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APPLICATION OF DISCRETE EVENT SIMULATION IN THE PERFORMANCE ANALYSIS OF AN OUTPATIENT UNIT

UNIVERSIDADE DO ALGARVE

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Mestrado em Gestão de Unidades de Saúde

Trabalho efetuado sob orientação de:

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Declaração de Autoria do Trabalho

Declaro ser o autor deste trabalho, que é original e inédito. Autores e trabalhos consultados estão devidamente citados no texto e constam da listagem de referências incluída.

Manuel Alfredo de Ponte Gallardo

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DEDICATION

This dissertation is dedicated to my wife and daughters, who have been a constant source of support and encouragement during the last two years. Without them, this dissertation would not have been possible.

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It would not have been possible to reach the end of this path without the availability, guidance, and commitment of the supervisors: Professor Sérgio Santos and Professor Carla Amado. I am very grateful to them.

At team members of the Special Exams Unit, thanks for all the support and availability.

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RESUMO

O Departamento da Consulta Externa do Grupo HPA Saúde, Unidade Hospitalar de Gambelas, oferece aos seus pacientes uma ampla oferta em especialidades médicas e cirúrgicas. No início de 2021, a consulta externa sofreu uma expansão e reestruturação, dando resposta ao elevado aumento na procura de exames, permitindo dar resposta aos pacientes, tendo como premissa a manutenção da elevada qualidade do serviço prestado.

Esta reestruturação do serviço de ambulatório, conseguiu aumentar a capacidade de resposta, a qualidade das suas instalações e os respetivos serviços prestados.

A Unidade de Exames Especiais é uma das unidades integrantes deste departamento, onde são realizados exames específicos de várias especialidades tais como, cardiologia, gastroenterologia, urologia e pneumologia. A unidade foi reestruturada e iniciou funções em maio de 2021. A nível da gestão operacional, esta reestruturação e ampliação da capacidade física da unidade, trouxe vários desafios, como a alteração dos fluxos de pacientes, a redistribuição de recursos físicos e humanos, e a necessidade de fazer um adequado planeamento da capacidade da unidade.

O planeamento da capacidade é complexo e é um grande desafio para os gestores, pois o desequilíbrio entre a oferta e a procura pode desencadear aumentos de tempo de espera de pacientes ou desperdício de recursos. Qualquer um destes desfechos negativos põe em causa o desempenho do serviço, tornando-o menos eficiente. Realizar um adequado planeamento da capacidade não é, no entanto, tarefa fácil dada a imprevisibilidade associada a estes serviços, a sazonalidade da procura, as flutuações de pacientes ao longo do dia e os padrões de comportamento dos próprios pacientes. Ainda assim, torna-se muito importante estudar qual o impacto que a alteração ou o ajustamento de determinados parâmetros ao nível deste planeamento poderá ter no desempenho da Unidade de Exames Especiais, para que sejam implementadas estratégias de melhoria da eficiência dos serviços e, consequentemente, do seu desempenho.

Este estudo tem como objetivo explorar a aplicação de um modelo de Simulação de Eventos Discretos (DES) para analisar o impacto do planeamento de capacidade no desempenho da Unidade de Exames Especiais. Em particular, este estudo tem como objetivos específicos, identificar quais as variáveis que mais condicionam o planeamento de capacidade e ainda identificar relações/interações entre o planeamento de capacidade e o tempo de espera dos pacientes.

A aplicação do modelo DES, irá permitir recriar o funcionamento do sistema real e realizar várias simulações, de forma a compreender como é que o sistema funciona e de que forma estratégias alternativas poderão afetar o desempenho do sistema. Irá também permitir perceber qual é o impacto do planeamento de capacidade no desempenho do serviço e qual é a relação entre a capacidade de planeamento e o tempo de espera dos pacientes.

Dada a complexidade da unidade e o caráter exploratório deste estudo, apenas foram considerados para o estudo os exames realizados pela especialidade de gastroenterologia.

Foram recolhidos dados referentes a todos os exames realizados às quintas-feiras na Unidade de Exames Especiais entre janeiro e abril de 2022. Nesse período, 261 pacientes tiveram exames agendados, mas 8 não compareceram. Os dados tratados referem-se, portanto, a um total de 253 pacientes. Esses dados foram extraídos do processo eletrónico do paciente, registos de enfermagem do processo clínico e do programa de agendamento de consultas.

O modelo DES foi aplicado para modelar o fluxo de pacientes da unidade utilizando o software SIMUL8, versão 29.0. Após a análise dos dados e a identificação das distribuições estatística mais adequadas para representar o comportamento de alguns parâmetros, o modelo foi devidamente configurado. Para validar o modelo DES, os resultados e a animação da simulação foram verificados por elementos da equipa da unidade. Uma análise comparativa foi também realizada através da comparação de dados reais com dados e resultados gerados pela simulação. A maioria das variáveis apresentou erros relativos substancialmente baixos, por exemplo, o tempo médio de permanência no sistema, obteve um erro relativo de 0,07. Os tempos médios dos procedimentos, também obtiveram bons resultados. Nomeadamente, o procedimento de colonoscopia dupla, colonoscopia baixa e endoscopia alta, obtiveram erros relativos negligenciáveis (de 0,01, 0,00 e 0,00 respetivamente). No entanto a variável desvio padrão do tempo no sistema apresentou um erro relativo superior a 10%. A diferença observada entre os valores reais e simulados podem estar associadas ao processo de desconstrução do modelo. O processo de preparação do paciente e o processo de recobro foram desconstruídos, em atividades menores e específicas, com o objetivo de compreender melhor a taxa de utilização dos recursos nestas mesmas atividades. Essa discrepância pode ser atribuída à utilização de uma distribuição média para atividades em vez de empregar uma distribuição adequada, o que permitiria diminuir a variabilidade da amostra resultando num valor de desvio padrão mais baixo.

Foram testados oito cenários, com o objetivo de identificar limitações e gargalos, maximizar a capacidade e melhorar o agendamento de exames e a otimização de recursos.

No Cenário nº 1, foi otimizado o número de agendamentos através da redução dos intervalos entre agendamentos de 30 minutos para 20 minutos em comparação ao modelo de simulação inicial, mantendo o horário de trabalho. O objetivo era maximizar a eficiência do modelo. Observou-se um aumento notável no número de exames realizados e na taxa de utilização de recursos. No entanto, isso levou a um aumento significativo no tempo de espera e no tempo de permanência do paciente no sistema. A sobrecarga do sistema neste cenário permitiu identificar um comportamento de gargalo na atividade do vestiário com uma taxa de congestionamento de 26,1% o que indica que a atividade de vestiário sofreu um alto índice de congestionamento e se tornou um fator limitante no fluxo de pacientes no processo.

A adição de um segundo vestiário no Cenário nº 2, mostrou uma diminuição dos tempos de espera e da taxa de congestionamento no vestiário, que reduziu de 26,1% para 15,96%, validando a opinião de especialistas de que esta atividade assume um comportamento de gargalo.

Os Cenários nº 3 e nº 4 foram conduzidos para testar a otimização de recursos com o objetivo de identificar limitações e comportamentos de gargalo em outras atividades ou recursos, visto que o Cenário nº 2 ainda observava congestionamento na atividade de vestiário. No Cenário nº 3, a adição de um enfermeiro extra para o processo de preparação e recobro teve um efeito positivo no sistema. Isso resultou em uma redução no tempo de preparação do paciente e no tempo de permanência no sistema. O congestionamento na atividade vestiário, diminuiu de 15,96% para 13,34%, o que pode ser interpretado como um potencial comportamento de gargalo do recurso enfermeiro alocado à preparação do paciente e recobro, nomeadamente quando está apenas um enfermeiro disponível. Neste cenário nº 3, o acréscimo de um enfermeiro, contribuiu para uma redução de 2,62% no congestionamento da atividade de vestiário. No entanto, verificou-se também que com esta adição extra, a taxa de utilização de recursos não foi eficiente, pois a taxa de utilização do enfermeiro do processo de preparação e recobro do paciente atingiu apenas 43%.

No Cenário nº 4, a adição de mais duas camas, ajudou a aliviar o comportamento de gargalo na atividade de vestiário. Isso levou a uma diminuição significativa da taxa de congestionamento nessa atividade de 13,34% para 2,38%. No entanto, também resultou em um aumento notável no tempo de espera para os exames e um discreto aumento no tempo de permanência no sistema.

Com base nas constatações do Cenário nº 4, que indicou um possível gargalo no processo de procedimento de exame, foi realizado um cenário de otimização de fluxos e de recursos. Nesse cenário (i.e. Cenário nº5), foi adicionada uma segunda sala de procedimentos, com uma equipa independente composta por médicos e enfermeiros. A adição da segunda sala de procedimentos resultou em uma diminuição significativa tanto no tempo de permanência do paciente no sistema quanto no tempo de espera. Observou-se, também, uma redução significativa da taxa de congestionamento da atividade vestiário, validando a suspeita que a atividade sala de procedimento assume um comportamento de gargalo, e que a adição de uma segunda sala, pode reduzir significativamente a taxa de congestionamento. No entanto, observou-se uma taxa de utilização dos recursos ineficiente.

No Cenário nº 6, devido às baixas taxas de utilização de recursos observadas no Cenário nº 5, foi utilizado o mesmo modelo de simulação mas com o objetivo de maximizar a capacidade através da otimização do fluxo, recursos e agendamento. Em particular, o Cenário nº 6 consubstanciou-se na otimização do agendamento (exames agendados a cada 12,5 minutos) com o intuito de maximizar a capacidade, mantendo a otimização de fluxos (dois vestiários e duas salas de procedimento) e recursos adequados ao incremento das salas de procedimento, duplicando o número de elementos das equipas e adicionando duas camas extras. Este cenário apresentou um alto nível de otimização de recursos, utilizando efetivamente os recursos disponíveis, otimizando o fluxo de pacientes e implementando uma abordagem de agendamento aprimorada. Isso resultou em maior eficiência, redução do tempo de espera e maior produtividade em relação ao número de exames realizados.

O cenário nº 6 emergiu como o cenário mais eficiente testado, no entanto, a sua implementação poderá não ser muito realista dado que obrigaria a modificações físicas do espaço, ajustamentos no fluxo dos pacientes e uma duplicação de alguns recursos. Com o intuito de testar um cenário mais realista, foi criado o cenário nº 7 usando a mesma modelação que o cenário nº 1, mas otimizando o agendamento de exames (exames agendados a cada 24,5 minutos) e os recursos (mantendo os mesmos que no cenário nº 1, mas com taxas de utilização elevadas). Este cenário teve em conta as restrições causadas pelos comportamentos gargalos identificados em cenários anteriores e demonstrou um bom desempenho ao reduzir efetivamente os tempos de espera e o tempo de permanência no sistema. Ao priorizar o agendamento e a otimização de recursos, o Cenário nº 7 visava obter uma alocação eficiente de recursos, mantendo uma abordagem realista e viável. Os resultados da simulação indicam que este cenário permitiria melhorar o fluxo de pacientes e reduzir os tempos de espera, contribuindo para melhorar o desempenho geral do sistema.

Finalmente, o Cenário nº 8, segue as orientações da Sociedade Portuguesa de Endoscopia Digestiva, que sugerem que existam tempos mínimos de agendamento de acordo com o tipo de exame. Neste cenário o agendamento dos procedimentos endoscópicos foi realizado seguindo os tempos recomendados e que são de 40 minutos para os procedimentos de endoscopia digestiva alta e colonoscopia, 30 minutos para os procedimentos de colonoscopia e 15 minutos para os procedimentos de endoscopia digestiva alta. O objetivo deste cenário alternativo era otimizar o agendamento de procedimentos endoscópicos mantendo o desempenho operacional do modelo. Com este cenário, observou-se uma redução no número de exames realizados bem como na taxa de utilização de recursos. A diminuição do tempo de espera teve um papel significativo na redução da média e desvio padrão do tempo gasto no sistema, bem como do tempo máximo. As melhorias alcançadas no Cenário nº 8 indicam que este cenário poderia ter um impacto positivo na satisfação do paciente, pois contribui para a redução do tempo de espera e para um processo mais eficiente.

Considerando as restrições e limitações inerentes à implementação no mundo real, o Cenário nº 7 é aquele que parece oferecer uma solução mais prática e viável, com potencial para otimizar o processo de calendarização de exames, levando a uma maior eficiência e melhoria na experiência do paciente.

Palavras-Chave: Planeamento de capacidade; Simulação de Eventos Discretos (*Discrete Event Simulation)*; Fluxo de pacientes; Unidade de ambulatório; Endoscopia.

ABSTRACT

The Outpatient Department of the HPA Saúde Group offers its patients a wide range of medical and surgical specialties. To provide better quality services with the current increase in patient needs, the hospital, at the beginning of 2021, expanded its facilities and restructured the outpatient service, increasing its responsiveness as well as the quality of its facilities and services provided to patients.

The Special Exams Unit is one of the units that integrates this department, where specific exams are conducted in various specialties such as cardiology, gastroenterology, urology, and pulmonology. The unit was restructured and started operations in May 2021. In terms of operational management, this restructuring and expansion of the unit's physical capacity brought challenges, such as changing patient flows, redistribution of physical and human resources, and regarding the need for proper capacity planning.

Capacity planning is complex and a major challenge for managers, as the imbalance between demand and supply can trigger increases in patient waiting times or waste of resources. Any of these negative outcomes jeopardize the performance of the service, making it less efficient. The intervention threshold in capacity planning is very tenuous, given factors such as unpredictability, seasonality, patient fluctuations throughout the day, and patient behavior patterns. Consequently, it is important to study the impact of this planning on the performance of the Special Exams Unit, so that strategies can be designed to improve the efficiency of the services, and as a result, their performance.

This study aims to explore the Application of Discrete Event Simulation (DES) to study the impact of capacity planning on the performance of the Special Exams Unit. Its specific objectives are to identify which variables affect capacity planning and to identify relationships/interactions between capacity planning and patient waiting time.

The application of DES will allow us to replicate the workings of the Unit and perform simulations to understand how the system works and how alternative strategies can impact the performance of the system. It will also help us identify what the impact of capacity planning is on service performance and what the relationship between capacity planning and patient waiting time is.

The Special Exams unit operates five days a week, Monday through Friday. The exams are usually scheduled between 8:30 and 12:30 a.m. and between 14:00 to 18:30 p.m., and there may be changes in the schedule according to the number of exams scheduled. Given the complexity of the Unit and the exploratory nature of this study, only exams performed by the gastroenterology specialty were considered for the study.

In order to develop and validate the simulation model, data were collected relating to all the exams performed on Thursdays at the Special Exams Unit between January and April 2022. During this period, 261 patients had exams scheduled, but 8 did not show up. The data used in the simulation refer, therefore, to data collected for 253 individual patients. These data were extracted from electronic record data from the hospital, nursing records from the patients' handling process, and from the appointment-scheduling system. These data were recorded and analyzed using Microsoft Excel version 365 and the Statistical Package for the Social Sciences version 28.0.1.0. The Stat::fit® version 2 program was used to analyze the statistical distributions of the collected data.

DES was applied in the modelling of the patients' flow at the Special Exams Unit using the software program SIMUL8, version 29.0. The patients' flow was mapped through interviews with experts from the Unit and through direct observation of the real process system. After data and statistical distribution analyses were performed, the simulation model was developed. To validate the DES model, the results from the baseline simulation were verified by experts from the Unit. The simulation animation was also analyzed by members of staff from the Unit, to confirm that patients in the model were following an appropriate flow. A comparative analysis was also performed through comparing real data and simulation output data. Most of the variables had acceptable results with minimal values of relative error. For example, the patients' average time in the system showed a relative error of 0.07, the average time of Upper and Lower GI endoscopy, Lower GI endoscopy and Upper GI endoscopy, had relative errors of 0.01, 0.00 and 0.00, respectively. One variable show, however, a relative error superior to 10%. For example, the indicator Standard Deviation regarding the total time spent by the patients in the system presents an error higher than 10%. These differences observed between real and simulated values might be associated with the model construction process. Some processes were deconstructed, in smaller and specific activities, with the objective of understanding better the resource utilization rate in the system. These discrepancies can eventually be attributed to the utilization of an average distribution to represent the time taken by certain activities instead of employing a better adjusted distribution due to the lack of some data.

Eight scenarios were tested, with the objective of identifying limitations and bottlenecks, maximizing capacity and improving scheduling appointment and resource optimization.

In Scenario No. 1, the number of appointments was optimized by reducing the scheduling intervals from 30 minutes to 20 minutes, while maintaining the same working hours used in the baseline simulation. The goal was to maximize the appointment efficiency of the model. A noticeable increase in the number of exams performed and in resource utilization was observed. However, this came at the cost of a significant increase in queuing time and the length of stay in the system. The overload on the system during this scenario allowed for the identification of a bottleneck behavior within the dressing room activity. The result of a block route of 26.1% in this activity, indicates that patients' flow experienced an elevated level of congestion and became a limiting factor in the overall process flow.

Adding a second dressing room on Scenario No.2, showed a decrease in the queuing times and also a decrease of the blocked route on the dressing room from 26.1% to 15.96%, validating experts' opinion that this activity assumes a bottleneck behavior.

Scenarios No. 3 and No. 4 were conducted to test resource optimization with the objective of identifying limitations and bottleneck behaviors in other activities or resources, considering that Scenario No. 2 still observed congestion in the dressing room activity. In Scenario No. 3, the addition of an extra nurse for the preparation and recovery process had a positive effect on the system. It resulted in a reduction in patient preparation time and length of stay on the system. The blocked route on the dressing room decreased from 15.96% to 13.80%. This reduction can be interpreted as the patient preparation and recovery process nurse behaving as a bottleneck resource, when only one nurse is available. In scenario No.3, the addition of one more nurse, contributed to the reduction of 2.62% in the blockage of the dressing room activity. However, it was also found that the resource utilization rate was not efficient, as the utilization rate of the patient preparation and recovery process nurse reached only 43%.

On Scenario No. 4, the addition of two more beds helped alleviate the bottleneck behavior in the dressing room. This led to a significant decrease in the blocked route of this activity from 13.80% to 2.64%. However, it also resulted in a notable increase in the queuing time for exams and a slight increase in the patients' length of stay in the system.

Based on the findings from Scenario No. 4, which indicated a potential bottleneck in the exams' procedure, a flow and resource optimization scenario was conducted (Scenario No. 5). In this scenario, a second procedure room was introduced, along with an independent team including medical professionals and nurses. The addition of the second procedure room resulted in a significant decrease in both patient length of stay in the system and queuing time. This confirmed that this activity can act as a bottleneck in the system.

On Scenario No. 6, due to low resource utilization rates observed on Scenario No. 5, we used the same model but with the objective of maximizing capacity through resource and scheduling optimization. Regarding scheduling optimization, we assumed that a patient would be admitted each 12,5 minutes. Regarding resource optimization, we assumed that the same resources of Scenario No. 5 would be used (i.e., 2 dressing rooms and 2 procedure rooms, each one with one independent team and 6 beds). In this scenario we observed a reduction on the queuing times, shorter patient length of stay, and a notable increase in the number of exams performed. Scenario No. 6 displayed an elevated level of resource optimization by effectively utilizing the available resources, optimizing the flow of patients, and implementing an enhanced scheduling approach. This resulted in an improvement in efficiency, reduced waiting times, and increased throughput in terms of the number of exams conducted.

Scenario No. 6 emerged as the most efficient scenario tested, however, due to hypothetical constraints such as the need for physical modifications of the space and potential complications in the patients’ flow, a more realistic scenario, Scenario No. 7, was explored. It aimed to optimize the model from Scenario No. 1 by focusing on scheduling and resource optimization. In Scenario No. 7, appointments were scheduled at every 24,5 minutes, ensuring high resource utilization while considering the limitations and bottlenecks identified in previous scenarios. This scenario demonstrated reliable performance by effectively reducing queuing times and the patients’ length of stay in the system. By prioritizing scheduling and resource optimization, Scenario No. 7 aimed to achieve efficient resource allocation while maintaining a realistic and feasible approach. This scenario allowed for an improvement in patient flow and a reduction in the waiting times, contributing to an enhanced overall performance of the system.

Finally, Scenario No. 8, follows the Portuguese Society of Digestive Endoscopy guidelines, which recommend different minimum scheduling times based on the type of procedure. For the Upper GI endoscopy, the recommendation is of 15 minutes, for the Lower GI endoscopy, it is 30 minutes and for the Upper and Lower GI endoscopy, it is 40 minutes. This scenario was tested to offer an alternative scheduling appointment optimization, using a Schedule of Arrivals. A dedicated spreadsheet was developed for manual control of patients' arrivals, following the guideline recommendations. This Scenario demonstrated a reduction in the number of exams conducted and in the resource utilization rate. The decrease in queuing times played a significant role in reducing the average and standard deviation of the time patients spent in the system, as well as the maximum time. The improvements achieved through Scenario No. 8 have a positive impact on patient satisfaction, as they contribute to shorter waiting times and to a more efficient process.

Considering the constraints and limitations inherent to real-world implementations, we believe that Scenario No. 7 provides a practical and viable solution that optimizes the scheduling process, resulting in an improvement in efficiency and in patients’ experience.

Keywords: Capacity planning; Discrete Event Simulation; Patient flow; Outpatient unit; Endoscopy.

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LIST OF ABBREVIATIONS

CI- Confidence interval
DES- Discrete Event Simulation
GI- Gastrointestinal
HPA- Hospital Particular do Algarve
Lbl- Label
Min- Minutes
No.- Number
QT- Queuing Time
SPSS - Statistical Package for the Social Sciences

1. INTRODUCTION

Researchers and healthcare professionals try, through innovation, to find solutions that foster performance improvement and cost reduction in healthcare services. To be efficient, these services must adopt performance-enhancing measures, considering their limitations such as the scarcity of limited resources and capacities (Hamrock, Paige, Parks, Scheulen & Levin, 2013; Jun, Jacobson & Swisher, 1999). Cost reduction places a great responsibility on managers as they must maximize operational efficiency to maintain or improve the quality of healthcare (Hamrock et al., 2013).

Outpatient services are a source of access to healthcare, due to their specificity of patient care, allowing urgent care, scheduled consultations, and follow-up of surgeries or treatments. With the increasing demand for this type of healthcare, outpatient services should reorganize and optimize their performance, improving their efficiency and maintaining patient satisfaction, considering their capacity limitations (Baril, Gascon & Cartier, 2014; Rohleder, Lewkonia, Bischak, Duffy & Hendijani, 2011). Efficiency plays a crucial role in ensuring patient satisfaction within the operational management of outpatient services. The variety of patient behavior patterns poses, however, a major challenge for operational management (Fan, Tang, Yan, Guo & Cao, 2019).

According to Jun et al. (1999:113) "Simulation modeling is attractive since it can be used to estimate the operational characteristics of a system as well as to observe the consequences of changes in planning or policies prior to when decisions are actually implemented, hence reducing the financial risks." Indeed, it is well known that simulation modeling, and in particular Discrete Event Simulation (DES), can be applied as a tool in resource distribution and capacity planning (Rau, Tsai, Liang, Tan, Syu, Jheng, Ciou & Jaw 2013).

The application of DES has proved effective in healthcare as it can be used to analyze performance in a versatile way. It can also be a valuable tool for management, as it allows a microscopic visualization of simulation outputs of individual care processes, but also a macroscopic view of how all these processes interact. The application of DES models in outpatient services aims to improve patient flow, reduce waiting times, maximize staff utilization, and achieve other gains in efficiency (Hamrock et al., 2013).

The Outpatient Department of the HPA Saúde Group offers its patients a wide range of medical and surgical specialties. To provide better quality services and with the current increase in patient needs, the hospital, at the beginning of 2021, expanded its facilities and restructured the outpatient service, increasing its responsiveness as well as the quality of the facilities and services provided to patients.

The Special Exams Unit is one of the units that integrates this Outpatient Department, where specific exams are performed according to the different specialties such as cardiology, gastroenterology, urology, and pulmonology. The unit was restructured and restarted operations in May 2021. In terms of operational management, this restructuring and expansion of the unit's physical capacity brought challenges, such as changing patient flows, redistribution, and acquisition of physical and human resources, and regarding the need for a proper capacity planning.

This study aims to explore the use of a DES model to study the impact of capacity planning on the performance of the Special Exams Unit. As specific goals, we aim to identify which variables affect capacity planning and to identify relationships/interactions between capacity planning and patient waiting time. With DES, it will be possible to perform simulations of what-if scenarios, in which several hypotheses can be evaluated to optimize capacity planning and to improve the performance of the Special Exams Unit. The use of DES will also allow us to assess the impact of changing procedures and operational flows without jeopardizing the real functioning of the unit, and without the negative impact that could emerge, if the measures were tested in a real context.

Due to the complexity of the unit, considering the different specialties and types of specific physical and human resources needed, only the exams performed by the gastroenterology specialty are considered in this study. This choice is also justified by the exploratory nature of this research.

This study is organized into five chapters. In chapter 1, Introduction, we outline the topic to be researched and provide a brief characterization of the Special Exams Unit. In chapter 2, the literature review is addressed, where studies related to the subject are analyzed. In chapter 3, Methodology, the entire process from data collection to data analysis is described. In chapter 4, the results and the discussion are presented. And, in chapter 5, Conclusion, we summarize the main findings of our study.

2. LITERATURE REVIEW

2.1 Discrete Event Simulation

DES is a type of computer simulation that reproduces the activity of a real system and provides the manager with tools to analyze performance measures on potential operational management changes (Hamrock et al., 2013). It provides an intuitive and flexible process, as it allows the simulation of dynamic behaviors of complex systems and interactions between various variables (Zhang, 2018).

According to Reese, Avansino, Brumm, Martin & Day (2020:2) “DES allows for the creation of a graphical model of a care process or clinic, which can then be used to test hypotheses about the behavior of that system under various alternative scenarios.” In fact, DES has been widely applied in healthcare to model systems. Since 2004, there has been a significant increase in the number of articles published documenting the use of DES on the health area and with the main interest of modeling the performance in hospitals (Günal & Pidd, 2010).

DES has been applied for modeling patient flow optimization (Baril et al., 2014; Demir, Southern, Verner & Amoaku, 2018; Kritchanchai & Hoeur, 2018; Sethi, Levine, Roh, Marx & Ramsey 2021; Elango, Sivalingam, Annamalai & Karthikeyan, 2022; Zou, Wang & Cheng, 2023), capacity planning (Cai & Jia, 2018; Kritchanchai & Hoeur, 2017; Ponis, Delis, Gayialis, Kasimatis & Tan, 2013; Rau et. al, 2013; Reese, et. al, 2020; Viana, Simonsen, Faraas, Schmidt, Dahl & Flo, 2020), appointment scheduling (Bakker & Tsui, 2017; Baril, Gascon, Miller & Bounhol, 2016; Diamant, Milner & Quereshy, 2018; Fan et al., 2019) and process design (Baril et al., 2014, 2016; Cai & Jia, 2018; Ponis et al., 2013).

DES is often applied for modeling patient flow optimization as illustrated by Baril et al. (2014) who mapped three different patients’ trajectories of an orthopedic clinic and analyzed the impact of resource assignment and appointment scheduling rules on patient flow. Kritchanchai & Hoeur (2017), studied the behavior of patient flow for a facility allocation of an outpatient unit to analyze the congestion of patient flow. Sethi et. al (2021) used, in turn, data records from a retinal clinic to evaluate patient flow during COVID pandemic with the purpose of planning the potential volume increase of patients.

The use of DES to analyze appointment scheduling can also be found on several papers. Baril et al. (2014), for example, used appointment scheduling rules to force a patient arrival standard and evaluated this rule using DES. To reduce patient waiting times and nurses' workload, Baril et al. (2016) demonstrated that an efficient appointment planning and scheduling can distribute better nurses' workload without extra resources. Fan et al. (2019) used, in turn, a simulation optimization framework to optimize patients scheduling in a medical outpatient service.

Many specialties have used DES in inpatient or outpatient units, clinics, or specialized hospitals, such as surgery (Cai & Jia, 2018; Diamant et al., 2018; Reese et al., 2020), orthopedic (Baril et al., 2014; Moretto, Comans, Chang, O`Leary, Osborne, Carter, Smith, Cavanagh, Blond & Raymer, 2019; Standfield, Comans, Raymer, O`Leary, Moretto & Scuffham, 2016), ophthalmology (Demir, Gunal, & Southern, 2016; Sethi et al., 2021), dialyses services (Allen, Bhanji, Willemsen, Dudfield, Logan & Monks, 2020), oncology (England, Harper, Crosby, Gartner, Arruda, Foley & Williamson, 2021), radiotherapy (Joustra, Van der Sluis & Van Dijk, 2010; Joustra, Kolfin, Van Dijk, Koning & Bakker, 2012) and endoscopy (Das, 2020; Day, Belson, Dessouky, Hawkins & Hogan, 2014), among others.

2.2 Capacity Planning

Capacity planning of an outpatient service consists of having the necessary resources available to improve performance (Baril et al., 2014). It is difficult to manage because, estimating the real needs of the service may be different from what was planned in theory (Gupta, Natarajan, Gafni, Wang, Shilton, Holder & Yusuf, 2007). Capacity planning is also a complex and ambiguous process where it is essential to counterbalance two opposing forces. On one hand, low capacity can contribute to an increase in patient waiting time and limit access to referrals. On the other hand, overcapacity can lead to wasted resources and unnecessary procedures. As pointed out by Gupta et al. (2007), temporary imbalances in demand and supply can also increase waiting lines. Due to financial constraints and increasing demand, services need to be efficient in the use of their resources. Improving efficiency of these services can be accomplished by boosting the match between demand and capacity (Demir et al., 2016).

Several publications have described using DES for capacity planning in distinct areas of intervention.

Reese et al. (2020) simulated the operations of an Ambulatory Surgical Center using DES, to model physical capacity, and identify how to avoid overcrowding of a post-anesthesia care unit while maintaining the same number of beds and increasing the number of operating rooms. The model was validated through face validity by a team of physicians and nurses, through internal validity with code review, and external validity. For safety and efficient operation during overcrowding, it was established by teams' opinion, that the weakly limit to be tolerated is 60 minutes of crowding. As a result, the total number of patients that can be seen per day is fifty.

Baril et al. (2014) analyzed the performance of an outpatient orthopedic service, using DES to study the relationships and interactions between patient flows, resource capacity, and appointment scheduling rules, to improve service performance. This model was evaluated to understand how to assign the offices and nurses to each orthopedist, considering four rules for scheduling appointments and three types of patient flows. The study concludes that for better performance, the appointment scheduling rule must be suitable for different patient flows.

Gupta et al. (2007) recognized that waiting times for procedures such as cardiac catheterizations were high and had a profound impact on the health system. Unit capacity planning was also a challenge, as it was difficult to predict what the actual need for the service would be. The researchers aimed to demonstrate that it was possible to perform these calculations using computer simulation. They concluded that determining capacity is a complex and dynamic process and that a combination of clinical and administrative data with computer simulation helps to estimate capacity needs and determine what the most appropriate strategy to minimize patient waiting lists is.

Rau et al. (2013) applied DES in an outpatient physiotherapy service to help with strategic planning of the service's capacity. Problems such as seasonality and fluctuations in patient visits to the service throughout the week interfered with the efficiency in planning the service's capacity. The study aimed to find the maximum service capacity limits per session. Several scenarios were analyzed on the impact of service capacity planning strategies with performance indicators such as dwell time and waiting time, among others, using the DES model. Sensitivity analysis showed that attending to more patients would significantly increase the number of patients in extra sessions. The average waiting time could be reduced by 45% when two therapists joined. Treating up to twelve new patients had no significant impact on patient return. It was also found that prioritizing new patients would reduce the average waiting time.

Viana et al. (2020), used a hybrid agent-based DES model to assess alternative settings to obtain information about clinic planning and decision-making support. This model was built to assess the maximum number of appointments that can be fulfilled during standard clinic opening hours. The accessibility to a cardiotocography machine was considered a bottleneck by the simulation model, which means that adding one cardiotocography machine would increase clinic performance. Furthermore, it was concluded that adjusting patient trajectories and scheduling appointments without additional resources, could reduce the length of stay of patients.

Day et al. (2014), in turn, applied DES to optimize efficiency and operation at a safety-net endoscopy center. The objective was to detect chances to improve patient performance while managing resource utilization and patient waiting times. DES was used to evaluate some proposed changes to improve efficiency. The validation of the model was made by expert opinion through meetings with staff members. The use of DES allowed the authors to conclude that slight modifications such as reducing appointment times, minimizing recovery room time, and increasing additional staff in the pre-procedure, had the potential to enhance the efficiency of the endoscopy center without increasing costs.

This study focuses on DES and capacity planning, applied to an outpatient service, more specifically, to an endoscopy unit. Although there are published papers exploring the use of DES for modeling pathway or patient trajectories of endoscopy centers, the number of papers exploring DES for capacity planning is small. Furthermore, to the best of our knowledge, no studies were yet published documenting the use of DES to study the impact of capacity planning on the performance of a Special Exams Unit in Portugal. Therefore, by achieving this objective, this study makes an important contribution to the literature.

3. METHODOLOGY

3.1 Simulation Process

Simulation is the application of a computer program to build a model of a real system and to test measures that might interfere with the system (Concannon, Elder, Hindle, Tremble & Tse, 2007). It can evaluate different scenarios to realize how decision-making interferes in complex systems, particularly with stochastic process times and demand (Romero, Dellaert, van der Geer, Frunt, Vullers & Krekels, 2013).

For the simulation to be as accurate and reliable as possible, it must follow a set of steps as illustrated in Figure 3.1.

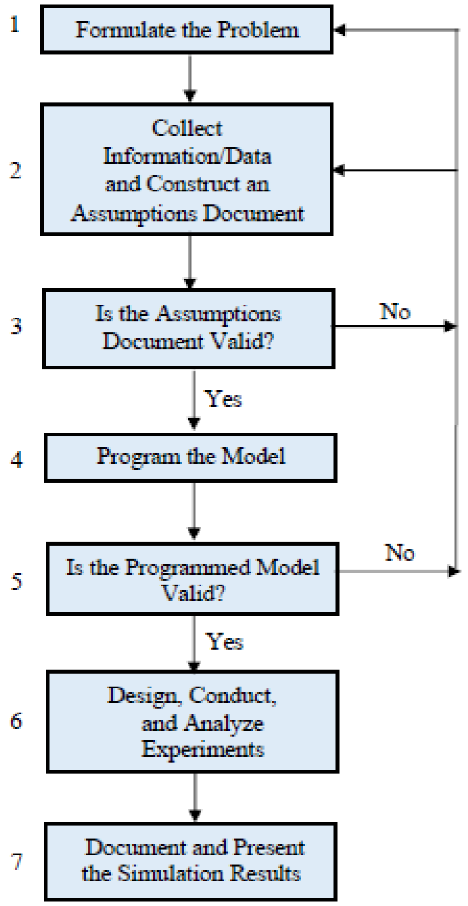

Figure 3.1- A seven-step approach for conducting a successful simulation study.

Source: Law (2008)

The formulation of the problem (step1) is one of most important stages of simulation model construction. To identify the problem and objectives to achieve, it is important to have the opinion of stakeholders, decision-makers, and experts. A meeting should be carried out to establish what the main and specific objectives are. Inaccurate objectives may lead to models with high complexity and with low reliability, the same is to say that simulation models should be simple and precise (Hamrock et al., 2013; Law, 2008).

On step 2, data and information should be collected for the different parameters of the model and a document should be written with all the assumptions considered. The detail of the information/data to be collected will depend on the desired accuracy of the simulation model. An inaccurate level of detail may lead to a failure in the interpretation of the functioning of the real system. When data is insufficient for describing a model parameter, assumptions need to be made and integrated into the simulation model (Hamrock et al., 2013; Law, 2008).

For assumption validation (step3), stakeholders and experts should be consulted to ensure that all assumption that had been made for the simulation model are validated. In case inconsistencies are detected, they need to be reviewed before advancing to the programming of the model (Law, 2008).

On step 4, programming the model, all data collected regarding the model parameters should be used to create a model of the functioning of the real system. In this step, specialized software like SIMUL8 can be used (Hamrock et al., 2013). SIMUL8 is a software for DES that was developed by SIMUL8 Corporation and can create a visual 2D model of a system process using six main components (i.e., Start points, Queues, Activities, Ends, Resources and Routing Arrows) (Kuncová, Fábri & Klímová, 2020).

Then, in step 5 - Program model validation, it is necessary to check if all parameters were adequately introduced (input data) in the software program. To ensure validation of a simulation model, it is crucial that the model satisfactorily reflects the functioning of the real system. To ensure that, a comparison can be made between the results generated by the simulation model and those obtained from the real system. Model validation can also occur through face validation, if the results from the simulation are reasonable and if they are consistent with system operability (Hamrock et al., 2013; Law, 2008).

On step 6, design, conduct, and analyze experiments, the model simulation is used to analyze various scenarios, and evaluate the impact of these scenarios on performance measures (Hamrock et al., 2013).

Finally, on step 7, document and present the results, all information about the simulation model should be documented, including assumptions considered, scenarios tested, and results obtained. For model reliability, an animation and a discussion of the construction and validation process of the model need to be included and presented to the decision makers (Law, 2008).

3.2 Conceptual Model

As indicated previously, in the Special Exams Unit exams are performed in several specialties such as Cardiology, Gastroenterology, Urology, and Pulmonology. Due to the complexity of the system object of analysis and the exploratory nature of this research, our analysis will only focus on the flow of gastroenterology patients.

The patient flow was mapped through interviews with experts from the Unit (i.e., members of staff), and through direct observation of the real process system (Figure 3.2).

The Special Exams Unit operates five days a week, Monday through Friday. The exams are scheduled between 8:30 a.m. to 12:30 p.m. and between 14:00 p.m. to 18:30 p.m. There may be changes in the schedule according to the number of exams scheduled. The Unit also opens on Saturdays if necessary. The gastroenterology exams are performed on a specific schedule. On Tuesday and Thursday exams are scheduled from 8:30 a.m. to 18:30 p.m. and on Monday from 8:30 a.m. to 12:30 p.m. However, biweekly they are also performed on Mondays from 14:00 p.m. to 18:30 p.m. In the same way, biweekly, exams are also schedule from 8:30 a.m. to 18:30 p.m. on Wednesdays and Fridays. To achieve the objectives proposed in this study, we focused only on Thursdays. This choice is justified by the fact that on this day of the week only gastroenterology exams are scheduled, and all the exams are conducted by the same gastroenterologist. However, a similar process can be adopted to analyze capacity planning of the Special Exams Unit for other days of the week.

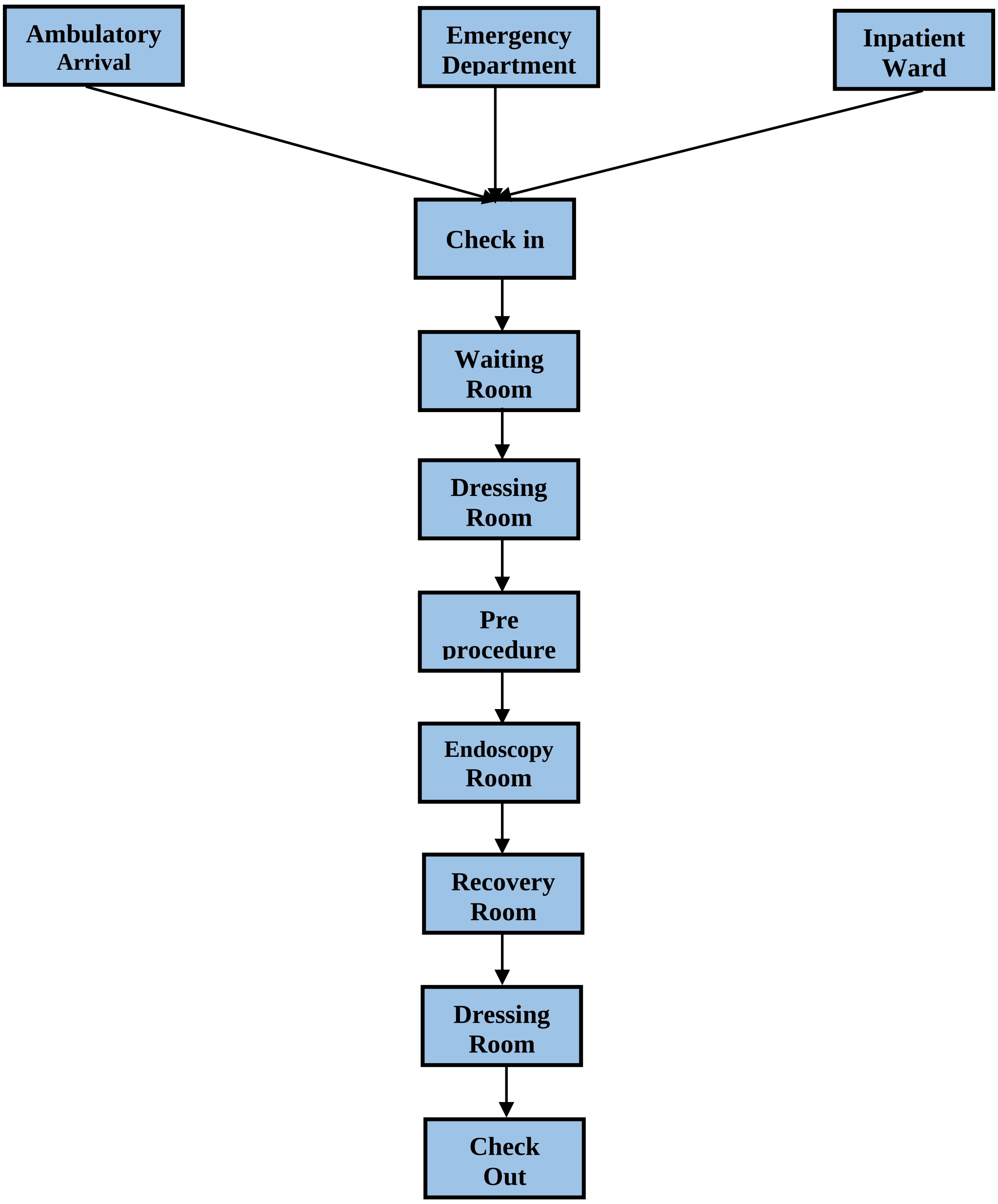

Figure 3.2 - Conceptual Model for the Special Exams Unit

Structurally, the Unit has a reception, a waiting room, a dressing room, a recovery room with 4 beds, which operates as a pre-preparation room and as a recovery room after sedation procedures, a procedure room for procedures without sedation, and a procedure room that can perform procedures with and without sedation. It also has a reprocessing room for endoscopes, and two offices intended for consultations. In the reprocessing room, 9 endoscopy instruments, 4 for upper gastrointestinal (GI) endoscopy and 5 for lower GI endoscopy, are available.

The Special Exams Unit is an ambulatory service but gives support to the inpatient ward and to patients from the emergency department. These patients are admitted to the Unit as extra patients on schedule. The gastroenterology exams are scheduled with an interval of 1 patient every 30 minutes.

The reception is exclusive for patients admitted to the Unit. When the patient arrives at the Unit, he/she is admitted and then goes to the waiting room and waits that the nurse calls him/her to initiate the preparation. When the nurse calls the patient for preparation, usually gives him/her orientation to change his/her clothes in the dressing room. In the preparation room, the nurse starts the patient's initial evaluation and collects the patient's data. To maintain elevated levels of quality, the hospital has a checklist for a secure procedure that needs to be fulfilled and which starts when the nurse calls the patient. After checking vital signs and putting on a peripheral venous catheter, if it is a procedure with sedation, the patient is ready for the exam and waits. To perform the procedure, in the procedure's room there will be 1 gastroenterologist, 1 anesthesiologist, and 2 nurses. Whenever this room is ready, a nurse from the procedure's room, transports the patient to the room. After confirming the type of exam with the patient and checking if consent for the exam and sedation have been signed, the procedure is initiated. When the exams are finished, the patient goes to the recovery room and stays there until he/she recovers from anesthesia. The nurse confirms that the patient is awake and does not show evidence of any complication from the exam or anesthesia and, if this is confirmed, the patient is discharged and sent to the dressing room. After the patient finishes changing his/her clothes, the patient is sent to the waiting room and then to reception for check-out. All patients are discharged after confirming that they have someone to take them home.

3.3 Data Analysis

Once the conceptual flow of patients was mapped and validated (see Figure 3.2), data were collected to allow the programming of a model for the Unit. In particular, we collected data related to all the exams performed on Thursdays at the Special Exams Unit between January and April 2022. During this period, 261 patients had exams scheduled, but 8 did not show up. Data were, therefore, collected for a total of 253 individual patient (Table 3.1). This data was extracted from electronic record data from the hospital, nursing records from the patients' handling process, and from the appointment-scheduling system. Of these 253 patients, 6 were exclude due to lack of data. The information was collected by categories, such as type of exam (upper and lower GI endoscopy, upper GI endoscopy and lower GI endoscopy), the number of exams performed per day, patient arrival (check-in), preparation process time for the exam, procedure exam time, recovery time and length of stay in the unit. Table 3.2 shows the parameters of the model, their definition, and the source of the data.

Table 3.1- Data summary of the Unit

Month	Day	Number of patients admitted	No show	Number of upper and lower GI endoscopy	Number of lower GI endoscopy	Number of upper GI endoscopy
January	6	17	0	9	5	3
	13	18	0	9	6	3
	20	17	0	9	6	2
	27	16	1	6	7	3
February	3	14	0	7	5	2
	10	14	0	8	3	3
	17	19	0	8	6	5
	24	16	1	11	4	1
March	3	13	0	5	6	2
	10	18	0	7	9	2
	17	16	2	5	7	4
	24	16	2	10	5	1
	31	11	0	4	6	1
April	7	18	0	9	7	2
	14	15	1	5	6	4
	21	15	1	4	7	4
	28	0	0	0	0	0
Total (n=261)		253	8 (3.1%)	116 (45.8%)	95 (37.5%)	42 (16.6%)

The check-in time was collected from the appointment schedule system and corresponds to the time when the patient reached the receptionist and was admitted to the Unit. Through nursing records and electronic record data from patients, it was possible to obtain four timestamps: verification from nurse before patient gets inside the procedure room (corresponds to the stage of the process when the nurse calls the patient to the dressing room and starts preparation), verification before the procedure begins, verification after the procedure finishes and verification before the patient goes out of the recovery room.

Table 3.2- Model parameters' definition

Parameter	Definition	Source
Check-in time	Time when patient is admitted to the system	Appointment schedule system
Dressing Room	Time in minutes that a patient spends by changing clothes and getting prepared to go into the procedures' room;	Electronic record data; Interviews with expert nurses from the unit;
Patient preparation process • **Nursing data patient collect;** • Patient preparation;	Time in minutes between the moment a nurse calls the patient to the dressing room and the moment the patient is called to the procedures' room; Time in minutes that a nurse takes to gather information from a patient and check that the patient´s process is complete; Time in minutes that a nurse takes to prepare a patient (placement of peripheral venous access, checking vital signs…)	Electronic record data; Nursing records (checklist secure procedure); Interviews with expert nurses from the unit;
Exam procedure process • **Exam preparation;** • Upper and Lower GI endoscopy procedure time; Lower GI endoscopy procedure time; Upper GI endoscopy procedure time; • Medical and Nursing reports;	Average time between the moment a patient enters the procedure room and the moment he/she is transferred to the recovery room; Time in minutes that takes to prepare the procedure`s room and prepare patients to initiate procedure; Average time that takes to do the procedure exam; Time in minutes that the medical team (gastroenterologist and anesthesiologist) and nurses take to make the exam`s report;	Electronic record data; Nursing records (checklist secure procedure); Interviews with expert nurses from the unit;
Recovery Process • Patient Recovery • Nursing Procedure	Average time between the moment a patient is transferred from the procedure room to the recovery room and the moment he/she is discharged from it. Time in minutes that a nurse takes to check the patient (Vital signs…) and prepare the patient for discharge (Remove peripheral venous access, instructing about the proper care after the exam and clarifying any pending questions);	Electronic record data Nursing records (checklist secure procedure)

Parameter	Definition	Source
Length of stay	Average time between the moment a patient is admitted to the system and the moment he/she is discharged from the recovery room	Appointment schedule system Electronic record data Nursing records (checklist secure procedure)

It is important to highlight that the patients' flow does not change according with the type of exam. The only difference is the time of the procedure, as some types of procedures (e.g., simultaneous upper and lower GI endoscopy procedure) take longer than others (e.g., only upper or only lower GI endoscopy procedure).

Due to lack of information on nursing records and electronic record data, some parameters were obtained through interviews with nurses from the Special Exams Unit, which helped to simplify this complex model.

Data were recorded and analyzed using Microsoft Excel version 365 and the Statistical Package for the Social Sciences version 28.0.1.0. (Table 3.3). The Stat::fit® version 2 program was used to analyze the statistical distributions of the collected data (Table 3.4).

Table 3.3- Summary Statistics of the Unit Data

	Preparation Process Time (min)	Upper and Lower GI Endoscopy Procedure Time (min)	Lower GI Endoscopy Procedure Time (min)	Upper GI Endoscopy Procedure Time (min)	Recovery Time (min)	Length of stay on system (min)
Valid Data	247	113	93	41	247	247
Mean	31.35	19.35	15.24	10.80	33.64	101.43
Std. Error of Mean	1.129	1.243	1.224	1.087	0.728	1.895
Median	30.00	17.00	14.00	9.00	31.00	95.00
Std. Deviation	17.742	13.211	11.800	6.961	11.449	29.78
Variance	314.790	174.534	139.248	48.461	131.076	886.799

Table 3.4- Statistical distributions of some parameters of the model

Parameter	Statistical Distribution	Values
Check-in	Probability Profile distribution	***
Upper and lower GI endoscopy procedure time	Pearson VI	9.81, 34.5, 62.2
Lower GI endoscopy procedure time	Probability Profile distribution	***
Upper GI Endoscopy procedure time	Pearson V	4.91, 44.5 (offset -1.09)

3.4 Discrete Event Simulation Model

A DES model was built to illustrate the Unit's workflow using SIMUL8 version 29.0 (Figure 3.3) and based on process map and data analysis.

The variables were set in the simulation according with the information presented in Table 3.5, and this information was a result of the data analysis performed.

Table 3.5- Information used in the modeling of the DES Model

Variables	
Number of waiting rooms	1
Number of beds of preparation/recovery room	4
Number of procedure rooms used	1
Number of patients scheduled per hour (8:30 a.m. -12:00 p.m. and 1:30 p.m. - 6:15 p.m.)	2
Check-in time	Average 5 minutes
Dressing room	Average 5 minutes
Bed Attribution	***
Patient Preparation Process	
Nursing Data Patient Collect	Average 5 minutes
Patient Preparation	Average 8 minutes
Exam Procedure Process:	
Exam Preparation	Average 5 minutes
Upper and Lower GI endoscopy	Pearson VI (9.81, 34.5, 62.2)
Lower GI endoscopy	Probability Profile distribution
Upper GI endoscopy	Pearson V (4.91, 44.5, offset -1.09)
Medical and nursing reports	Average 8 minutes
Recovery Process	
Patient Recovery	Average 20 minutes
Nursing Procedures	Average 10 minutes
Check-out	Average 5 minutes

The model was programmed attending to the flow of the patients and the values estimated for the parameters. Admission activity was configurated using an average of one patient every 30 minutes. Considering that lunch time takes place between 13:00 pm. to 14:00 pm., the admission activity was constrained using a shift pattern with a morning shift (8:30 a.m. to 12:00 p.m.), and an afternoon shift (13:30 p.m.-18:15 p.m.).

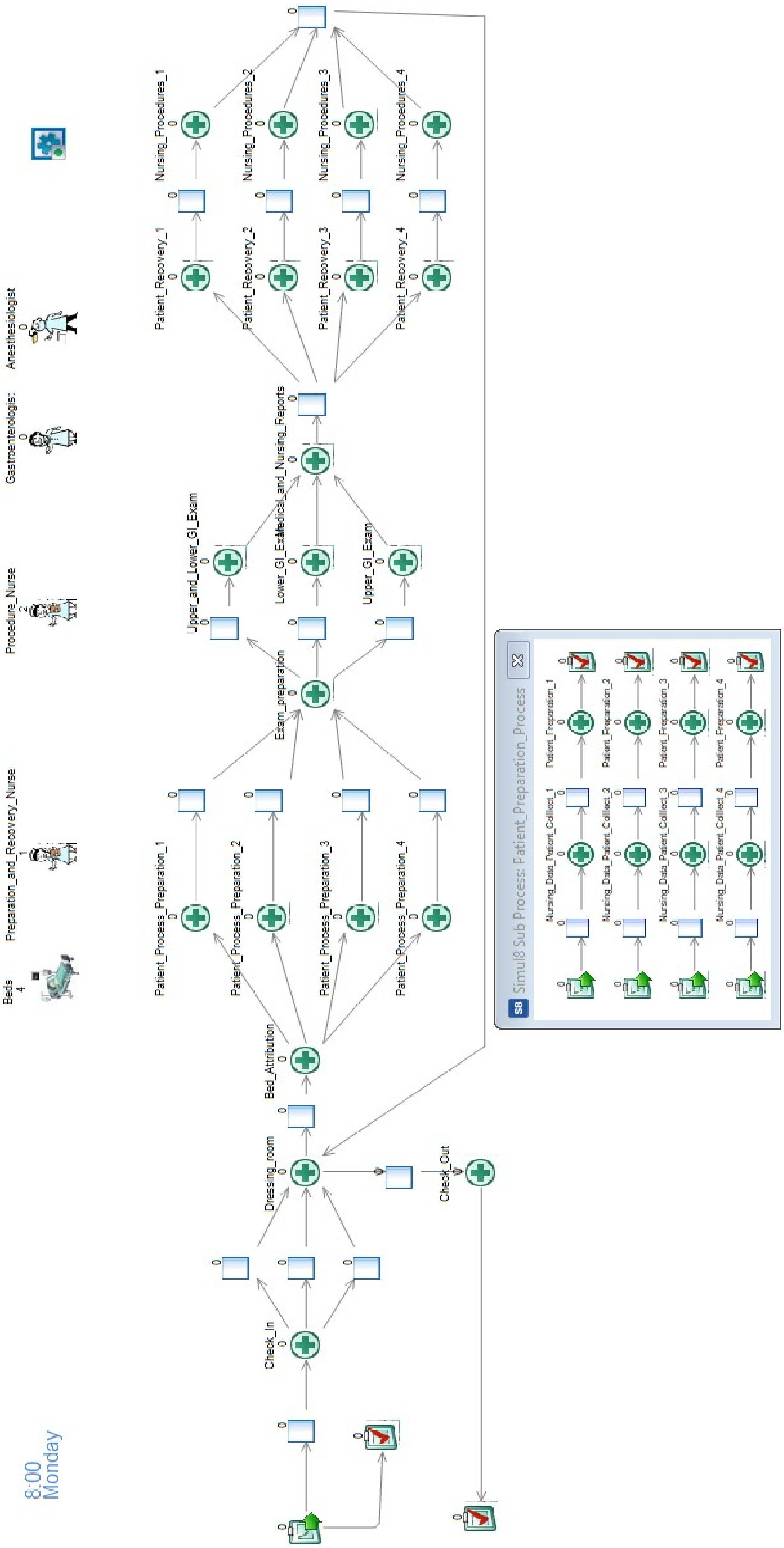

Figure 3.3- Model Structure

For the routing of patients, it was used a percent discipline to queue for check-in and no-show, with the values of 97% and 3%, respectively.

Unfortunately, it was not possible to gather data for the check-in, so it was assumed an average registering time of 5 minutes. In terms of the check-in of patients, it was also created a label (lbl_Exam_Type) and defined a probability profile for the triage considering the number of patients admitted for the diverse types of exams (Figure 3.4).

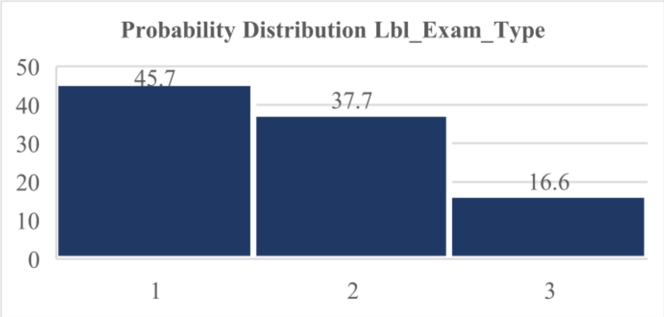

Figure 3.4- Probability Distribution Lbl_Exam_Type

Three value attributes were set on this probability profile: a value of 1 for Upper and Lower GI Endoscopy, a value of 2 for Lower GI Endoscopy and a value of 3 for Upper GI Endoscopy.

Three different waiting rooms were also defined by type of exam, to control for the number of patients admitted by type of exam. Capacity of the system was set to infinite, and no shelf life was assumed to maximize throughput.

Due to the COVID pandemic, all patients submitted to exams with sedation need to bring a negative certificate test, carried out in the last 72 hours before the exam appointment. Sometimes, the patient forgets to do the test or has an inconclusive result. In these cases, it is offered to the patient the option of taking an express COVID test in the hospital laboratory, which delays the appointment and increases waiting room time.

The dressing room activity, due to lack of information about how much time patients spend at the dressing room, was configurated with an average of 5 minutes and it was validated with nursing experts' opinion. This is a complex activity because it can be a bottleneck activity according to the nursing experts, due to the fact that this is the same room where patients' change clothes for getting inside the unit preparation room and where they go once they are discharged from the preparation room. To prevent the model simulation from reintroducing into the system a patient that had already done the exam procedure, it was attributed to the Lbl_Exam_Type a value of 4 at the Upper and lower GI Exam, Lower GI Exam and Upper GI exam. So that the routing out of patients from the dressing room was made by a discipline condition, using lbl_Exam_Type value. Labels with values of 1, 2 and 3 had the indication to continue to queue for bed attribution, while patients with the label value of 4 were sent to queue for check-out.

In the real system it is attributed a bed to a patient when he/she goes inside the preparation room and maintains the same bed during the total length of stay at the unit. In the model simulation, configuring the situation of bed attribution presented some challenges. To address this, a setup was implemented where, upon receiving a work item, a resource bed was assigned to it. A specific requirement was set to ensure that this resource could not be released or freed during the process. This configuration aimed to simulate a situation where once a patient was allocated to a bed, the patient would remain in that bed during the full simulation, reflecting a realistic constraint in the system. In order to avoid blocked routes, a dressing room group was established, consisting of bed allocation and queue assignment objects. It was configured to allow only one work item at a time, ensuring that the model simulation does not receive more than one work item at these two objects. Additionally, this setup prevents the dressing room from receiving any other work item that could potentially block the route.

It is important to bear in mind that the patient flow at the Unit is not unidirectional. Although in Figure 3.2 a unidirectional flow is represented, this was only to simplify the understanding of the process. In practice, after the patient passes through the dressing room, he/she is assigned to a bed where he/she will be prepared and then, in the same bed, he or she will go to the procedure room and comes back to the preparation process for recovery once the procedure is performed. The patient preparation process and the recovery process have different processing times. To bypass this situation, we designed four work centers for preparation prior to admission of the patient in the procedure room and four work centers after the procedure, for recovery beds. To each work center was attributed a distribution time according to parameter model specifications.

The patient preparation process was configurated using a timing orientation by subprocess, and 4 subprocesses were create, one for each bed (Figure 3.5).

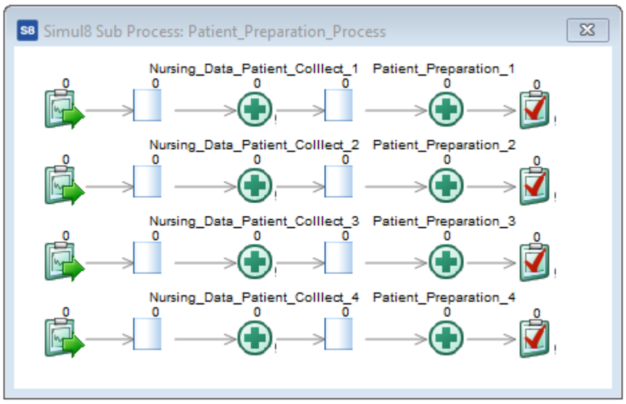

Figure 3.5- Simul8 Subprocess: Patient Preparation Process

Each subprocess was created using the same objects. Start point was configurated with none (no automated arrival's), queues with infinite capacity and no shelf life. The activities Nursing data patient collect, and Patient preparation were created using data information from nursing experts' opinion and were configurated with an average of 5 and 8 minutes, respectively. In order to mitigate blocked routes and manage the workload efficiently on the patient preparation route, a group was formed incorporating all the objects utilized in the subprocess along with the queue for exam preparation. The group was configured to accommodate a maximum of 4 work items, representing the available beds for patients. This configuration ensures that the model simulation on the patient preparation route does not exceed the limit of 4 work items, promoting smoother workflow and preventing congestion.

The procedure Exam Process was divided in 3 principal activities. The exam preparation was configurated with an average of 5 minutes. To rout out patients it was used a discipline by condition, using the label lbl_Exam_Type with different destinations. A value of 1 was used for the Upper and Lower GI endoscopy procedure room, a value of 2 for the Lower GI endoscopy procedure room, and a value of 3 for the Upper GI endoscopy procedure room.

The Procedure exam room in the real system corresponds to only one procedure room with sedation. The last version of SIMUL8 enables a single work center configurated with a label control by timing, making possible to attribute to each label value a different statistical distribution. This situation was tested but it was not possible to obtain operation times by label, only an average of this time, which would be not comparable to the data we obtained for the real system, as it refers to each particular type of procedure. So, we decided to create specific procedure rooms for each type of exams. As a consequence, three different work centers were created, each one with a specific distribution time, dependent on the type of exam to be performed.

In the procedure room, GI endoscopic instruments are used for diagnostic and therapeutic intervention (e.g., polypectomy), therefore, the procedure time can increase according to the degree of complexity of the intervention. In order to determine the values to consider in the simulation model regarding this parameter, we decided to remove extreme outliers from data (Figure 3.6, 3.7, 3.8).

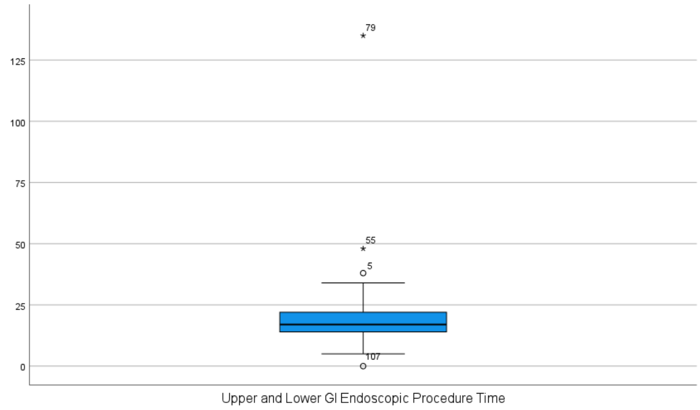

Figure 3.6- Upper and Lower GI Endoscopy Simple Boxplot

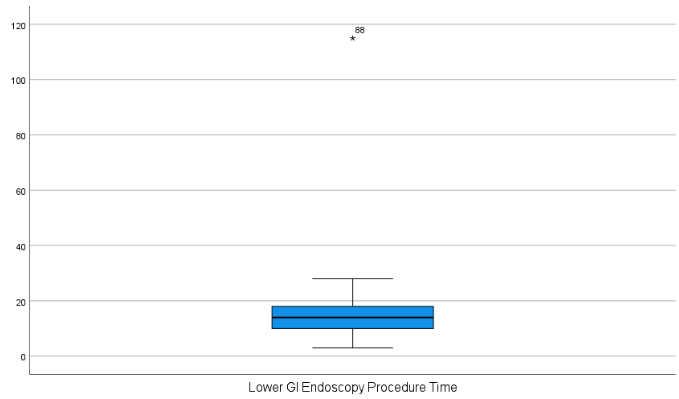

Figure 3.7 - Lower GI Endoscopy Simple Boxplot

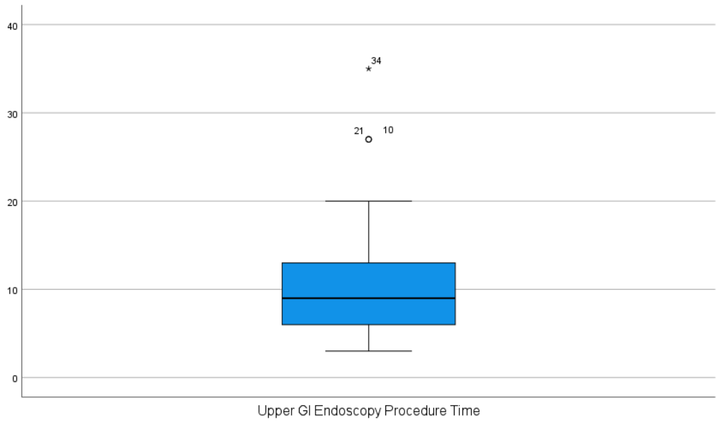

Figure 3.8- Upper GI Endoscopy Simple Boxplot

To determine the Upper and Lower GI endoscopy procedure room time it was used information for 111 patients. Through Stat::fit® analysis, the Pearson VI distribution (Table 3.6), was identified as providing the best fit, with values of alpha1 9.81, alpha2 34.5 and beta 62.2 (Figure 3.9).

Table 3.6 - Stat::fit® Autofit of Distribution: Upper and Lower GI Data Analysis

Distribution	Rank	Acceptance
Pearson 6(0, 62.2, 9.81, 34.5)	100	Do not reject
Beta (0, 2.59e+004, 7.67, 1.09e+004)	58.4	Do not reject
Pearson 5(-22, 34.3, 1.34e+003	51	Do not reject
Lognormal(-24.3, 3.73, 0.159)	32.4	Do not reject
Erlang(-11.3, 19, 1.54)	29.7	Do not reject
Chi Squared(-6.95, 25.1)	27.8	Do not reject
Gamma(-11.3, 18.4, 1.59)	27.5	Do not reject
Weibull(-1.83, 3.08, 22.2)	2.71	Do not reject
Normal(18.1, 6.82)	2.29	Do not reject

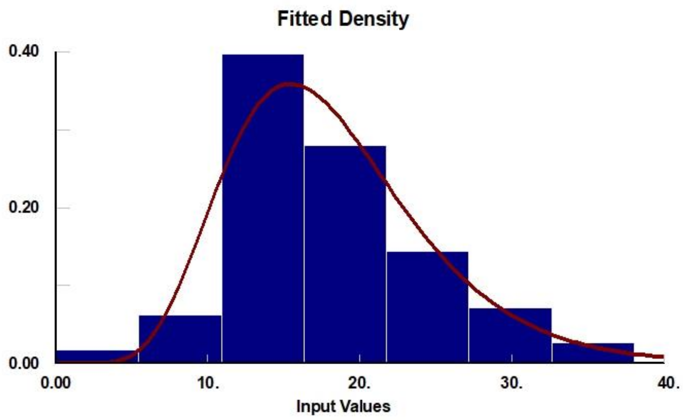

Figure 3.9- Pearson VI Distribution of Upper and Lower GI Endoscopy Procedure

For the model parameter, Lower GI endoscopic procedure room time, a similar procedure was performed but using data for 92 patients. The Stat::fit® analysis, also suggests that the Pearson VI distribution (Table 3.7) provides a reasonable fit (rank 50.9), with values of alpha1 4.55, alpha2 16.3 and beta 38.2 (Figure 3.10). However, after introducing this information into the simulation model and performing some tests, it was concluded that the results generated differed significantly from the ones observed in the real system, so we decided to define and use a probability distribution profile for this parameter as illustrated in Figure 3.11. This ensured that the simulation model generated more reliable results.

Table 3.7- Stat::fit® Autofit of Distribution: Lower GI Data Analysis

Distribution	Rank	Acceptance
Pearson 6(3, 38.2, 4.55, 16.3)	50.9	Do not reject
Pearson 5(-16.7, 32.8, 980)	45.5	Do not reject
Lognormal(-11.5, 3.22, 0.211)	38.4	Do not reject
Chi Squared(-1.63, 15.8)	38.2	Do not reject
Erlang(-3.33, 10, 1.75)	35.2	Do not reject
Gamma(-3.33, 10.1, 1.73)	35.2	Do not reject
Beta(3, 44.8, 2.91, 7.88)	17.9	Do not reject
Weibull(1.96, 2.35, 13.7)	13.4	Do not reject
Rayleigh(2.6, 9.04)	10.9	Do not reject

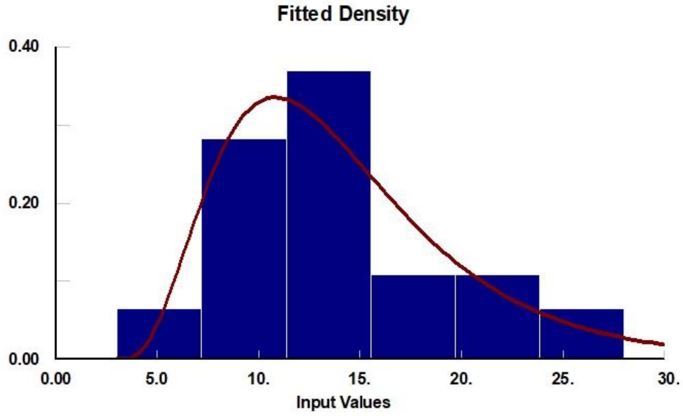

Figure 3.10- Pearson VI Distribution of Lower GI Endoscopy Procedure

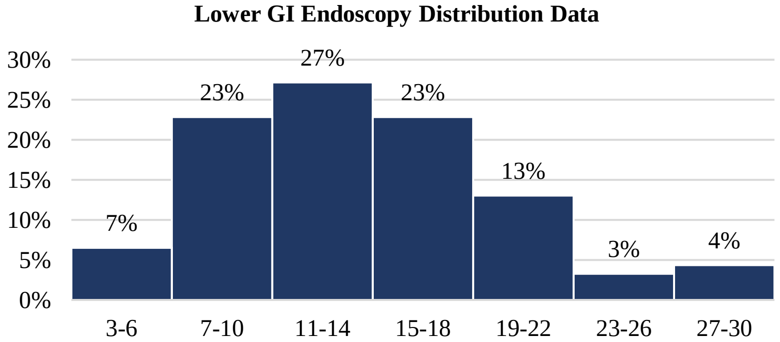

Figure 3.11 - Lower GI Endoscopy Distribution Data

For the Upper GI endoscopic procedure room time, we only had data for 40 patients. Despite this, the Stat::fit® analysis, suggested that the Pearson V distribution offered a good fit, rank 99.9 (Table 3.8), with alpha 4.91 and beta 44.5, offset -1.09 (Figure 3.12).

Table 3.8- Stat::fit® Autofit of Distribution: Upper Data Analysis

Distribution	Rank	Acceptance
Pearson 5(-1.09, 4.91, 44.5)	99.9	Do not reject
Lognormal(1.1, 2.02, 0.619)	95.2	Do not reject
Erlang(2.65, 2, 3.77)	72.5	Do not reject
Gamma(2.65, 1.66, 4.54)	68.8	Do not reject
Weibull(2.85, 1.27, 7.9)	51.9	Do not reject
Beta (3, 7e+004, 2.06, 1.91e+004)	37.9	Do not reject
Pearson 6(3, 11.5, 3.13, 5.72)	32.7	Do not reject
Chi Squared(-0.976, 10.9)	31.8	Do not reject
Rayleigh(0.958, 7.71)	6.39	Do not reject

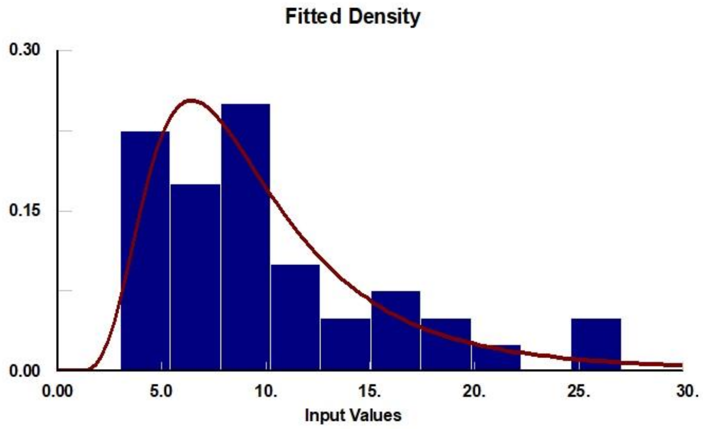

Figure 3.12 – Person V Distribution of Upper GI Endoscopy

The Medical and Nursing report activity was configurated using an average duration of 8 minutes, using information obtained from nursing experts' opinion. The routing out was modelled by using the circulate discipline and the label lbl_Exam_Type was changed to a value of 4.

Recovery time data was collected from nursing records (Figure 3.13), but when it was analyzed on the Stat::fit® software, no statistical distribution provided a good fit (Table 3.9). We could have used a probabilistic profile distribution using data collected. However, we decided to divide the recovery time process into 2 activities: patient recovery and nursing procedures. One of the reasons for choosing this modeling is related with the time the nurse stays with the patient. If only one activity was defined, with an average time of 30 minutes, the resource would remain in that activity for the entire time, which is not correct, according to the opinion of the nursing experts. According to them, the average time is 10 minutes, so the Nursing procedures were configurated with an average duration of 10 minutes and Patient recovery with an average duration of 20 minutes.

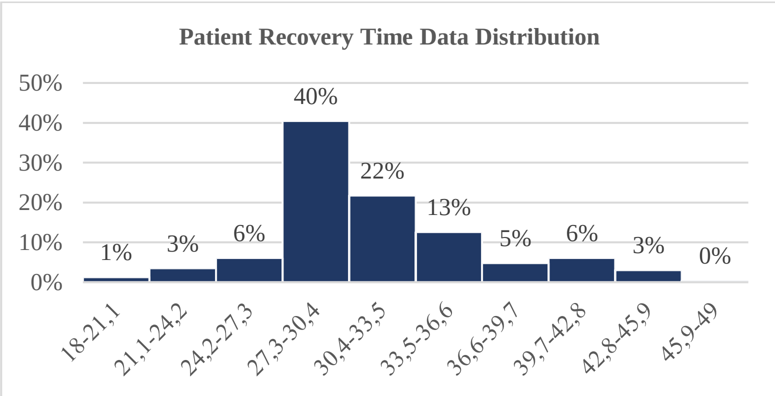

Figure 3.13 -Recovery Bed Distribution Data

Table 3.9- Stat::fit® Autofit of Distribution: Patient Recovery Time Data Analysis

Distribution	Rank	Acceptance
Pearson 5(-5.31, 64.3, 2.35e+003)	0.982	Reject
Beta (18, 46, 3.76, 3.78)	0	Reject
Erlang (6.51, 29, 0.872)	0	Reject
Gamma (6.51, 29.1, 0.869)	0	Reject
Lognormal (-10.5, 3.74, 0.109)	0	Reject
Normal (31.8, 4.65)	0	Reject
Exponential (18, 13.8)	0	Reject
Pearson 6(18, 42.7, 10.7, 34)	0	Reject
Triangular (17.8, 46.6, 30)	0	Reject

Considering that it was not possible to obtain data regarding the time taken to do the check-out of the patients, for the purpose of this study it was assumed that this activity had an average duration of 5 minutes.

This model simulation uses human and physical resources. During the patient preparation process and the recovery process, nursing care is provided by only one nurse, denominated in the model as Preparation and Recovery nurse. This resource was configurated as only 1 available, working between 8:00 a.m. to 20:00 p.m. but with an availability of 91.6%, to account for 1 hour of lunch time.

For the Exam procedure process, 2 nurses are needed. On the simulation model they are denominated as Procedure Nurses. This resource was configurated as only 2 available, working between 8:00 a.m. to 20:00 p.m. but with an availability of 91.6%, considering the same rationale mentioned above.

The Gastroenterologist and Anesthesiologist resources are used to perform the activities Procedure exams and Medical and Nursing reports and only 1 resource of each type is available. These resources were configurated to account that only 1 resource of each type is available, and to account that they work between 9:00 a.m. to 20:00 p.m. but with an availability of 90.9%, as1 hour of lunch time was removed.

As mentioned previously, this simulation model specifically focuses on the flow of gastroenterology exams. Due to the absence of available data and the complexity it would introduce to the model, certain activities that can be performed by human resources are not explicitly mentioned. Consequently, the utilization rates of these resources may not precisely reflect reality and can result in lower utilization rates than those observed in practice. However, despite this limitation, our model can still provide valuable insights and yield reliable results.

It is also important to highlight that for the procedures to take place, as mentioned above, a set of resources need to be available. In particular, it was considered that each procedure could only be carried out if one gastroenterologist, one anesthesiologist and two nurses were available. Resource utilization was used to guarantee that only one procedure was performed at each time to correspond to reality (only one procedure room is used at the Unit).

For simulation purposes, the clock property units were set to minutes, with a format of day time, and with a specific day of the week, only one day per week. For the running time of the simulation, we defined the starting time at 8:00 a.m. with a duration of 12 hours, to guarantee that the unit is empty at the end of the day. The warmup period was set to 0.

To promote throughput and maximize capacity, we assumed that endoscopes were always available. Cleaning time after each procedure and patient discharge was not considered in the model.

3.5 Model Validation

In order to validate the DES model and guarantee its accuracy, the results from the baseline simulation were verified by experts from the Unit (gastroenterologist and nurses from the procedure room/recovery room). The simulation animation was also analyzed by experts from the Unit, to confirm that patients in the model were following an appropriate flow.

A comparative analysis was also performed by comparing real data with the simulation output data, with the objective to validate the model. Reliable results were obtained, with some of the variables showing a good correlation with the unit's real data.

Despite the complexity of the simulation model, the model generated reasonable results, which allowed its validation and allowed us to proceed to the next stage, which we discuss in what follows, related with the analysis and testing of scenarios.

4. RESULTS/ DISCUSSION

4.1 Results Obtained

A total of 261 patients had exams scheduled between January and April of 2022, corresponding only to one day per week. In this case, it corresponds to Thursdays. Of those 261 patient appointments scheduled, only 253 patients were admitted to the Special Exams Unit as 8 patients did not show up for the exam. Data were collected from patient information, such as, the appointment schedule system, electronic record data and nursing records. In order to configurate the simulation model, all extreme outliers were removed trough SPSS analysis (Table 4.10).

Table 4.10- Summary Statistics of the Unit Data -Without Extreme Outliers

	Preparation Process Time (min)	**Upper and Lower GI Endoscopy Procedure Time (min)**	**Lower GI Endoscopy Procedure Time (min)**	**Upper GI Endoscopy Procedure Time (min)**	**Recovery Time (min)**	**Length of stay on the system (min)**
Valid Data (observations)	246	111	92	40	230	247
Mean	31.01	18.05	14.15	10.20	31.80	100.93
Std. Deviation	16,953	6.853	5.497	5.858	4.659	28.790

An average of 16 patients were admitted every Thursday. These patients followed the flow depicted in our conceptual model. The preparation process between the dressing room and the moment the patient enters the procedure room, takes an average of 31.01 minutes with a standard deviation of 16.95 minutes. After getting inside the procedure room, the process has various times according to the type of exam performed. Patients admitted for an upper and lower GI endoscopy, take an average of 18.05 minutes with a standard deviation of 6.85 minutes. The lower GI endoscopy procedure takes on average 14.15 minutes with a standard deviation of 5.49 minutes. In turn, patients admitted for an upper GI endoscopy procedure take on average 10.2 minutes with a standard deviation of 5.86 minutes. After the exam, patients need to recover from the procedure in the recovery room. Recovery takes on average 31.8 minutes with a standard deviation of 4.66 minutes. Through data analysis it was possible to establish that the length of stay in the unit was around 100.93 minutes with a standard deviation of 28.79 minutes. This high standard deviation can be associated to several factors, such as, patients being admitted without COVID certification tests or due to procedures taking much longer than normal due to their complexity. As indicated before, for other parameters, such as check in and check out, because data was not available, we assumed that these processes take an average of 5 minutes.

A simulation model was developed to reproduce the current process of the Special Exams Unit based on real values from the data collected. To obtain an elevated level of precision, with a confidence interval (CI) of 95%, the simulation was run 902 times.

A comparison between the real data from the Special Exams Unit and the Simulation output data was performed. Due to the complexity in data interpretation, the analysis was conducted using multiple tables, segmenting them by process. Overall, we can conclude that the model developed produces acceptable results for most of the variables. In some cases, the fit can even be considered particularly good.

As we can see from the table with the Admissions and Exams performed (Table 4.11), most of the variables had acceptable results, but one variable shows a relative error superior to 10%. For example, the indicator Standard Deviation regarding the total time in the system presents an error higher than 10%. This significant difference between observed and simulated values could be associated with the model programming process, for example, the patient preparation process had a specific statistical distribution (Gamma, 4.02, 8.47), but we decided to dissect this data process, using for each activity an average statistical distribution, and this may have an impact on standard deviation of the total time in the system.

Table 4.11- Admission and Exams performed Output- Comparison between the Special Exams Unit Data and Baseline Simulation Output Data

Variables	**Special Exams Unit**		**Baseline Simulation output data**	**Relative Error**
			Average 95% CI	
Admission	**Number Entered**	**261**	**263.82**	**0.01**
No show	Number Completed	**8**	**8.03**	**0.00**
Exams performed	Number Completed	**253**	**255.31**	**0.01**
	Average Time in System	**100.93**	**108.26**	**0.07**
	Standard Deviation	**28.79**	**17.58**	**0.39**
	Maximum Time in System	**205**	**187.13**	**0.09**

As mentioned earlier, the Patient Preparation Process has a significant impact on simulation modelling. In the real patient preparation process, patients take an average of 31.01 minutes with a standard deviation of 16.95 minutes. This significant standard deviation time is justified by the waiting time for exam that can differ according to the complexity of the exam for example. On this model simulation, we used subprocesses by timing, with the aim to achieve accuracy on the modelling of the real activity performance of the Special Exams Unit. The patient preparation process from the real data is represented by the variables patient length of stay and waiting time for exam. If we look at the variables related with the Patient Preparation Process (Table 4.12), we conclude that most of the variables show a relative error superior to 10%, however this may be acceptable due to the modelling complexity and data interpretation.

Table 4.12- Patient Preparation Process Output- Comparison between the Special Exams Unit Data and Baseline Simulation Output Data

Variables	**Special Exams Unit**		**Baseline Simulation output data** Average 95% CI	**Relative Error**
Preparation process 1	Average Time	**31.01**	**36.75** [1]	**0.19**
	Standard Deviation	**16.95**	*	*
Patient Preparation length of stay 1	Average Time in System	*	**27.95**	*
	Standard Deviation	*	**7.1**	*
Queue 1 for Exam Preparation	Average Time in System	*	**8.8**	*
	Standard Deviation	*	**12.68**	*
Preparation process 2	Average Time	**31.01**	**36.77**	**0.19**
	Standard Deviation	**16.95**	*	*
Patient Preparation length of stay 2	Average Time in System	*	**27.88**	*
	Standard Deviation	*	**7.1**	*
Queue 2 for Exam Preparation	Average Time in System	*	**8.89**	*
	Standard Deviation	*	**12.71**	*
Preparation process 3	Average Time	**31.01**	**36.9**	**0.19**
	Standard Deviation	**16.95**	*	*
Patient Preparation length of stay 3	Average Time in System	*	**27.97**	*
	Standard Deviation	*	**7.17**	*
Queue 3 for Exam Preparation	Average Time in System	*	**8.93**	*
	Standard Deviation	*	**12.71**	*
Preparation process 4	Average Time	**31.01**	**37.09**	**0.20**
	Standard Deviation	**16.95**	*	*
Patient Preparation length of stay 4	Average Time in System	*	**28.1**	*
	Standard Deviation	*	**7.2**	*
Queue 4 for Exam Preparation	Average Time in System	*	**8.99**	*
	Standard Deviation	*	**12.76**	*

[1] The average time of preparation process 1 in the actual system corresponds to the sum of the time in the patient preparation length of stay 1 plus the time on queue 1 for Exam preparation in the simulation model. For example, Preparation process 1 (Average time)= 31.01 minutes corresponds to the sum of patient preparation length of stay 1(average time)=27.95 minutes plus queue 1 for Exam preparation (average time)=8.8 minutes. This sum is equal to 36.75 minutes. The relative error was calculated using this formula: Relative Error = (|Exact Value - Approximate Value| / |Exact Value|). Same logic was used on the remnant variables.

In which regards the Exams Process output (Table 4.13), all the variables show a relative error inferior to 10%. The variable Lower GI Endoscopy initially was configurated with a Pearson VI distribution that provided a reasonable fit but after some run simulations the results generated differed significantly from the ones observed in the real system. The configuration with a probability distribution profile was the best choice providing good reliable results.

Table 4.13- Exams Process Output- Comparison between the Special Exams Unit Data and Baseline Simulation Output Data

Variables	Special Exams Unit		Baseline Simulation output data Average 95% CI	Relative Error
Procedure Room - Upper and Lower GI Endoscopy	Average Time	**18.05**	*	**0.01**
	Standard Deviation	**6.85**	*	*
	Operation Time	*	**17.87**	*
	Number Completed jobs	**113**	**117.64**	**0.04**
Procedure Room - Lower GI Endoscopy	Average Time	**14.15**	*	**0.00**
	Standard Deviation	**5.49**	*	*
	Operation Time	*	**14.1**	*
	Number Completed jobs	**93**	**95.68**	**0.03**
Procedure Room - Upper GI Endoscopy	Average Time	**10.2**	*	**0.00**
	Standard Deviation	**5.85**	*	*
	Operation Time	*	**10.19**	*
	Number Completed jobs	**41**	**42.45**	**0.04**

In turn, the Patient recovery process from the real data is represented in the simulation model by three variables - patient recovery, waiting time from the queue to nursing procedure and nursing procedure. Regarding the Patient Recovery Process (Table 4.14), all the variables show a relative error inferior to 10%.

Table 4.14- Patient Recovery Process Output- Comparison between the Special Exams Unit Data and Baseline Simulation Output Data

Variables	Special Exams Unit		Baseline Simulation output data Average 95% CI	Relative Error
Patient Recovery Process 1	Average Time	**31.8**	**31.9** [2]	**0.00**
	Standard Deviation	**4.65**	*	*
Patient Recovery_1	Operation time	*	**19.76**	*
Queue for Nursing_Procedures_1	Average Time	*	**1.95**	*
	Standard Deviation	*	**3.05**	*
Nursing_Procedures_1	Operation time	*	**10.19**	*

[2] The average time of Patient Recovery process 1 in the actual system corresponds to the sum of the time in the patient recovery 1, the time on queue for nursing procedures and operation time of nursing procedures 1 in the simulation model. For example, Patient Recovery process 1 (Average time)= 31.08 minutes corresponds to sum of patient recovery 1(average time)=19.76 minutes plus queue 1 for nursing procedures (average time)=1.95 minutes plus Nursing procedures (operation time)=10.19 minutes. This sum is equal to 31.9 minutes. Same logic was used on the remnant variables.

Variables	Special Exams Unit		Baseline Simulation output data Average 95% CI	Relative Error
Patient Recovery Process 2	Average Time	**31.8**	**32.09**	**0.01**
	Standard Deviation	**4.65**	*	*
Patient Recovery_2	Operation time	*	**20.2**	*
Queue for Nursing_Procedures_2	Average Time	*	**1.99**	*
	Standard Deviation	*	**3.1**	*
Nursing_Procedures_2	Operation time	*	**9.9**	*
Patient Recovery Process 3	Average Time	**31.8**	**32.14**	**0.01**
	Standard Deviation	**4.65**	*	*
Patient Recovery_3	Operation time	*	**20.12**	*
Queue for Nursing_Procedures_3	Average Time	*	**1.99**	*
	Standard Deviation	*	**3.09**	*
Nursing_Procedures_3	Operation time	*	**10.03**	*
Patient Recovery Process 4	Average Time	**31.8**	**32.0**	**0.01**
	Standard Deviation	**4.65**	*	*
Patient Recovery_4	Operation time	*	**20.09**	*
Queue for Nursing_Procedures_4	Average Time	*	**1.99**	*
	Standard Deviation	*	**3.07**	*
Nursing_Procedures_4	Operation time	*	**9.92**	*

This simulation model demonstrated a high degree of complexity, and some of the variables showed a relative error superior to 10%. However, the model simulation sill generates valid and meaningful results.

4.2 Scenarios Tested

One of the objectives of this study was to evaluate the impact of capacity planning on the performance of the Special Exams Unit and identify variables that can affect capacity planning. Considering that the model revealed a good fit, some scenarios were tested in order to assess their impact on the performance of the system. Various simulation models were developed to test scenarios aiming to maximize the capacity of the Special Exams Unit. These scenarios are discussed in what follows.

4.2.1- Scenario No.1: Maximizing Appointment Efficiency

The first scenario tested consisted in reducing the scheduling time between appointments from 30 minutes (baseline simulation) to 20 minutes, maintaining the working hours of the baseline simulation (8:00 a.m.- 20:00 p.m.). This was based on the simulation observation that reducing the time between appointments further would lead to a notable number of patients being unable to complete their exams by the end of the day. According to experts from the Special Exams Unit, this is an uncommon occurrence, so we have chosen to optimize the model using the same operating hours of the baseline model.

To allow the increase of admissions per day, admission activity was configurated using a fixed value of 20 minutes. Considering that lunch time takes place between 13:00 pm. to 14:00 pm., this activity was constrained using a shift pattern with a morning shift (8:30 a.m. to 12:40 p.m.), and an afternoon shift (13:30 p.m. to 17:00 p.m.). Appointments were scheduled so that one patient would be admitted at every 20 minutes. This represents an increase of patient admission from 16 to 22 patients per day. The other model parameters were the same as in the baseline simulation model.

This scenario demonstrates that scheduling exams at every 20 minutes and maintaining the same working hours and the same resources as in the baseline simulation (Table 4.15), increases the number of patients admitted (355) and increases the number of exams performed (342.75). The average time in the system, also raised to 175.56 minutes, more 67.3 minutes per patient than the baseline simulation output with an increase also in the standard deviation from 17.58 to 50.83 minutes. The maximum time in the system also increases from 187.13 to 362.53 minutes, however, on figure 4.14, we can see that 68% of patients complete their exams within the same maximum time as patients from the baseline scenario, and 90% of patients complete their exams in less than 240 minutes.

Table 4.15- Admission and Exams performed Output- Comparison between Baseline Output and Scenario No.1: Maximizing Appointment Efficiency

Variables		**Baseline Simulation Output**	**Scenario No.1: Maximizing Appointment Efficiency**
		Average 95% CI	
Admission	**Number Entered**	**263.82**	**355**
No show	Number Completed	**8.03**	**10.73**
Exams performed	Number Completed	**255.31**	**342.75**
	Average Time in System	**108.26**	**175.56**
	Standard Deviation	**17.58**	**50.83**
	Maximum Time in System	**187.13**	**362.53**

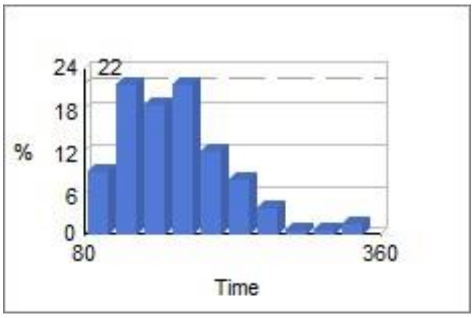

Figure 4.14- Scenario No.1: Maximizing Appointment Efficiency - Time in System

In which regards the Patient Preparation Process output (Table 4.16), we can observe a significant increase on the average and standard deviation of the patient preparation length of stay and queue for exam preparation. Compared to the baseline output, approximately 19% of patients completed their preparation in under 30 minutes on average, while only 14% experienced a waiting time of less than 8 minutes in the queue for exam preparation.

Table 4.16- Patient Preparation Process Output- Comparison between Baseline Simulation Output and Scenario No.1: Maximizing Appointment Efficiency

Variables		Baseline Simulation Output	Scenario No.1: Maximizing Appointment Efficiency
		Average 95% CI	
Patient Preparation length of stay 1	Average Time in System	**27,95**	**70.24**
	Standard Deviation	**7,1**	**40.70**
Queue 1 for Exam Preparation	Average Time in System	**8,8**	**32.29**
	Standard Deviation	**12,68**	**20.23**
Patient Preparation length of stay 2	Average Time in System	**27,88**	**70.51**
	Standard Deviation	**7,1**	**40.75**
Queue 2 for Exam Preparation	Average Time in System	**8,99**	**32.41**
	Standard Deviation	**12,71**	**20.39**
Patient Preparation length of stay 3	Average Time in System	**27,97**	**70.35**
	Standard Deviation	**7,17**	**40.65**
Queue 3 for Exam Preparation	Average Time in System	**8,93**	**32.38**
	Standard Deviation	**12,71**	**20.13**
Patient Preparation length of stay 4	Average Time in System	**28,1**	**70.67**
	Standard Deviation	**7,2**	**40.62**
Queue 4 for Exam Preparation	Average Time in System	**8,99**	**32.52**
	Standard Deviation	**12,76**	**20.02**

In the analysis of the Exams Process output comparison (Table 4.17), it was observed that there were no significant changes in operation times related to the type of procedure, but an increase of the number of completed exams was observed. Upper and lower GI endoscopy experienced an increase from, 117.64 to 158.04 exams, Lower GI endoscopy from 95.68 to 128.82 and Upper GI endoscopy from 42.45 to 56.94. This represents an additional 40.4 completed upper and lower GI endoscopy exams, 33.14 completed lower GI endoscopy exams and 14.49 completed upper GI endoscopy exams.

Table 4.17- Exams Process Output- Comparison between Baseline Output and Scenario No.1: Maximizing Appointment Efficiency

Variables		Baseline Simulation Output	Scenario No.1: Maximizing Appointment Efficiency
		Average 95% CI	
Procedure Room - Upper and Lower GI Endoscopy	Number of completed jobs	**117.64**	**158.04**
	Operation Time	**17.87**	**18.06**
Procedure Room - Lower GI Endoscopy	Number of completed jobs	**95.68**	**128.82**
	Operation Time	**14.1**	**14.38**
Procedure Room - Upper GI Endoscopy	Number of completed jobs	**42.45**	**56.94**
	Operation Time	**10.19**	**10.36**

As implied in this scenario, the increase in the number of scheduled appointments without the addition of any extra resources has led to an evident rise in resource utilization, as observed in this test simulation (Figure 4.15).

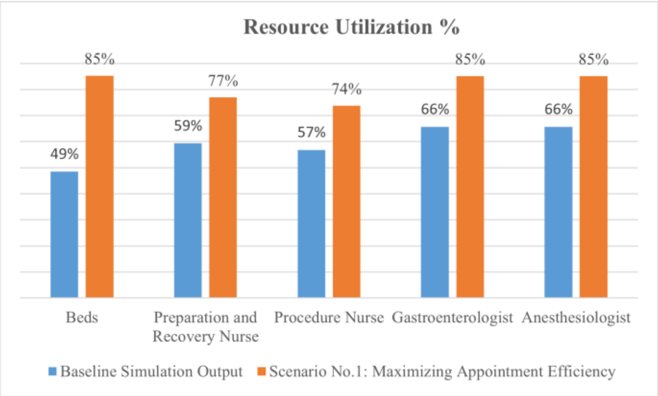

Figure 4.15- Resource Utilization- Comparison between Baseline simulation Output and Scenario No.1: Maximizing Appointment Efficiency

Regarding the resources' utilization analysis, we observe that the resources bed and medical team (gastroenterologist and anesthesiologist) experienced the most significant increases in utilization. Bed utilization increased from 49% to 85%, indicating a rise of 36% and the utilization of the medical team increased from 66% to 85% representing an increase in their utilization of 19%. As mentioned before, it is important to note that these utilization rates may differ from the reality, indicating that the actual utilization of these resources could be higher than the results show. The additional increase of 36% on bed utilization, indicates that a larger proportion of available beds were occupied during the simulation, suggesting a higher demand for the patient's preparation process and recovery process. This suggest that the capacity of the existing beds was efficiently utilized. The increase of 19% in the utilization of the medical team is justified by the fact that they would be more frequently engaged in performing procedures due to the additional number of completed exams performed.

In the queuing analysis, the waiting room queuing time (Table 4.18) showed the most significant increase, which contributed to an overall increase in the length of stay within the system. As expected, in this scenario, because the number of scheduled appointments increases but no additional resources are added, it is observed an increase in the queuing time for the upper and lower GI endoscopy waiting room, which increases from an average of 0.29 minutes (with a standard deviation of 0.99) to an average of 13.74 minutes (with a standard deviation of 23.60). The queuing time for the lower GI endoscopy waiting room increases from an average of 0.29 minutes with a standard deviation of 1.01 to an average of 13.78 minutes with a standard deviation of 23.71 minutes. Finally, the queuing time for the upper GI endoscopy waiting room increases from an average of 0.28 minutes (and standard deviation of 0.83 minutes) to an average of 13.74 minutes and a standard deviation of 23.55 minutes. On average, around 72% of admitted patients would experience queuing times of less than 10 minutes in the waiting room.

Table 4.18- Waiting room Queuing time Output- Comparison between Baseline Output and Scenario No.1: Maximizing Appointment Efficiency

Variables		**Baseline Simulation Output**	**Scenario No.1: Maximizing Appointment Efficiency**
		Average 95% CI	
Upper And Lower GI Waiting Room	Average Queuing Time	**0.29**	**13.74**
	Standard Deviation of Queuing Time	**0.99**	**23.60**
	Maximum Queuing Time	**5.90**	**111.30**
Lower GI Waiting Room	Average Queuing Time	**0.29**	**13.78**
	Standard Deviation of Queuing Time	**1.01**	**23.71**
	Maximum Queuing Time	**5.75**	**109.44**
Upper GI Waiting Room	Average Queuing Time	**0.28**	**13.74**
	Standard Deviation of Queuing Time	**0.83**	**23.55**
	Maximum Queuing Time	**4.48**	**97.61**

The increased queuing time in the waiting room can have several implications, including increased patient dissatisfaction due to increased patients’ length of stay in the system, including both in the waiting room and in the subsequent stages of their care. Also, it may cause potential disruptions to the overall flow of the system.

There were no significant changes or modifications noted in the patient recovery process. However, the activities in the dressing room exhibited a notable increase of blocked route, increasing from 0.04% to 26.10%. This substantial increase supports the experts' opinion that the dressing room may act as a bottleneck in the system.

4.2.2- Scenario No.2: Enhancing Flow Optimization - Dressing Room Activity

A second scenario was evaluated to confirm that the dressing room activity acts as a bottleneck. This scenario maintained the same conditions as the previous one (appointments at every 20 minutes) but included an additional dressing room. This modification converted the simulation model from a closed system to an open system, ensuring that patients who have completed their exams and those who have not, do intersect or cross paths in the same dressing room. This is a hypothetical scenario where creating another dressing room is not currently practical, but it is possible. However, achieving this would require constructing an additional dressing room and making physical modifications to the Special Exams Unit. This simulation model was configurated with the same model parameters as the last scenario tested, but with an extra dressing room in comparison to the baseline simulation.

This scenario demonstrates (Table 4.19) that there is not meaningful change on the number of exams performed (342.75 to 342.60). The average time in the system, slightly increased from 175.56 to 180.25 minutes, which means more 4.69 minutes per patient than in scenario No.1. The standard deviation and the maximum time in the system did not reveal significant variation, 50.83 to 51.00 minutes, and 362.53 to 367.84 minutes, respectively. Less than 64% of patients complete their exams within the same maximum time as patients from the baseline scenario (Figure 4.16).

Table 4.19- Admission and Exams performed Output- Comparison between Scenario No.1: Maximizing Appointment Efficiency and Scenario No.2: Enhancing Flow Optimization: Dressing Room Activity

Variables		Scenario No.1: Maximizing Appointment Efficiency	Scenario No.2: Enhancing Flow Optimization- Dressing Room Activity
		Average 95% CI	
Admission	**Number Entered**	**355**	**355**
No show	Number Completed	**10.73**	**10.73**
Exams performed	Number Completed	**342.75**	**342.60**
	Average Time in System	**175.56**	**180.25**
	Standard Deviation	**50.83**	**51.00**
	Maximum Time in System	**362.53**	**367.84**

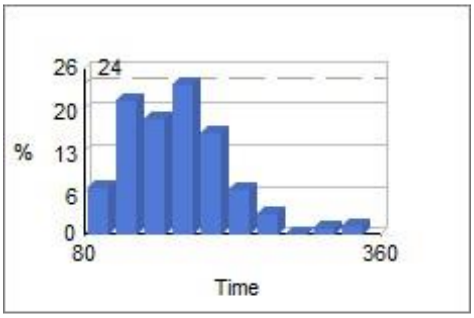

Figure 4.16- Scenario No.2 -Enhancing Flow Optimization- Dressing Room Activity - Time in System

In which regards the Patient Preparation Process output (Table 4.20), we can observe no significant alterations on the results.

Table 4.20- Patient Preparation Process Output- Comparison between Scenario No.1: Maximizing Appointment Efficiency and Scenario No.2: Enhancing Flow Optimization- Dressing Room Activity

Variables		Scenario No.1: Maximizing Appointment Efficiency	Scenario No.2: Enhancing Flow Optimization- Dressing Room Activity
		Average 95% CI	
Patient Preparation length of stay 1	Average Time in System	**70.24**	**70.10**
	Standard Deviation	**40.70**	**40.77**
Queue 1 for Exam Preparation	Average Time in System	**32.29**	**32.30**
	Standard Deviation	**20.23**	**20.22**
Patient Preparation length of stay 2	Average Time in System	**70.51**	**70.36**
	Standard Deviation	**40.75**	**40.80**
Queue 2 for Exam Preparation	Average Time in System	**32.41**	**32.45**
	Standard Deviation	**20.39**	**20.41**
Patient Preparation length of stay 3	Average Time in System	**70.35**	**70.19**
	Standard Deviation	**40.65**	**40.68**
Queue 3 for Exam Preparation	Average Time in System	**32.38**	**32.39**
	Standard Deviation	**20.13**	**20.10**
Patient Preparation length of stay 4	Average Time in System	**70.67**	**70.49**
	Standard Deviation	**40.62**	**40.67**
Queue 4 for Exam Preparation	Average Time in System	**32.52**	**32.56**
	Standard Deviation	**20.02**	**20.00**

The analysis of the Exams Process output comparison (Table 4.21) also reveals that there were no significant changes in operation times and number of completed jobs, according to the type of procedure.

Table 4.21- Exams Process Output- Comparison between Scenario No.1: Maximizing Appointment Efficiency and Scenario No.2: Enhancing Dressing Room Efficiency: Flow Optimization

Variables		Scenario No.1: Maximizing Appointment Efficiency	Scenario No.2: Enhancing Flow Optimization- Dressing Room Activity
		Average 95% CI	
Procedure Room - Upper and Lower GI Endoscopy	Number of completed jobs	**158.04**	**158.04**
	Operation Time	**18.06**	**18.22**
Procedure Room - Lower GI Endoscopy	Number of completed jobs	**128.82**	**128.82**
	Operation Time	**14.38**	**14.37**
Procedure Room - Upper GI Endoscopy	Number of completed jobs	**56.94**	**56.94**
	Operation Time	**10.36**	**10.40**

Also, the results of the utilization analysis show that the rates of resources' utilization remain consistent, maintaining their position as in scenario No.1.

In the queuing analysis, the waiting room queuing time (Table 4.22) revealed a significant reduction in the average queuing time, standard deviation time and maximum queuing time. It is observed a reduction in the queuing time for the upper and lower GI endoscopy, which decreases from an average of 13.74 (with a standard deviation of 23.60) to an average of 4.97 minutes, with a decrease of the standard deviation to 12.96 minutes. The queuing time for the lower GI endoscopy reduces from an average of 13.78 minutes with a standard deviation of 23.71 to an average of 5.02 minutes with a standard deviation of 13.06 minutes. Finally, the queuing time for the upper GI endoscopy decreases from an average of 13.74 minutes (and standard deviation of 23.55 minutes) to an average of 5.03 minutes and a standard deviation of 12.49 minutes. There is also a significant reduction on the maximum queuing time. The Upper and Lower GI maximum queuing time reduced from 111.30 to 75.94 minutes, less 35.36 minutes than in the previous scenario, the Lower GI maximum queuing time reduced from 109.44 to 73.64 minutes, less 35.80 minutes than before and the Upper GI maximum queuing time reduced from 97.61 to 61.78 minutes, less 35.83 minutes than in scenario 1. There is a significant growth in the percentage of patients that experience queuing times of less than 10 minutes in the waiting room, increasing from 72% to 88%.

Table 4.22- Waiting room Queuing time Output- Comparison between Scenario No.1: Maximizing Appointment Efficiency and Scenario No.2: Enhancing Dressing Room Efficiency: Flow Optimization

Variables		**Scenario No.1: Maximizing Appointment Efficiency**	**Scenario No.2: Enhancing Flow Optimization- Dressing Room Activity**
		Average 95% CI	
Upper And Lower GI Waiting Room	Average Queuing Time	**13.74**	**4.97**
	Standard Deviation of Queuing Time	**23.60**	**12.96**
	Maximum Queuing Time	**111.30**	**75.94**
Lower GI Waiting Room	Average Queuing Time	**13.78**	**5.02**
	Standard Deviation of Queuing Time	**23.71**	**13.06**
	Maximum Queuing Time	**109.44**	**73.64**
Upper GI Waiting Room	Average Queuing Time	**13.74**	**5.03**
	Standard Deviation of Queuing Time	**23.55**	**12.49**
	Maximum Queuing Time	**97.61**	**61.78**

There were no significant changes or modifications noted in the patient recovery process. However, significant changes were observed on the dressing room activity. As discussed before, in Scenario 1, this activity exhibited a notable increase of blocked route (26.1%). In scenario 2, the changes performed led to a reduction of the blocked route to 15.96%, which means a reduction of 10.14% when compared with the previous scenario.

Some evidence, such as the decrease in waiting room queuing times and the reduction in the percentage of blocked routes, provides support for the experts' opinion that the dressing room functions as a bottleneck within the system. This scenario has the potential to contribute to the reduction of queuing times and to the increase of patients' satisfaction.

4.2.3- Scenario No.3: Enhancing Resource Optimization – Extra preparation and recovery process nurse

A notable percentage of blocked routes (15.96%) still occurs at the dressing room No.1 in scenario No.2, which could be attributed to resource limitations. With only one nurse responsible for both the patient preparation and recovery processes, and with a utilization rate of 77%, certain activities may need to wait for the resource to become available, consequently increasing queuing time. So, another scenario was tested to confirm that the nurse responsible for patient preparation and recovery process, may act as a bottleneck resource.

This scenario maintained the same conditions as the previous one (appointments with 20 minutes intervals and with an extra dressing room) but included an additional preparation and recovery nurse.

This scenario demonstrates (Table 4.23) that there is a slight increase on the standard deviation time (0.23 minutes), but there is a significant reduction on the average and maximum times on the system. The average time in the system, decreased from 180.25 to 168.50 minutes, less 11.75 minutes per patient than in scenario No.2, with a reduction also in the maximum time in the system from 367.84 to 357.58 minutes, less 10.26 minutes. Less than 67.5% of patients complete their exams within the same maximum time as patients from the baseline scenario (Figure 4.17).

Table 4.23- Admission and Exams performed Output- Comparison between Scenario No.2: Enhancing Flow Optimization: Dressing Room Activity and Scenario No.3: Enhancing Resource Optimization: Extra preparation and recovery process nurse

Variables		Scenario No.2: Enhancing Flow Optimization- Dressing Room Activity	Scenario No.3: Enhancing Resource Optimization: Extra preparation and recovery process nurse
		Average 95% CI	
Admission	**Number Entered**	**355**	**355.00**
No show	Number Completed	**10.73**	**10.73**
Exams performed	Number Completed	**342.60**	**342.93**
	Average Time in System	**180.25**	**168.50**
	Standard Deviation	**51.00**	**51.23**
	Maximum Time in System	**367.84**	**357.58**

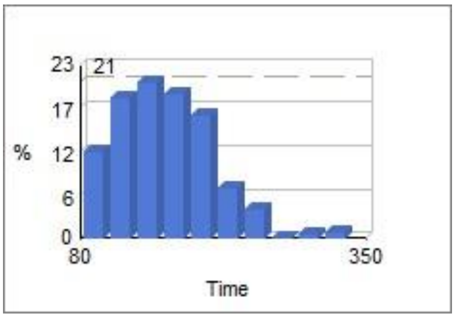

Figure 4.17- Scenario No.3: Enhancing Resource Optimization - Extra preparation and recovery process nurse - Time in System

Regarding the Patient Preparation Process output (Table 4.24), we can observe a significant reduction of patient preparation length of stay. The average time on the system, is now approximately less 10 minutes than in the previous scenario. The standard deviation also had a minor reduction. In which regards the average queuing time to exam preparation we observe a slight increase.

Table 4.24- Patient Admission and Exams performed Output- Comparison between Scenario No.2: Enhancing Flow Optimization: Dressing Room Activity and Scenario No.3: Enhancing Resource Optimization: Extra preparation and recovery process nurse

Variables		Scenario No.2: Enhancing Flow Optimization- Dressing Room Activity	Scenario No.3: Enhancing Resource Optimization: Extra preparation and recovery process nurse
		Average 95% CI	
Patient Preparation length of stay 1	Average Time in System	**70.10**	**59.60**
	Standard Deviation	**40.77**	**38.64**
Queue 1 for Exam Preparation	Average Time in System	**32.30**	**38.81**
	Standard Deviation	**20.22**	**19.74**
Patient Preparation length of stay 2	Average Time in System	**70.36**	**59.82**
	Standard Deviation	**40.80**	**38.71**
Queue 2 for Exam Preparation	Average Time in System	**32.45**	**39.02**
	Standard Deviation	**20.41**	**19.68**
Patient Preparation length of stay 3	Average Time in System	**70.19**	**59.61**
	Standard Deviation	**40.68**	**38.61**
Queue 3 for Exam Preparation	Average Time in System	**32.39**	**38.99**
	Standard Deviation	**20.10**	**19.53**
Patient Preparation length of stay 4	Average Time in System	**70.49**	**59.89**
	Standard Deviation	**40.67**	**38.59**
Queue 4 for Exam Preparation	Average Time in System	**32.56**	**39.16**
	Standard Deviation	**20.00**	**19.36**

In the analysis of the Exams Process output (Table 4.25), we observe that there were no significant changes in operation times and number of completed jobs, based on the type of procedure.

Table 4.25- Exams Process Output- Comparison between Scenario No.2: Enhancing Flow Optimization: Dressing Room Activity and Scenario No.3: Enhancing Resource Optimization: Extra preparation and recovery process nurse

Variables		Scenario No.2: Enhancing Flow Optimization- Dressing Room Activity	Scenario No.3: Enhancing Resource Optimization: Extra preparation and recovery process nurse
		Average 95% CI	
Procedure Room - Upper and Lower GI Endoscopy	Number of completed jobs	**158.23**	**158.06**
	Operation Time	**18.18**	**18.08**
Procedure Room - Lower GI Endoscopy	Number of completed jobs	**128.6**	**128.84**
	Operation Time	**14.54**	**14.38**
Procedure Room - Upper GI Endoscopy	Number of completed jobs	**56.76**	**56.95**
	Operation Time	**10.37**	**10.39**

In the analysis of resource utilization (Figure 4.18), the utilization rate of the resources remains consistent, maintaining its position from the previous scenario tested. The only change observed is a decrease in the percentage of utilization of the preparation and recovery nurses, from 77% to 43%. This decrease was expected since the number of nurses increased from 1 to 2.

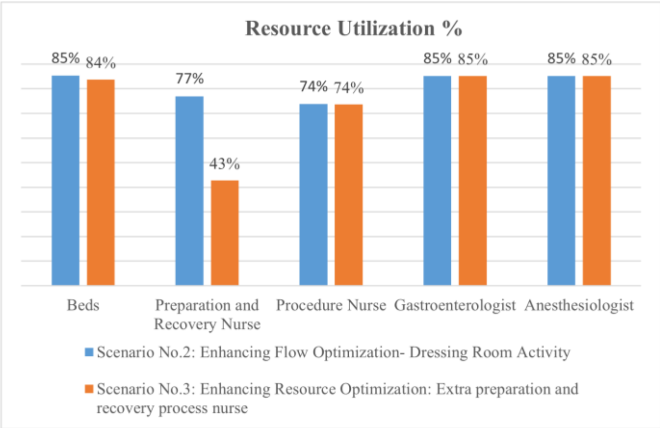

Figure 4.18- Resource Utilization- Comparison between Scenario No.2: Enhancing Flow Optimization: Dressing Room Activity and Scenario No.3: Enhancing Resource Optimization: Extra preparation and recovery process nurse

In the queuing analysis, the waiting room queuing time (Table 4.26) revealed a slight reduction in queuing average time, standard deviation time and maximum queuing time. There is an increase in the percentage of patients that experience queuing times less than 10 minutes in the waiting room, which increases from 88% to 90%.

Table 4.26- Waiting room Queuing time Output- Comparison between Scenario No.2: Enhancing Flow Optimization: Dressing Room Activity and Scenario No.3: Enhancing Resource Optimization: Extra preparation and recovery process nurse

Variables		**Scenario No.2: Enhancing Flow Optimization- Dressing Room Activity**	**Scenario No.3: Enhancing Resource Optimization: Extra preparation and recovery process nurse**
		Average 95% CI	
Upper And Lower GI Waiting Room	Average Queuing Time	**4.97**	**4.21**
	Standard Deviation of Queuing Time	**12.96**	**11.63**
	Maximum Queuing Time	**75.94**	**71.24**
Lower GI Waiting Room	Average Queuing Time	**5.02**	**4.26**
	Standard Deviation of Queuing Time	**13.06**	**11.73**
	Maximum Queuing Time	**73.64**	**69.33**
Upper GI Waiting Room	Average Queuing Time	**5.03**	**4.29**
	Standard Deviation of Queuing Time	**12.49**	**10.99**
	Maximum Queuing Time	**61.78**	**56.79**

There were no significant changes or modifications noted in the patient recovery process.

Regarding the dressing room activity, identified previously as a bottleneck, this activity exhibited a decrease of the blocked route from 15.96% to 13.80%, less 2.16%. This discrete reduction in the blocked route can be interpreted as the resources behaving as a bottleneck when the system is overloaded. Adding one more nurse has shown positive effects on the system by reducing patient preparation time and length of stay. However, this scenario is not efficient as it does not significantly reduce the blocked route on dressing room activity, and the resources' utilization percentage remains underutilized (43%).

4.2.4- Scenario No.4: Enhancing Resource Optimization – Extra Beds

To study the blocked route on the system identified in scenario No.3, another scenario was evaluated. It consisted in increasing the capacity of the unit from 4 to 6 beds and maintaining the same conditions as in the previous scenario (appointments 20 minutes apart with an extra dressing room process) with an exception that the preparation and recovery process nurse was set to 1 such as in the baseline simulation, due to the low resource utilization (43%) observed on scenario No.3. This simulation model was configured with the same model parameters as the previous scenario test, but with an additional 2 beds who were configured with the same settings as the beds in the baseline simulation.

This scenario, as shown in Table 4.27, demonstrates that there is no significant impact on the variables. Less than 69% of patients complete their exams within the same maximum time as patients from the baseline scenario, and less than 91% of patients complete their exams below 240 minutes (Figure 4.19).

Table 4.27- Admission and Exams performed Output- Comparison between Scenario No.3: Enhancing Resource Optimization: Extra preparation and recovery process nurse and Scenario No.4: Enhancing Resource Optimization – Extra Beds

Variables		Scenario No.3: Enhancing Resource Optimization: Extra preparation and recovery process nurse	Scenario No.4: Enhancing Resource Optimization – Extra Beds
		Average 95% CI	
Admission	**Number Entered**	**355.00**	**355.00**
No show	Number Completed	**10.73**	**10.73**
Exams performed	Number Completed	**342.93**	**342.84**
	Average Time in System	**168.50**	**175.95**
	Standard Deviation	**51.23**	**49.33**
	Maximum Time in System	**357.58**	**362.22**

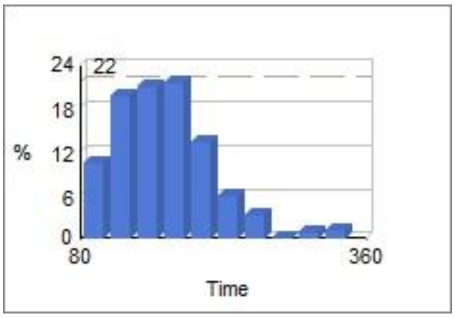

Figure 4.19- Scenario No.4: Enhancing Resource Optimization – Extra Beds- Time in System

Regarding the Patient Preparation Process output (Table 4.28), we can observe a significant reduction on the average and standard deviation of patient preparation length of stay, a reduction of the average time of the patient on the system of 14 minutes and a reduction of 15 minutes in the standard deviation. Exhibiting an inverse correlation, the average and the standard deviation of queuing time for exam, show an increase of 17 and 16 minutes, respectively.

In the analysis of the Exams Process output, we observe that there were no significant changes in operation times and number of completed jobs, based on the type of procedure.

In the analysis of resource utilization (Figure 4.20), the utilization rate of resources remains consistent, maintaining its position from the previous scenario tested. The only change observed is a decrease in the percentage of utilization for the beds, from 84% to 72%. This decrease was expected since the number of beds increased from 4 to 6. The rate of utilization of the preparation and recovery nurse increased which was expected considering that the number of nurses was reduced from 2 to 1.

Table 4.28- Patient Preparation Process Output- Comparison between Scenario No.3: Enhancing Resource Optimization: Extra preparation and recovery process nurse and Scenario No.4: Enhancing Resource Optimization – Extra Beds

Variables		Scenario No.3: Enhancing Resource Optimization: Extra preparation and recovery process nurse	Scenario No.4: Enhancing Resource Optimization – Extra Beds
		Average 95% CI	
Patient Preparation length of stay 1	Average Time in System	**59.60**	**45.48**
	Standard Deviation	**38.64**	**23.35**
Queue 1 for Exam Preparation	Average Time in System	**38.81**	**55.06**
	Standard Deviation	**19.74**	**36.06**
Patient Preparation length of stay 2	Average Time in System	**59.82**	**45.12**
	Standard Deviation	**38.71**	**23.36**
Queue 2 for Exam Preparation	Average Time in System	**39.02**	**55.26**
	Standard Deviation	**19.68**	**35.94**
Patient Preparation length of stay 3	Average Time in System	**59.61**	**45.75**
	Standard Deviation	**38.61**	**23.33**
Queue 3 for Exam Preparation	Average Time in System	**38.99**	**55.84**
	Standard Deviation	**19.53**	**35.85**
Patient Preparation length of stay 4	Average Time in System	**59.89**	**45.89**
	Standard Deviation	**38.59**	**23.21**
Queue 4 for Exam Preparation	Average Time in System	**39.16**	**56.05**
	Standard Deviation	**19.36**	**36.12**
Patient Preparation length of stay 5	Average Time in System	*	**45.75**
	Standard Deviation	*	**23.16**
Queue 5 for Exam Preparation	Average Time in System	*	**55.64**
	Standard Deviation	*	**35.92**
Patient Preparation length of stay 6	Average Time in System	*	**45.97**
	Standard Deviation	*	**23.30**
Queue 6 for Exam Preparation	Average Time in System	*	**56.01**
	Standard Deviation	*	**35.94**

In the analysis of the Exams Process output, we observe that there were no significant changes in operation times and number of completed jobs, based on the type of procedure.

In the analysis of resource utilization (Figure 4.20), the utilization rate of resources remains consistent, maintaining its position from the previous scenario tested. The only change observed is a decrease in the percentage of utilization for the beds, from 84% to 72%. This decrease was expected since the number of beds increased from 4 to 6. The rate of utilization of the preparation and recovery nurse increased which was expected considering that the number of nurses was reduced from 2 to 1.

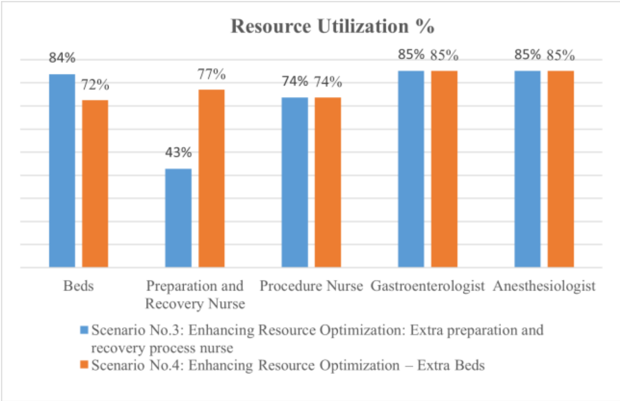

Figure 4.20- Resource Utilization- Comparison between Scenario No.3: Enhancing Resource Optimization: Extra preparation and recovery process nurse and Scenario No.4: Enhancing Resource Optimization – Extra Beds

In the queuing analysis, the waiting room queuing time (Table 4.29) revealed a significant reduction in average queuing time, standard deviation time and maximum queuing time. It is observed a reduction in the queuing time for the upper and lower GI endoscopy, which decreases from an average of 4.21 minutes (with a standard deviation of 11.63) to an average of 0.66 minutes, with a standard deviation of 2.25 minutes. The queuing time for the lower GI endoscopy reduces from an average of 4.26 minutes with a standard deviation of 11.73 to an average of 0.65 minutes with a standard deviation of 2.18 minutes. Finally, the queuing time for the upper GI decreases from an average of 4.29 minutes and standard deviation of 10.99 minutes to an average of 0.73 minutes and a standard deviation of 1.76 minutes. There is also a significant reduction on the maximum queuing time for upper and lower GI, lower GI, and upper GI, from 71.24 to 20.10 minutes, from 69.33 to 18.92 minutes and from 56.79 to 14.18 minutes, respectively. Approximately 98% of patients experience queuing times less than 10 minutes in the waiting room.

There were no significant changes or modifications noted in the patient recovery process.

The dressing room activity in this scenario exhibited a significant decrease of blocked route from 13.80% to 2.64%, less 11.16%. Adding 2 more beds to the system has the potential to diminish the impact of the dressing room as a bottleneck, however, this intervention did not reduce patient length of stay on the system. In fact, it increased 7.5 minutes. Despite decreasing the patient's preparation length of stay on process preparation time, there was a notable increase in queuing time for the exam. This observation can be explained by considering that the Exam Procedure Process is a bottleneck activity.

Table 4.29- Waiting room Queuing time Output- Comparison between Scenario No.3: Enhancing Resource Optimization: Extra preparation and recovery process nurse and Scenario No.4: Enhancing Resource Optimization – Extra Beds

Variables		**Scenario No.3: Enhancing Resource Optimization: Extra preparation and recovery process nurse**	**Scenario No.4: Enhancing Resource Optimization – Extra Beds**
		Average 95% CI	
Upper And Lower GI Waiting Room	Average Queuing Time	**4.21**	**0.66**
	Standard Deviation of Queuing Time	**11.63**	**2.25**
	Maximum Queuing Time	**71.24**	**20.10**
Lower GI Waiting Room	Average Queuing Time	**4.26**	**0.65**
	Standard Deviation of Queuing Time	**11.73**	**2.18**
	Maximum Queuing Time	**69.33**	**18.92**
Upper GI Waiting Room	Average Queuing Time	**4.29**	**0.73**
	Standard Deviation of Queuing Time	**10.99**	**1.76**
	Maximum Queuing Time	**56.79**	**14.18**

Despite configuring this scenario with only one nurse for patient preparation and recovery process, a scenario was evaluated with two available nurses maintaining all the other parameters as in scenario No.4. Acknowledging that the utilization of this resource is not efficient (43%), the increment of another nurse reduced patient length of stay with results similar to those of scenario No.3, but showed non favorable outcomes, such as a significant increase of queuing time to exam, average queuing time and maximum queuing time (150 minutes).

4.2.5- Scenario No.5: Enhancing Flow and Resource Optimization – Extra Procedure Room

To confirm that the exam procedure process acts as a bottleneck activity, another scenario was tested. In this scenario it was introduced another procedures' room, which is equivalent to considering that the Unit had enough resources to carry out two procedures at the same time.

As it was explained previously, the human resources were considered a constraint in the baseline simulation, because they have been configured to perform only one exam at each time and the system only releases resources when exams are completed. For this scenario, the resources were duplicated, allowing them to perform two exams at the same time, simulating two procedure rooms. Table 4.30 provides a comparison of the results of the scenario discussed previously with the new scenario.

Table 4.30- Admission and Exams performed Output- Comparison between Scenario No.4: Enhancing Resource Optimization – Extra Beds and Scenario No.5: Enhancing Flow and Resource Optimization – Extra Procedure Room

Variables		Scenario No.4: Enhancing Resource Optimization – Extra Beds	Scenario No.5: Enhancing Flow and Resource Optimization – Extra Procedure Room
		Average 95% CI	
Admission	**Number Entered**	**355.00**	**355**
No show	Number Completed	**10.73**	**10.60**
Exams performed	Number Completed	**342.84**	**344.25**
	Average Time in System	**175.95**	**93.25**
	Standard Deviation	**49.33**	**10.01**
	Maximum Time in System	**362.22**	**130.82**

This scenario demonstrates that adding another procedure's room, decreases the average time in the system, from 175.95 to 93.25 minutes, less 82.7 minutes than in scenario Nº 4. The standard deviation also decreases from 49.33 to 10.01 minutes. Maximum time in system also decreases from 362.22 to 130.82 minutes, less 231.4 minutes.

Regarding the Patient Preparation Process output (Table 4.31), we can observe a significant reduction on all variables. On average, 97.2% of patients admitted, experienced a length of stay on the patient preparation process, lower than 30 minutes.

Regarding the Exams Process output analysis (Table 4.32), there are no significant changes in operation times and number of completed jobs, based on the type of procedure. This scenario also showed that Procedure room 1 conducted a slightly higher percentage of exams compared to Procedure room 2, with a distribution of 54.4% and 45.6% respectively.

Table 4.31- Patient Preparation Process Output- Comparison between Scenario No.4: Enhancing Resource Optimization – Extra Beds and Scenario No.5: Enhancing Flow and Resource Optimization – Extra Procedure Room

Variables		Scenario No.4: Enhancing Resource Optimization – Extra Beds	Scenario No.5: Enhancing Flow and Resource Optimization – Extra Procedure Room
		Average 95% CI	
Patient Preparation length of stay 1	Average Time in System	**45.48**	**23.51**
	Standard Deviation	**23.35**	**3.02**
Queue 1 for Exam Preparation	Average Time in System	**55.06**	**0.14**
	Standard Deviation	**36.06**	**0.57**
Patient Preparation length of stay 2	Average Time in System	**45.12**	**23.48**
	Standard Deviation	**23.36**	**3.09**
Queue 2 for Exam Preparation	Average Time in System	**55.26**	**0.13**
	Standard Deviation	**35.94**	**0.56**
Patient Preparation length of stay 3	Average Time in System	**45.75**	**23.50**
	Standard Deviation	**23.33**	**3.28**
Queue 3 for Exam Preparation	Average Time in System	**55.84**	**0.15**
	Standard Deviation	**35.85**	**0.62**
Patient Preparation length of stay 4	Average Time in System	**45.89**	**23.49**
	Standard Deviation	**23.21**	**3.14**
Queue 4 for Exam Preparation	Average Time in System	**56.05**	**0.14**
	Standard Deviation	**36.12**	**0.61**
Patient Preparation length of stay 5	Average Time in System	**45.75**	**23.59**
	Standard Deviation	**23.16**	**3.17**
Queue 5 for Exam Preparation	Average Time in System	**55.64**	**0.60**
	Standard Deviation	**35.92**	**2.20**
Patient Preparation length of stay 6	Average Time in System	**45.97**	**23.53**
	Standard Deviation	**23.30**	**3.29**
Queue 6 for Exam Preparation	Average Time in System	**56.01**	**0.13**
	Standard Deviation	**35.94**	**0.54**

Table 4.32- Exam Process Output- Comparison between Scenario No.4: Enhancing Resource Optimization – Extra Beds and Scenario No.5: Enhancing Flow and Resource Optimization – Extra Procedure Room

Variables		Scenario No.4: Enhancing Resource Optimization – Extra Beds	Scenario No.5: Enhancing Flow and Resource Optimization – Extra Procedure Room
		Average 95% CI	
Procedure Room - Upper and Lower GI Endoscopy	Number of completed jobs	**158.07**	**86.02**
	Operation Time	**18.11**	**18.03**
Procedure Room 2- Upper and Lower GI Endoscopy	Number of completed jobs	***	**72.16**
	Operation Time	***	**17.88**
Procedure Room - Lower GI Endoscopy	Number of completed jobs	**128.83**	**70.12**
	Operation Time	**14.45**	**13.74**
Procedure Room 2- Lower GI Endoscopy	Number of completed jobs	***	**58.83**
	Operation Time	***	**14.03**
Procedure Room - Upper GI Endoscopy	Number of completed jobs	**56.95**	**31.22**
	Operation Time	**10.36**	**10.44**
Procedure Room 2- Upper GI Endoscopy	Number of completed jobs	***	**25.89**
	Operation Time	***	**10.61**

In the analysis of the utilization of resources (Figure 4.21), a decrease in the utilization rate of resources was noted. Medical team (gastroenterologist and anesthesiologist) utilization also decreased from 85 to 47% while the exam process nurse utilization decreased from 74% to 41%. This decrease can be justified by the addition of another procedure room, duplicating the team as mentioned previously, and maintaining the same number of appointments. Furthermore, the preparation and recovery process nurse utilization, decreased from 77% to 43%, which can be attributed to the increase in the configuration of available nurses from 1 to 2. The beds utilization reduction from 72% to 36% follows the same rationale than the medical team, reducing patient length of stay on the system and leaving more disponible resources available.

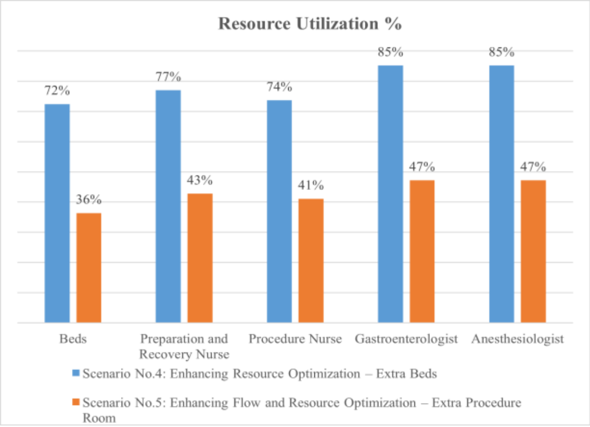

Figure 4.21- Resource Utilization- Comparison between Scenario No.4: Enhancing Resource Optimization – Extra Beds and Scenario No.5: Enhancing Flow and Resource Optimization – Extra Procedure Room

In the queuing analysis, the waiting room queuing time has shown that on scenario No.5 average queuing time was equal to 0. This indicates that after admission, patients did not experience any queuing time in the waiting room and were directly admitted to the patient preparation process.

There were no significant changes or modifications noted in the patient recovery process.

Dressing room activity exhibited a decreased of blocked route from 2.64% to 0%.

This scenario demonstrated that adding another procedure room contributed to a significant reduction of patient length of stay on the system and on the queuing time on the patients' preparation process. This reduction can be interpreted as an indicative bottleneck behavior, leading to the conclusion that the procedure room serves as a bottleneck activity. However, despite the reduction of patient length of stay and queuing time, the resources' utilization percentage remains underutilized, implying inefficiency.

4.2.6- Scenario No.6: Enhancing Flow and Resource Optimization – Maximize capacity

The last scenario tested demonstrated favorable outcomes, including a significant reduction on the patient length of stay on the system which is one of the most important key performance indicators. However, the percentage of resource utilization exhibited inefficiency, due to underutilized resources. This showed that this scenario had potential to improve performance, if adequate resource utilization was achieved, preventing overcapacity and unnecessary elevated queuing time. In order to maximize capacity another scenario was tested.

Scenario No.6 consisted in scheduling the appointments 12.5 minutes apart with the same unit working hours as in the baseline simulation (8:00 a.m.- 20:00 p.m.). The model construction assumed the same parameters as in scenario No.5 (2 procedure rooms each one with one team, 2 dressing rooms, 6 beds, 2 nurses for preparation and recovery).

As discussed above, to allow the increase of admissions per day, admission activity was configurated using a fixed value of 12.5 minutes. Due to lunch time between 13:00 pm. to 14:00 pm., this activity was constrained using a shift pattern with a morning shift (8:30 a.m. to 12:45 p.m.), and an afternoon shift (13:30 p.m.-18:00 p.m.). The remnant parameters of the model were the same as in the baseline simulation model.

In this scenario, it is evident that scheduling exams at intervals of 12.5 minutes while maintaining the same model construction as in scenario No.5 and baseline simulation configuration, leads to a significant increase in the number of patients admitted (672) (Table 4.33). Moreover, this scheduling and configuration approach, results in a considerable increase in the number of exams performed, reaching 650.07 exams. This represents a difference of more 394.76 exams than in the baseline simulation and 305.82 exams than those achieved in scenario No.5. The average time in the system and standard deviation, when compared to the baseline simulation, increased from 108.26 minutes to 117.33 minutes and from 17.58 minutes to 21.65 minutes, respectively. Maximum time in the system increased from 187.13 to 225.48 minutes, however, as figure 4.22 shows, 99.89% of patients complete their exams within the same maximum time as patients from the baseline scenario.

Table 4.33- Admission and Exams performed Output- Comparison between Baseline Output and Scenario No.5 and Scenario No.6: Enhancing Flow and Resource Optimization – Maximize capacity

Variables		**Baseline Simulation Output**	**Scenario No.5: Enhancing Flow and Resource Optimization – Extra Procedure Room**	**Scenario No.6: Enhancing Flow and Resource Optimization – Maximize capacity**
		Average 95% CI		
Admission	**Number Entered**	**263.82**	**355**	**672**
No show	Number Completed	**8.03**	**10.60**	**20.18**
Exams performed	Number Completed	**255.31**	**344.25**	**650.07**
	Average Time in System	**108.26**	**93.25**	**117.33**
	Standard Deviation	**17.58**	**10.01**	**21.65**
	Maximum Time in System	**187.13**	**130.82**	**225.48**

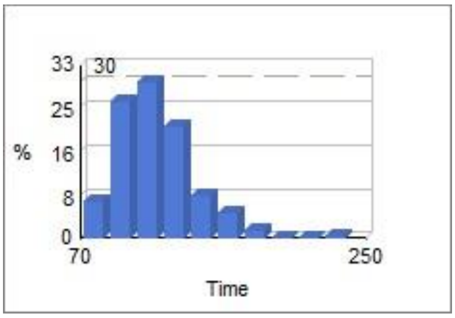

Figure 4.22- Scenario No.6: Enhancing Flow and Resource Optimization – Maximize capacity- Time in System

Regarding the Patient Preparation Process output (Table 4.34), we can observe an increase in both the average and the standard deviation of the patient preparation length of stay when comparing the results with scenario No. 5 to the baseline simulation output. In the queuing time for exam preparation analyses, we can observe a decrease in both the average and the standard deviation when compared with the baseline simulation output. Compared to the baseline output, approximately 43.9% of patients completed their preparation in under 30 minutes on average.

Table 4.34- Patient Preparation Process Output- Comparison between Baseline Simulation Output, Scenario No.5 and Scenario No.6: Enhancing Flow and Resource Optimization – Maximize capacity

Variables		Baseline Simulation Output	Scenario No.5: Enhancing Flow and Resource Optimization – Extra Procedure Room	Scenario No.6: Enhancing Flow and Resource Optimization – Maximize capacity
		Average 95% CI		
Patient Preparation length of stay 1	Average Time in System	**27.95**	**23.51**	**37.16**
	Standard Deviation	**7.1**	**3.02**	**15.54**
Queue 1 for Exam Preparation	Average Time in System	**8.8**	**0.14**	**2.30**
	Standard Deviation	**12.68**	**0.57**	**4.37**
Patient Preparation length of stay 2	Average Time in System	**27.88**	**23.48**	**37.40**
	Standard Deviation	**7.1**	**3.09**	**15.80**
Queue 2 for Exam Preparation	Average Time in System	**8.99**	**0.13**	**2.44**
	Standard Deviation	**12.71**	**0.56**	**4.49**
Patient Preparation length of stay 3	Average Time in System	**27.97**	**23.50**	**37.30**
	Standard Deviation	**7.17**	**3.28**	**15.72**
Queue 3 for Exam Preparation	Average Time in System	**8.93**	**0.15**	**2.34**
	Standard Deviation	**12.71**	**0.62**	**4.39**
Patient Preparation length of stay 4	Average Time in System	**28.1**	**23.49**	**37.30**
	Standard Deviation	**7.2**	**3.14**	**15.56**
Queue 4 for Exam Preparation	Average Time in System	**8.99**	**0.14**	**2.35**
	Standard Deviation	**12.76**	**0.61**	**4.41**
Patient Preparation length of stay 5	Average Time in System	***	**23.59**	**37.31**
	Standard Deviation	***	**3.17**	**15.70**
Queue 5 for Exam Preparation	Average Time in System	***	**0.60**	**2.37**
	Standard Deviation	***	**2.20**	**4.41**
Patient Preparation length of stay 6	Average Time in System	***	**23.53**	**37.31**
	Standard Deviation	***	**3.29**	**15.70**
Queue 6 for Exam Preparation	Average Time in System	***	**0.13**	**2.36**
	Standard Deviation	***	**0.54**	**4.38**

In the analysis of the Exams Process output comparison (Table 4.35), it was observed that there were no significant changes in operation times based on the type of procedure and an increase of the number of completed exams. In comparison to the baseline simulation output, Upper and lower GI endoscopy, experienced an increase from, 117.64 to 298.53 exams, Lower GI endoscopy from 95.68 to 244.52 and Upper GI endoscopy from 42.45 to 108.21. This represents an additional 180.89 completed upper and lower GI endoscopy exams, 148.84 lower GI endoscopy exams and 65.76 upper GI endoscopy exams. In comparison to scenario No.5, Upper and lower GI endoscopy, experienced an increase from, 158.18 to 298.53, Lower GI endoscopy from 128.95 to

244.52 and Upper GI endoscopy from 57.11 to 108.21. This represents an additional of 140.35 completed exams to upper and lower GI endoscopy, 115.57 of completed exams to lower GI endoscopy and 51.1 completed exams to upper GI endoscopy.

Table 4.35-Exam Process Output- Comparison between Baseline Output and Scenario No.5 and Scenario No.6: Enhancing Flow and Resource Optimization – Maximize capacity

Variables		Baseline Simulation Output	Scenario No.5: Enhancing Flow and Resource Optimization – Extra Procedure Room	Scenario No.6: Enhancing Flow and Resource Optimization – Maximize capacity
		Average 95% CI		
Procedure Room - Upper and Lower GI Endoscopy	Number of completed jobs	**117.64**	**86.02**	**112.02**
	Operation Time	**17.87**	**18.03**	**18.12**
Procedure Room 2- Upper and Lower GI Endoscopy	Number of completed jobs	*******	**72.16**	**186.51**
	Operation Time	*******	**17.88**	**18.15**
Procedure Room - Lower GI Endoscopy	Number of completed jobs	**95.68**	**70.12**	**91.98**
	Operation Time	**14.1**	**13.74**	**14.10**
Procedure Room 2- Lower GI Endoscopy	Number of completed jobs	*******	**58.83**	**152.54**
	Operation Time	*******	**14.03**	**14.09**
Procedure Room - Upper GI Endoscopy	Number of completed jobs	**42.45**	**31.22**	**40.57**
	Operation Time	**10.19**	**10.44**	**10.46**
Procedure Room 2- Upper GI Endoscopy	Number of completed jobs	*******	**25.89**	**67.64**
	Operation Time	*******	**10.61**	**10.00**

Scheduled appointments and resource utilization were optimized to minimize resource waste and decrease queuing time with the objective of reducing patient length of stay on the system while maintain operational efficiency and performance. The objective was to maintain the same resource utilization performance as in scenario No.1(Figure 4.23).

Regarding the result utilization analysis, all resources experienced a substantial increase in utilization when compared to scenario No.5. The beds utilization increased from 36% to 81%, the utilization of nurses from the patient preparation and recovery process also increased from 43% to 73%. Similarly, the utilization of nurses from the Exam Process increased from 41% to 70% and the medical team (Gastroenterologist and anesthesiologist) increased from 47% to 81%. In comparison with scenario No.1 there was a slight reduction on the utilization of all resources of approximately 4%. This reduction of 4% on resource utilization is considered acceptable for this scenario, as the focus was to maintain a balance between high capacity with high resource utilization rate, reducing patient waiting time.

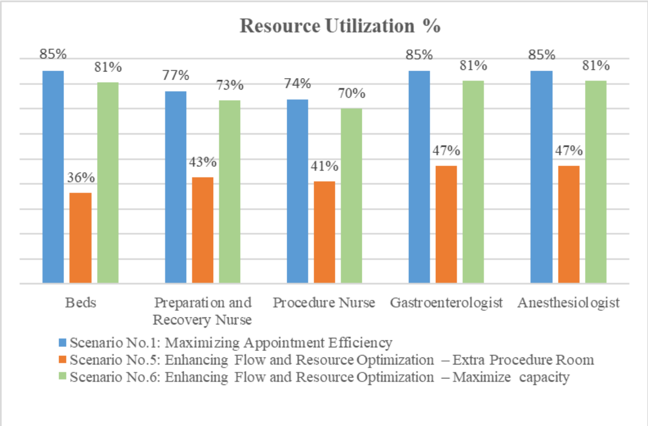

Figure 4.23-Resource Utilization- Comparison between Scenario No.1, Scenario No.5 and Scenario No.6: Enhancing Flow and Resource Optimization – Maximize capacity

In the queuing analysis, the waiting room queuing time (Table 4.36) showed an increase in all variables, but not very expressive with exception of the maximum queuing time. However, approximately 92% of patients admitted experienced queuing times lower than 8 minutes in the waiting room.

Table 4.36- Waiting room Queuing time Output- Comparison between Baseline Output and Scenario No.6: Enhancing Flow and Resource Optimization – Maximize capacity

Variables		**Baseline Simulation Output**	**Scenario No.6: Enhancing Flow and Resource Optimization – Maximize capacity**
		Average 95% CI	
Upper And Lower GI Waiting Room	Average Queuing Time	**0.29**	**2.16**
	Standard Deviation of Queuing Time	**0.99**	**6.34**
	Maximum Queuing Time	**5.90**	**42.85**
Lower GI Waiting Room	Average Queuing Time	**0.29**	**2.21**
	Standard Deviation of Queuing Time	**1.01**	**6.42**
	Maximum Queuing Time	**5.85**	**42.16**
Upper GI Waiting Room	Average Queuing Time	**0.28**	**2.19**
	Standard Deviation of Queuing Time	**0.83**	**6.33**
	Maximum Queuing Time	**4.48**	**36.75**

This scenario demonstrated that it is possible to improve scenario No.5 trough enhancing scheduling appointments while maintaining a high resource utilization and reducing patient waiting time. This scenario also contributed to improve performance and operational efficiency through the increased number of exams performed and the reduction in the patients' length of stay in the system. These improvements had a positive impact on overall model simulation, making this scenario the most efficient scenario evaluated. However, it is important to mention, that this is a hypothetical scenario, which involves physical modifications and the construction of an additional dressing room. A second procedure room is available but is not used for procedures with sedation. In a scenario where procedures with sedation were required, it could also present some challenges, such as interfering on patient flows. Furthermore, hiring a second medical team may prove to be expensive. It would be necessary to perform a cost benefit analysis considering the patient demand for this type of exams in order to determine if the investment would be justified.

4.2.7- Scenario No.7: Enhancing Appointment Scheduling- Capacity Optimization

Considering that scenario No.6 emerged as the most efficient scenario tested, despite the hypothetical constraints, physical modification required, potential complications on patient flows with second procedure room, and related costs with a second medical team, another scenario was tested, with the objective of providing an alternative that minimized these hypothetical issues and closely resembled the actual unit configuration. With the information obtained during the previous scenarios, bottlenecks and limitations observed, this scenario has the objective to improve the performance observed on scenario No.1, which has a model simulation similar to the Special Exams Unit.

In Scenario 7, appointments were scheduled 24.5 minutes apart while maintaining the working hours of the baseline simulation (8:00 a.m.- 20:00 p.m.). Model construction assumed the same parameters as scenario No.1 (without extra dressing room and resources).

To allow the increase of admissions per day, admission activity was configurated using a fixed value of 24.5 minutes. Due to lunch time taking place between 13:00 pm. to 14:00 pm., this activity was constrained using a shift pattern with a morning shift (8:30

a.m. to 12:45 p.m.), and an afternoon shift (13:30 p.m.-17:40 p.m.). The remnant model parameters were the same as in the baseline simulation model.

This scenario demonstrates that scheduling exams at every 24,5 minutes, while maintaining the same resources as in Scenario No.1, optimized the average time in the system, the standard deviation, and the maximum time in system, with considerable time reduction (Table 4.37). The number of patients admitted, and number of Exams performed, decreased from 355 to 330 patients and from 342.75 to 319.42 exams, respectively. The average time in the system, decreased from 175.56 minutes to 129.33 minutes, less 46.23 minutes per patient than in Scenario No.1 with a decrease also in the standard deviation from 50.83 minutes to 27.35. Maximum time in system also decreased significantly from 362.53 minutes to 254.91, less 107.62 minutes. This current result stills remain high, however, as figure 4.24 shows, 96.8% of patients complete their exams within the same maximum time as patients from the baseline scenario (187.13 minutes).

Table 4.37- Admission and Exams performed Output- Comparison between Scenario No.1: Maximizing Appointment Efficiency and Scenario No.7: Enhancing Appointment Scheduling- Capacity Optimization

Variables		Scenario No.1: Maximizing Appointment Efficiency	Scenario No.7: Enhancing Appointment Scheduling- Capacity Optimization
		Average 95% CI	
Admission	**Number Entered**	**355**	**330**
No show	Number Completed	**10.73**	**9.98**
Exams performed	Number Completed	**342.75**	**319.42**
	Average Time in System	**175.56**	**129.33**
	Standard Deviation	**50.83**	**27.35**
	Maximum Time in System	**362.53**	**254.91**

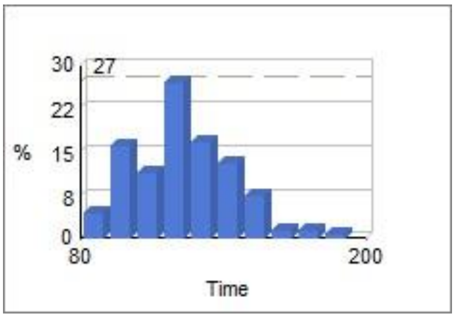

Figure 4.24- Scenario No.7: Enhancing Appointment Scheduling- Capacity Optimization - Time in System

Regarding the Patient Preparation Process output (Table 4.38), we can observe a significant decrease on the average and standard deviation of patient preparation length of stay and queuing time for exam preparation. This decrease aligns with the expected outcome resulting from the optimization process. Compared to the Scenario No.1, approximately 47.1% of patients completed their preparation in under 30 minutes on average, while only 29.9% experienced a waiting time of less than 8 minutes in the queue for exam preparation.

Table 4.38- Patient Preparation Process Output- Comparison between Scenario No.1: Maximizing Appointment Efficiency and Scenario No.7: Enhancing Appointment Scheduling- Capacity Optimization

Variables		Scenario No.1: Maximizing Appointment Efficiency	Scenario No.7: Enhancing Appointment Scheduling- Capacity Optimization
		Average 95% CI	
Patient Preparation length of stay 1	Average Time in System	**70.24**	**35.00**
	Standard Deviation	**40.70**	**14.74**
Queue 1 for Exam Preparation	Average Time in System	**32.29**	**22.00**
	Standard Deviation	**20.23**	**19.00**
Patient Preparation length of stay 2	Average Time in System	**70.51**	**35.13**
	Standard Deviation	**40.75**	**14.92**
Queue 2 for Exam Preparation	Average Time in System	**32.41**	**22.17**
	Standard Deviation	**20.39**	**19.11**
Patient Preparation length of stay 3	Average Time in System	**70.35**	**34.99**
	Standard Deviation	**40.65**	**14.75**
Queue 3 for Exam Preparation	Average Time in System	**32.38**	**22.12**
	Standard Deviation	**20.13**	**18.88**
Patient Preparation length of stay 4	Average Time in System	**70.67**	**35.15**
	Standard Deviation	**40.62**	**14.76**
Queue 4 for Exam Preparation	Average Time in System	**32.52**	**22.32**
	Standard Deviation	**20.02**	**18.87**

In the analysis of the Exams Process output comparison (Table 4.39), it was observed that there were no significant changes in operation times based on the type of procedure, but the number of completed exams by type of exam decreased. Upper and lower GI endoscopy experienced a decrease from 158.04 to 147.19, Lower GI endoscopy from 128.82 to 119.81 and Upper GI endoscopy from 56.94 to 52.97.

Table 4.39- Exams Process Output- Comparison between Scenario No.1: Maximizing Appointment Efficiency and Scenario No.7: Enhancing Appointment Scheduling- Capacity Optimization

Variables		Scenario No.1: Maximizing Appointment Efficiency	Scenario No.7: Enhancing Appointment Scheduling- Capacity Optimization
		Average 95% CI	
Procedure Room - Upper and Lower GI Endoscopy	Number of completed jobs	**158.04**	**147.19**
	Operation Time	**18.06**	**18.10**
Procedure Room - Lower GI Endoscopy	Number of completed jobs	**128.82**	**119.81**
	Operation Time	**14.38**	**14.07**
Procedure Room - Upper GI Endoscopy	Number of completed jobs	**56.94**	**52.97**
	Operation Time	**10.36**	**10.25**

As implied in this scenario, the reduction of the interval between appointments, from 30 minutes to 24.5 minutes, increased the number of scheduled appointments, leading to an evident rise in resource utilization, as observed in Figure 4.25. However, it was not possible to achieve a resource utilization percentage rate as high as the one observed in scenario No. 1 due to the risk of increasing queuing times and patient length of stay on the system. In which regards the resources utilization analysis, all resources experienced a substantial increase in utilization when compared to the baseline simulation output. In comparison to the baseline scenario, the beds utilization increased from 49% to 72%, the utilization of nurses from the preparation and recovery process also increased from 59% to 72%. Similarly, the utilization of nurses from the Exam Process increased from 57% to 69% and the medical team (Gastroenterologist and anesthesiologist) increased from 66% to 80%. In comparison with scenario No.1 there was a slight reduction in the utilization rate of beds, which decreased from 85% to 72%, the utilization of nurses from the preparation and recovery process also decreased from 77% to 72%. Similarly, the utilization of nurses from the Exam Process decreased from 74% to 69% and the medical team (Gastroenterologist and anesthesiologist) decreased from 85% to 80%.

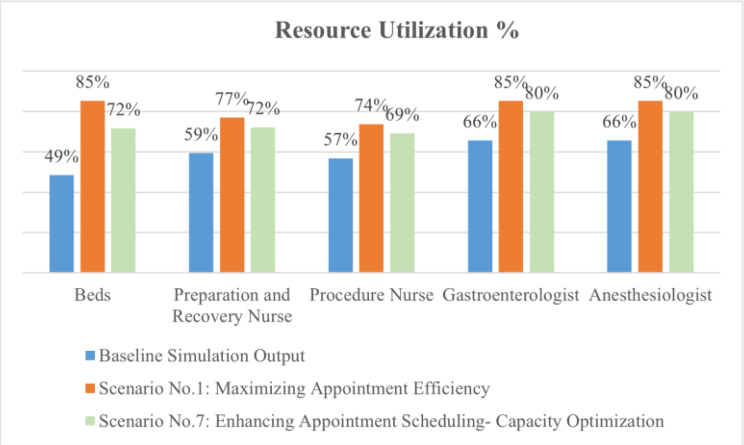

Figure 4.25- Resource Utilization- Comparison between Baseline simulation Output, Scenario No.1: Maximizing Appointment Efficiency and Scenario No.7: Enhancing Appointment Scheduling- Capacity Optimization

This reduction of resource utilization is considered acceptable for this scenario, as the focus was to maintain a balance between high capacity with high resource utilization rate, reducing patient waiting time and length of stay in the system. Increasing the number of appointments allowed achieving higher levels of utilization rates, but it became evident that when the system was overloaded without adding any additional resources, some issues occur such as, queuing time increases, blocked route increases at one of the bottlenecks of the system (dressing room), so this seems to be an optimal resource utilization rate considering all limitations of this simulation model.

In the queuing analysis, the waiting room queuing time (Table 4.40) showed the most significant decrease in queuing time, which contributed to an overall reduction in the length of stay within the system. It is observed a decrease in the queuing time for the upper and lower GI endoscopy waiting room, which decreases from an average of 13.74 minutes (with a standard deviation of 23.60) to an average of 0.62 minutes (with a standard deviation of 2.48 minutes). The queuing time for the lower GI endoscopy waiting room decreases from an average of 13.78 minutes with a standard deviation of 23.71 minutes to an average of 0.64 minutes with a standard deviation of 2.46 minutes. Finally, the queuing time for the upper GI endoscopy waiting room decreases from an average of 13.74 minutes (and standard deviation of 23.55 minutes) to an average of 0.62 minutes and a standard deviation of 2.24 minutes. On average, around 98.8% of admitted patients would experience queuing times of less than 8 minutes in the waiting room.

Table 4.40- Waiting room Queuing time Output- Comparison between Baseline Output and Scenario No.1: Maximizing Appointment Efficiency

Variables		**Scenario No.1: Maximizing Appointment Efficiency**	**Scenario No.7: Enhancing Appointment Scheduling- Capacity Optimization**
		Average 95% CI	
Upper And Lower GI Waiting Room	Average Queuing Time	**13.74**	**0.62**
	Standard Deviation of Queuing Time	**23.60**	**2.48**
	Maximum Queuing Time	**111.30**	**19.89**
Lower GI Waiting Room	Average Queuing Time	**13.78**	**0.64**
	Standard Deviation of Queuing Time	**23.71**	**2.46**
	Maximum Queuing Time	**109.44**	**18.06**
Upper GI Waiting Room	Average Queuing Time	**13.74**	**0.62**
	Standard Deviation of Queuing Time	**23.55**	**2.24**
	Maximum Queuing Time	**97.61**	**13.13**

During the testing of Scenario No.1, it was observed that the dressing room activity exhibited a bottleneck behavior, experiencing an increase of blocked route of 26.10%. This information was taken into consideration during the optimization process. In this optimized scenario (Scenario No.7), it is observed a blocked route of 2.14%. As mentioned earlier, when the system is overloaded, the dressing room activity intensifies this bottleneck behavior, increasing the percentage of blocked route.

This scenario demonstrated that enhancing scenario No.1 through scheduling appointments optimization, while maintaining reasonable resource utilization and reducing patient waiting time is possible leading to the achievement of notable improvements. Considering all limitations of the model simulation, including activities with bottleneck behavior, this scenario resulted in an optimal number of exams performed and a significant reduction in patient length of stay within the system. This optimization process had a positive impact on model simulation, making this scenario more efficient than scenario No.1.

4.2.8- Scenario No.8: Enhancing Appointment Scheduling according to the Portuguese Society of Digestive Endoscopy

At the moment, there are no specific guidelines regarding the duration required for performing endoscopy examinations. However, it is internationally accepted a minimum duration for procedures such as upper gastrointestinal endoscopy (7 minutes) and colonoscopy (6 to 10 minutes) for withdrawal time of endoscope after reaching the cecum. There are no standardized times for inserting the endoscope, as it may vary depending on whether it is a diagnostic or interventional examination, and also depending on other factors that could extend the procedure duration, such as inadequate intestinal preparation (Sadio & Almeida, 2023).

The Portuguese Society of Digestive Endoscopy recommends different minimum scheduling times based on the type of procedure. For the Upper GI endoscopy, recommends 15 minutes, for the Lower GI endoscopy, 30 minutes and for the Upper and Lower GI endoscopy 40 minutes (Sadio & Almeida, 2023).

Considering the guideline recommendations of the Portuguese Society of Digestive Endoscopy, another scenario was tested, with the objective of providing an alternative scenario to optimize appointment scheduling and capacity planning while maintaining operational performance of model simulation.

The simulation model for this scenario was modified to incorporate three distinct admissions, each corresponding to a specific type of procedure: Upper and Lower GI examination, Lower GI examination, and Upper GI examination. The number of exams admitted follows the Probability Distribution Lbl_Exam_Type (Figure 3.4). Upper and Lower GI endoscopy (45.7%), Lower GI endoscopy (37.7%), and Upper GI endoscopy (16.6%).

These three admissions were configured using a Schedule of Arrivals. A dedicated spreadsheet was developed for manual control of patients' arrivals, following the guideline recommendations (Table 4.41).

Table 4.41- Schedule of Arrivals

	Upper and Lower GI Exams (40 minutes)	Lower GI Exam (30 minutes)	Upper GI Exams (15 minutes)
08:30	X		
09:10			X
09:25		X	
09:55	X		
10:35		X	
11:05	X		
11:45			X
12:00	X		
12:40		X	
13:30		X	
14:00	X		
14:40	X		
15:20		X	
15:50			X
16:05	X		
16:45		X	
17:25	X		
18:05		X	
18:35	X		

No constraints using shift patterns at admission were added, and we removed label action on the Check in activity. The remnant parameters of the model were the same as the ones used in the baseline simulation model.

This scenario demonstrates that scheduling exams according to the Portuguese Society of Digestive Endoscopy, while maintaining the same resources as in the baseline simulation would decrease the number of patients admitted from 263.82 to 235, less 28.82 patients, and would also decrease the number of exams performed from 255.31 to 227.76, less 27.55 exams (Table 4.42). The average time in the system, would decrease from

108.26 minutes to 103.73 minutes, less 4.53 minutes per patient than in the baseline simulation output with a decrease also in the standard deviation from 17.58 to 14.30 minutes. The maximum time in the system would also decrease from 187.13 to 152.84 minutes.

Table 4.42- Admission and Exams performed Output- Comparison between Baseline Output and Scenario No.8: Enhancing Appointment Scheduling according to the Portuguese Society of Digestive Endoscopy

Variables		**Baseline Simulation Output**	**Scenario No.8: Enhancing Appointment Scheduling according to the Portuguese Society of Digestive Endoscopy**
		Average 95% CI	
Admission	**Number Entered**	**263.82**	***
Upper and Lower GI Admission	**Number Entered**	***	**107**
Lower GI Admission	**Number Entered**	***	**80**
Upper GI Admission	**Number Entered**	***	**48**
No show	Number Completed	**8.03**	**7.24**
Exams performed	Number Completed	**255.31**	**227.76**
	Average Time in System	**108.26**	**103.73**
	Standard Deviation	**17.58**	**14.30**
	Maximum Time in System	**187.13**	**152.84**

Regarding the Patient Preparation Process output (Table 4.43), we can observe a decrease in the average and standard deviation of the patient preparation length of stay and queuing time for exam preparation. Compared to the baseline output, approximately 79% of patients completed their preparation in under 30 minutes, while only 68% experienced a waiting time of less than 8 minutes in the queue for exam preparation.

In the analysis of the Exams Process output comparison (Table 4.44), it was observed that there were no significant changes in operation times based on the type of procedure and a decrease of the number of completed exams. Upper and lower GI endoscopy experienced a decrease from 117.64 to 104.78 exams, Lower GI endoscopy from 95.68 to 85.19 exams and Upper GI endoscopy from 42.45 to 37.78 exams. This represents a reduction of 12.86 completed upper and lower GI endoscopy exams, 10.49 of completed lower GI endoscopy exams and 4.67 of completed upper GI endoscopy exams.

Table 4.43- Patient Preparation Process Output- Comparison between Baseline Simulation Output and Scenario No.8: Enhancing Appointment Scheduling according to the Portuguese Society of Digestive Endoscopy

Variables		Baseline Simulation Output	Scenario No.8: Enhancing Appointment Scheduling according to the Portuguese Society of Digestive Endoscopy
		Average 95% CI	
Patient Preparation length of stay 1	Average Time in System	**27,95**	**26.04**
	Standard Deviation	**7,1**	**5.47**
Queue 1 for Exam Preparation	Average Time in System	**8,8**	**6.76**
	Standard Deviation	**12,68**	**10.03**
Patient Preparation length of stay 2	Average Time in System	**27,88**	**26.10**
	Standard Deviation	**7,1**	**5.55**
Queue 2 for Exam Preparation	Average Time in System	**8,99**	**6.70**
	Standard Deviation	**12,71**	**10.04**
Patient Preparation length of stay 3	Average Time in System	**27,97**	**26.14**
	Standard Deviation	**7,17**	**5.66**
Queue 3 for Exam Preparation	Average Time in System	**8,93**	**6.78**
	Standard Deviation	**12,71**	**9.92**
Patient Preparation length of stay 4	Average Time in System	**28,1**	**26.20**
	Standard Deviation	**7,2**	**5.67**
Queue 4 for Exam Preparation	Average Time in System	**8,99**	**6.89**
	Standard Deviation	**12,76**	**10.10**

Table 4.44- Exams Process Output- Comparison between Baseline Output and Scenario No.8: Enhancing Appointment Scheduling according to the Portuguese Society of Digestive Endoscopy

Variables		Baseline Simulation Output	Scenario No.8: Enhancing Appointment Scheduling according to the Portuguese Society of Digestive Endoscopy
		Average 95% CI	
Procedure Room - Upper and Lower GI Endoscopy	Number of completed jobs	**117.64**	**104.78**
	Operation Time	**17.87**	**18.47**
Procedure Room - Lower GI Endoscopy	Number of completed jobs	**95.68**	**85.19**
	Operation Time	**14.1**	**14.19**
Procedure Room - Upper GI Endoscopy	Number of completed jobs	**42.45**	**37.78**
	Operation Time	**10.19**	**10.51**

The decrease in the number of scheduled appointments has led to an expected decrease in resource utilization, as observed in this simulation test (Figure 4.26).

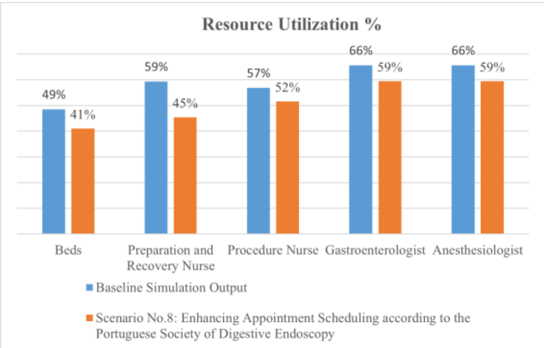

Figure 4.26-Resource Utilization- Comparison between Baseline simulation Output and Scenario No.8: Enhancing Appointment Scheduling according to the Portuguese Society of Digestive Endoscopy

As can be observed from the resource utilization analysis, the nurse allocated to the preparation and recovery process experienced the most significant decrease, from 59% to 45%, less 14%. Bed utilization decreased from 49% to 41%, and medical team utilization decreased from 66% to 59%, representing a reduction of 7% of their utilization.

In the queuing analysis, the waiting room queuing time (Table 4.45) showed a slight reduction in queuing time.

Table 4.45- Waiting room Queuing time Output- Comparison between Baseline simulation Output and Scenario No.8: Enhancing Appointment Scheduling according to the Portuguese Society of Digestive Endoscopy

Variables		**Baseline Simulation Output**	**Scenario No.8: Enhancing Appointment Scheduling according to the Portuguese Society of Digestive Endoscopy**
		Average 95% CI	
Upper And Lower GI Waiting Room	Average Queuing Time	**0.29**	**0.34**
	Standard Deviation of Queuing Time	**0.99**	**1.05**
	Maximum Queuing Time	**5.90**	**5.59**
Lower GI Waiting Room	Average Queuing Time	**0.29**	**0.34**
	Standard Deviation of Queuing Time	**1.01**	**1.04**
	Maximum Queuing Time	**5.75**	**5.45**
Upper GI Waiting Room	Average Queuing Time	**0.28**	**0.34**
	Standard Deviation of Queuing Time	**0.83**	**0.93**
	Maximum Queuing Time	**4.48**	**4.48**

The dressing room did not exhibit a bottleneck behavior in this scenario, showing a decrease from 0.04% to 0%.

This scenario showed that simulating the system based on the recommendations of the Portuguese Society of Digestive Endoscopy resulted in a significant reduction in the number of exams conducted and resource utilization rates, however, the decrease in queuing time played a significant role in reducing the average and standard deviation of the time spent in the system, as well as in reducing the maximum time in the system. This improvement has a positive impact on patient satisfaction and contributes to the delivery of high-quality care.

4.3 Limitations

In this study, the primary source of collected data was the nursing records from the patients' handling process. These records were manually recorded, which introduces a potential risk of human error that could affect the accuracy of the results obtained. However, to mitigate the impact of this risk, the sampling of the data collected was expanded, increasing the sample size.

Despite the valuable opinion and data collected from Experts from the Special Exams Unit, it would be important to have more accurate data, such as, electronic record data, from all activity's times performed by the medical team and nurses. This additional information would provide a more detailed analysis, and more reliable results.

5. CONCLUSION

The Special Exams Unit is a multispecialty unit that offers several types of exams to the patients that arrive through ambulatory care, inpatient services or through the emergency department. In terms of operational management, this unit has an elevated level of complexity, due to different patients flows, scheduling appointments and resources needed, according to each specialty. All this complexity makes it difficult to manage capacity planning with the objective of maximizing the performance of the unit.

DES was applied to study the patient flow in the Special Exams unit. The patient flow was mapped through interviews with experts from the unit and through direct observation of the real process system. The data was extracted from electronic record data from the hospital, nursing records from the patients' handling process, and from the appointment-scheduling system.

During model construction several obstacles were identified. For example, one of the model parameters did not have a suitable statistical distribution to represent it. To overcome the challenges associated with the Lower GI endoscopy procedure, a probability distribution profile was created in SIMUL8, incorporating real data. This approach ensured that the simulation model produced more reliable and accurate results. By utilizing the probability distribution profile, the variability observed in the actual Lower GI endoscopy process was effectively captured in the simulation.

In order to promote a better understanding of the resources' utilization rates, the patients' preparation and recovery processes, were deconstructed, in smaller and specific activities. Instead of using a suitable distribution fit for the preparation process and a probabilistic distribution profile for the recovery process, it was used an average distribution in some of the activities within this process. By using an average distribution, the simulation model approximated the average time taken for these activities, providing a simplified representation of the variability. While this approach may not capture the full range of outcomes, it still offers insights into the resource utilization rates within the model system.

Overall, the simulation model developed displayed a reasonable fit to the real system as the outputs obtained for some variables were close to the ones observed in the real system. In some cases, however, the errors produced by the model exceeded 10% of the observed values, which suggests that some improvements still can be introduced in the model. This was the case, for example, for the variable time in the system. The variables related to the patient preparation process, as well as the standard deviation time in the system, also demonstrated errors exceeding 10%. This discrepancy could be attributed to the utilization of an average distribution for activities instead of employing a suitable distribution. By using an average distribution, the simulation model may not adequately capture the full range of variability and potential outcomes within the patient preparation process. However, despite these values the simulation model generates valid and meaningful results.

Eight scenarios were tested, with the objective of identifying limitations and bottlenecks, maximizing capacity, and improving scheduling appointments and resource utilization. The purpose of these scenarios was to assess the system's performance under different conditions and identify areas where improvements can be made. By testing various scenarios, it becomes possible to evaluate the impact of distinct factors and strategies on the system's efficiency and effectiveness. This includes assessing the effectiveness of appointment scheduling methods, optimizing the allocation of resources, and identifying potential constraints or bottlenecks within the system.

In Scenario No. 1, where the objective was to maximize appointment efficiency with inter-arrival times of 20 minutes, there was a notable increase in the number of exams performed and resource utilization rates. However, this came at the cost of a significant increase in queuing time and the length of stay in the system. The overload on the system during this scenario allowed for the identification of a bottleneck behavior within the dressing room activity. The result of a blocked route of 26.1% indicates that the dressing room activity experienced an elevated level of congestion and became a limiting factor in the overall process flow.

Adding a second dressing room on Scenario No.2, showed a decrease in the queuing times and of the blocked route on dressing room No.1 from 26.1% to 15.96%, validating experts' opinion that this activity assumes a bottleneck behavior.

Scenario No. 3 and No. 4 were conducted to test resource optimization with the objective of identifying limitations and bottleneck behaviors in other activities or resources, considering that Scenario No. 2 still observed congestion in the dressing room activity. In Scenario No. 3, the addition of an extra nurse for the preparation and recovery process had a positive effect on the system. It resulted in a reduction in patient preparation time and length of stay. However, it was also found that the resource utilization rate was not efficient, reaching only 43%. Furthermore, when the system became overloaded, a potential bottleneck behavior was observed, with the blocked route decreasing from 15.96% to 13.80%. On Scenario No. 4, the addition of two more beds (increasing the total from 4 to 6 beds) helped alleviate the bottleneck behavior in the dressing room. This led to a significant decrease in the blocked route from 13.80% to 2.64%. However, it also resulted in a notable increase in queuing time for exams and length of stay in the system.

Based on the findings from Scenario No. 4, which indicated a potential bottleneck in the Exam Procedure Process, a flow and resource optimization scenario was conducted. In this scenario, a second procedure room was introduced, along with an independent team comprising medical professionals and nurses. The addition of the second procedure room and independent team resulted in a significant decrease in both patients' length of stay in the system and queuing time. This confirmed the presence of a bottleneck behavior. On Scenario No. 6, due to the low resource utilization rates on scenario No.5, the same model was utilized but with the objective of maximizing capacity through flow, resource optimization, and scheduling. In this scenario, appointments were scheduled at intervals of 12.5 minutes, which led to reduced queuing times, shorter patient length of stay, and a notable increase in the number of exams performed. Scenario No. 6 displayed an elevated level of resource optimization by effectively utilizing the available resources, optimizing the flow of patients, and implementing an enhanced scheduling approach. This resulted in an improved efficiency, reduced waiting times, and increased throughput in terms of the number of exams conducted.

Scenario No. 6 emerged as the most efficient scenario tested; however, due to hypothetical constraints such as the need for physical modifications and potential complications in patient flows with a second procedure room, a more realistic scenario, Scenario No. 7, was explored. Scenario No. 7 aimed to optimize the model from Scenario No. 1 by focusing on scheduling and resource optimization. In Scenario No. 7, appointments were scheduled at intervals of 24.5 minutes, ensuring high resource utilization while considering the limitations and bottlenecks identified in previous scenarios. This scenario demonstrated reliable performance by effectively reducing queuing times and the length of stay in the system. By prioritizing scheduling and resource optimization, Scenario No. 7 aimed to achieve efficient resource allocation while maintaining a realistic and feasible approach. This scenario allowed for improved patient flow and reduced waiting times, contributing to enhanced overall system performance.

The Portuguese Society of Digestive Endoscopy provides specific recommendations for minimum scheduling times based on the type of procedure. In Scenario No. 8, these guidelines were considered to create an alternative scenario focused on optimizing appointment scheduling and capacity planning. This scenario demonstrated a reduction in the number of exams conducted and resource utilization rate. The decrease in queuing time played a significant role in reducing the average and standard deviation of the time spent in the system, as well as the maximum time. The improvements achieved through Scenario No. 8 have a positive impact on patient satisfaction, as they contribute to shorter waiting times and a more efficient process.

Considering the constraints and limitations inherent in the real-world implementation, it* is our opinion that Scenario No. 7 provides a practical and viable solution that optimizes the scheduling process, leading to improved efficiency and patient experience.

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