Resource

Usage

Instantaneous Utilization	Average	Half Width	Minimum Value	Maximum Value
Attendants	0.4632	(Insufficient)	0.00	1.0000
Lab Examination Nurse	0.4271	(Insufficient)	0.00	1.0000
Screening Nurse	0.4454	(Insufficient)	0.00	1.0000
ECG Nurse	0.4047	(Insufficient)	0.00	1.0000
Nurse	0.0947	0,017746478	0.00	1.0000
Inhalation	0.00	(Insufficient)	0.00	0.00
Inhalation Place	0.08011045	(Insufficient)	0.00	1.0000
Intravenous Places	0.2331	(Insufficient)	0.00	0.6000
Intravenous Medications	0.00	(Insufficient)	0.00	0.00
Physician	0.8902	(Insufficient)	0.00	1.0000
Technician	0.4739	(Insufficient)	0.00	1.0000

Figure 3: Occupancy Level with the Proposed Improvements
Source: Prepared by the Authors (2016).

In both the tests, changing the number of attendants during the day caused no change in the occupancy levels. Therefore, one can consider the report of Figure 3 as a result of the proposal. One can see an increase in the occupancy levels of the attendants and the drug room nurse, as well as a significant decrease in the occupancy level of the screening nurse. Figure 4 shows the impacts of the proposed improvement compared to waiting times in queues at the Polyclinic.

In this report, one can see a significant decrease in the average waiting time of patients in screening process, as well as a maximum waiting time of approximately 15 minutes. Based on these results, the Polyclinic is suggested to use one of the receptionists, during half of the workday, in administrative services or another activity, in order to make better use of their workload.

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Queue

Time

Waiting Time	Average	Half Width	Minimum Value	Maximum Value
Screening Support.Queue	0.00	(Insufficient)	0.00	0.00
Doctor's Office 1 for New Patients.Queue	20.5548	(Insufficient)	0.00	89.3738
Doctor's Office 2 for Returning Patients.Queue	17.9509	(Insufficient)	0.00	63.7879
ECG.Queue	11.7073	(Insufficient)	0.00	47.2064
Laboratory-Based.Queue	3.6422	(Insufficient)	0.00	38.5320
Intramuscular Medication.Queue	0.00	(Insufficient)	0.00	0.00
Inhalation Medication.Queue	0.00	(Insufficient)	0.00	0.00
Intravenous Medication.Queue	0.00	(Insufficient)	0.00	0.00
Form Completion.Queue	2.0951	(Insufficient)	0.00	14.7847
Inhalation Preparation.Queue	0.00	(Insufficient)	0.00	0.00
Intravenous Medication Preparation.Queue	0.00	(Insufficient)	0.00	0.00
X-Ray.Queue	4.7255	(Insufficient)	0.00	46.1386
Screening.Queue	2.3522	(Insufficient)	0.00	15.4626

Figure 4: Waiting Times in Queues with the Proposed Improvements
Source: Prepared by the Authors (2016).

Based on the changes suggested, a last change is proposed. While there is an improvement in the system performance, according to Figure 3, the drug room nurse remains as the idlest employee, with an average occupancy level of only 9.47%. This resource accounts for 2 employees. Accordingly, another system simulation was carried out taking into account only 1 nurse on duty. Figure 5 shows the impact of this change on the occupancy levels of resources.

Resource

Usage

Instantaneous Utilization	Average	Half Width	Minimum Value	Maximum Value
Attendants	0.4276	(Insufficient)	0.00	1.0000
Lab Examination Nurse	0.4371	(Insufficient)	0.00	1.0000
Screening Nurse	0.4558	(Insufficient)	0.00	1.0000
ECG Nurse	0.3106	(Insufficient)	0.00	1.0000
Nurse	0.1775	(Insufficient)	0.00	1.0000
Inhalation	0.00	(Insufficient)	0.00	0.00
Inhalation Place	0.07350458	(Insufficient)	0.00	1.0000
Intravenous Places	0.1987	(Insufficient)	0.00	0.5000
Intravenous Medications	0.00	(Insufficient)	0.00	0.00
Physician	0.8615	(Insufficient)	0.00	1.0000
Technician	0.5412	(Insufficient)	0.00	1.0000

Figure 5: Occupancy Levels with Change in the Number of Nurses
Source: Prepared by the Authors (2016).

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One can see from this report that there is no significant change in the occupancy levels, except for the nurse, whose occupancy level now is 17.75%. Figure 6 shows the impact of this last change on the waiting time of each process.

Queue

Time

Waiting Time	Average	Half Width	Minimum Value	Maximum Value
Screening Support.Queue	0.1974	(Insufficient)	0.00	3.7397
Doctor's Office 1 for New Patients.Queue	11.7604	(Insufficient)	0.00	65.6565
Doctor's Office 2 for Returning	8.5567	(Insufficient)	0.00	30.9895
ECG.Queue	2.3476	(Insufficient)	0.00	19.3145
Laboratory-Based.Queue	1.2209	(Insufficient)	0.00	9.4629
Intramuscular Medication.Queue	0.06534447	(Insufficient)	0.00	0.9212
Inhalation Medication.Queue	0.00	(Insufficient)	0.00	0.00
Intravenous Medication.Queue	0.00	(Insufficient)	0.00	0.00
Form Completion.Queue	1.5769	(Insufficient)	0.00	17.4357
Inhalation Preparation.Queue	0.00	(Insufficient)	0.00	0.00
Intravenous Medication Preparation.Queue	0.1150	(Insufficient)	0.00	2.5048
X-Ray.Queue	5.7603	(Insufficient)	0.00	34.4779
Screening.Queue	2.3062	(Insufficient)	0.00	13.7284

Figure 6: Waiting Times with Change in the Number of Nurses
Source: Prepared by the Authors (2016).

What is interesting from this last report is that there is a greater decrease in the waiting time of each process of the health unit with only 1 nurse less, showing that it is important to carry out several tests in the same study model, until the best distribution of the resources available is found.

As mentioned in the methodology, discrete events simulation is a technique that lets one consider a number of scenarios where there might be a greater or lesser performance of the resources available in the study system. In this research, the proposal only comprises the screening process, reception, and nurse. However, other scenarios could be explored, such as increasing or decreasing the number of doctors and technicians on duty.

This change was implemented in the simulation of this case study, but the proposed improvement was not addressed due to the high level of idleness of the health unit's resources and longer waiting times. When the number of doctors was changed from 2 to 3, this resulted in zero queues, but there was 50% less occupancy of each available resource, except for the ECG nurse, with 52.31%, and the doctors, with average occupancy of 59.21%. When changed downwards,

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considering 1 doctor, this doctor would have occupancy of 99.69% based on a new simulation through the software.

Since the Polyclinic has only 1 X-ray technician, the test consisted of changing it to 2. Again, results were not found to be satisfactory. The technician had 70.21% of idleness, the doctor's occupancy level went up to 90.95%, and there was an average waiting time of approximately 27 minutes. This would cause a new bottleneck in the system, so the change was not included in the proposed improvements.

These last data confirm that the possibilities are many. Accordingly, the aim of the proposed improvements was only to remove the bottleneck and adjust the Polyclinic's system in order to provide a certain balance in the occupancy levels of resources, while increasing the service level provided because of shorter waiting times throughout the health unit's service system.

5. FINAL CONSIDERATIONS

The objective of the study was to introduce the discrete events simulation technique as a hospital management tool, objective which was met based on the study of the real case of a health unit. The data were collected in the field.

Another important finding was the need to carry out several tests and simulations based on different characteristics, in order to consider a scenario of a general greater system performance with a greater service level at the same time. These results show how the technique is implemented. This allowed for an analysis of the system behavior through changes in simulations and avoided empiricism and, subsequently, potential losses or unnecessary works in the reallocation of resources.

This research increases our knowledge of the study of operations with the discrete events simulation technique, which, as mentioned in the section "Theoretical Grounding", is one of many OR-based techniques. Finally, many other techniques can be tested in real cases, allowing one to consider and evidence the significance of these tools in the study of operations in order to avoid changes in operations without any scientific basis.

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