Queueing System Analysis
A case study

Janaina Cristina Ferreira

Dissertation presented to Escola Superior de Tecnologia e Gestão of Instituto Politécnico de Bragança to obtain the Master Degree in Industrial Engineering

Supervised by:

Prof. Dra. Carla Alexandra Soares Geraldes

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Dedication

I dedicate this work for every woman in the world. They make me feel gorgeous, believer and powerful. Your fight is my fight, for every girl. You are capable to do anything.

Be brave and strong.

Always fight like a girl.

Acknowledgements

I am thankful for my parents Josefa and Valdeir, my sister Jaqueline and my brother in law Álvaro, my grandparents Ana and Adonias, Maria and Anibal (in memoriam), my mother's family, my boyfriend Jaime and my friends.

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I am thankful for UTFPR and IPB, for the agreement that gave me the best experience in my life: Trust myself and fly away!

Abstract

The application of simulation tools in the construction of models that represent areal system is increasingly important in the analysis and optimization of production and management processes. This study aims to analyze and optimize a queuing system in a Health Care Unit in the district of Bragança, Portugal. In particular, the check-in process of patients/customers in the health care unit is analyzed to carry out complementary diagnostic tests, treatments and external consultations in different medical specialities. The health care unit is faced with longer check-in waiting times than desired, so it is intended with this work to find solutions to increase the efficiency of the system. Thus, quantitative models for the management of queues will be approached and studied to indicate the expected performance of the system without having to quantify the waiting cost. Given the complexity of the system, the simulation technique will be used to develop different types of mathematical and logical models that reproduce the behaviour of the system under study. The system was modelled using the Simio® software, which is a tool for modelling discrete events by simulation, based on intelligent objects. A validation model was used to simulate the real system as a parameter for comparing the results obtained from the analysis of 4 alternative scenarios that present solutions for optimizing the queues. The results presented in this study can be used as a decision method and implemented following the reality of the Health Care Unit.

Keywords: Waiting Queue; Optimization; Simio®.

Resumo

A aplicação de ferramentas de simulação na construção de modelos que representem um sistema real tem se mostrado cada vez mais importante na análise e otimização de processos produtivos e administrativos. Esse estudo tem como objetivo a análise e otimização de um sistema de filas de espera numa unidade de saúde do distrito de Bragança, Portugal. Em particular, é analisado o processo de check-in dos pacientes/utentes na unidade de saúde para a realização de exames complementares de diagnóstico, tratamentos e consultas externas nas diferentes especialidades médicas. A unidade de saúde depara-se com tempos de espera de check-in superiores ao desejado, pelo que se pretende com este trabalho encontrar soluções que permitam aumentar a eficiência do sistema. Assim, serão abordados e estudados modelos quantitativos para a gestão de filas de espera com o propósito de indicar o desempenho esperado do sistema sem que seja necessário quantificar o custo de espera. Dada a complexidade do sistema, será usada a técnica de simulação para o desenvolvimento de diferentes tipos de modelos matemáticos e lógicos que reproduzam o comportamento do sistema em estudo. O sistema foi modelado utilizando o software Simio®, que é uma ferramenta de modelagem de eventos discretos por simulação, baseada em objetos inteligentes. Para simular o sistema real foi construído um modelo de validação utilizado como parâmetro de comparação dos resultados obtidos a partir da análise de 4 cenários alternativos que apresentam soluções para otimização das filas de espera. Os resultados apresentados nesse estudo podem ser utilizados como método de decisão e implementados em acordo com a realidade da unidade de saúde.

Palavras-chave: filas de espera; otimização; Simio®.

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Acronyms

DES Discrete Event Simulation.

FIFO First-In First-Out.

HCU Health Care Unit.

HDU High Dependency Unit.

MGRT Maximum Guaranteed Response Time.

NHS National Health Service.

NIQ Number In Queue.

SIMIO Simulation Modeling based on Intelligent Objects.

SME Subject-Matter Experts.

WHO World Health Organization.

Chapter 1

Introduction

In this chapter will be presented an overview of the scientific research proposal, the main objectives that led this case study and the structure of the dissertation.

1.1 Background

Nowadays, healthcare needs to improve their services to be prepared for the always-increasing number of customers, perform services properly and ensure customer satisfaction. According to the World Health Organization (WHO), in healthcare services, the principal response to assess the efficiency is the waiting time for patients [1], being waiting time, the time that a patient takes to be attended from the moment he arrives at the health system until his effective care.

The National Health System of Portugal has a document that regulates waiting times for services that need to be previously scheduled and services in the emergency department.

According to the Charter of Patients' Rights and Duties, every citizen has the right to receive care within the maximum guaranteed response time (MGRT), which are defined annually by an ordinance of the Ministry of Health for all types of care without urgency [2]. This regulation allows the improvement in patient care, optimizing the efficiency of service provision and provides a better overall condition to the population.

In this technological and fast-paced society, people should not and do not want to wait in long queues. It is a fact that very long waiting times are the main cause of patient dissatisfaction, causing frustration and bad patient experience. For this reason, Health Care Unit establishments need to have as a priority a relationship of trust with the patient and need to ensure satisfaction and good care [3].

This case study of queue management intends to find solutions that can be implemented in a Health Care Unit in the district of Bragança that is facing problems. Using simulation models that describe the Health Care Unit, seeking to optimize the efficiency of the system and minimize the waiting times for check-in.

1.2 Objectives

This case study has the goal to analyse and optimize a queueing system in a Health Care Unit of Bragança District, focusing on improving the patient/customer check-in process and verifying the waiting time for complementary diagnostic exams, treatments and medical appointment of different specialities at the unit. Therefore, it is considered:

- Find solutions to increase system efficiency;
- Apply a queueing system methodology to develop a mathematical model that represents the real-world situation;
- Validate the model using the software SIMIO® (Simulation Software based on Intelligent Objects);
- Simulate different scenarios and analyse the parameters to improve the progress of the waiting process, numbers of incoming entities and system layout.

1.3 Structure of The Thesis

This thesis is divided into 6 chapters it is recommended to read this section for a better understanding of the objectives and development of this thesis.

Chapter 1 introduces to the reader in terms of what is proposed, the objectives and motivations to apply simulation to improve the Health Care Unit environment.

Chapter 2 introduces the literature reviews to the reader, the concepts about simulation, queueing theory, mathematical models, the software used in the study as well as the parameters and the influence of the Discrete-Event Simulations (DES).

Chapter 3 presents the Health Care Unit, identifying the process flows, the problems and possibles solutions.

Chapter 4 presents the simulation modelling and parameters, the measurement performances that are used to validate the model.

Chapter 5 discuss the simulation and analysis of 4 scenarios in the models, the changes and the results.

Chapter 6 provides a brief synopsis of the study's development, presents its main results and conclusion, modifications for future work are also proposed.

Chapter 2

Literature Review

An approach with the most important concepts and theories applied in this thesis, such as simulation, queueing theory and the software Simio LLC are presented in this section.

2.1 Simulation

Simulation application depends only on the imagination users. Despite many definitions, T. Gogg and J. Mott defines "Simulation is an art and science of creating a representation of process or system for experimentation and evaluation" [4].

Simulation is a strong tool to solve problems and find the most suitable solution for a model of a real world. It is possible to simulate risks, reduce costs, predict events even when you have an incomplete dataset. Simulation analytical or computational helps the user to predict the performance of a system and to experiment with several possibilities [4],[5],[6].

2.1.1 System and Models

A system is a set of objects that develop together some interaction to reach an aim. Some examples are a production system manufacturing automobiles, a simple waiting line or a complex airport. It is essential to understand the behaviour and performance obtained in different configurations and circumstances in a system [5], [6].

A system is often affected by changes outside it. Due to that, it needs to define a boundary system on the environment. A careful observation of the particular conditions can lead to reliable conclusions [5], [6].

Types of Models

Physical and analytical models can be used by the developer to understand the limitations, constraints, advantages and disadvantages in the real system. The simulated model is used to predict the effect of changes in the system, to design, emulate and to operate the system [5].

Simulations models may be classified as static or dynamic, stochastic or deterministic, discrete or continuous [6].

- **Static and Dynamic Simulation**

  The dynamic simulation model is the one that represents the change of the system over time, and the static simulation model is one that evidences a particular point in time [6].

- **Stochastic and Deterministic Simulation**

  Simulations also may be stochastic or deterministic. the most common is a stochastic simulation, where the random variables represent the variations in a model system. One example is a system that involves people because there is always a variation, external inputs may vary and mistakes can be made. In the deterministic simulation, there are no random variables, inputs are predetermined and the outputs are set. This type is more used as model-based decision and schedules applications [5], [6].

- **Discrete and Continuous System**

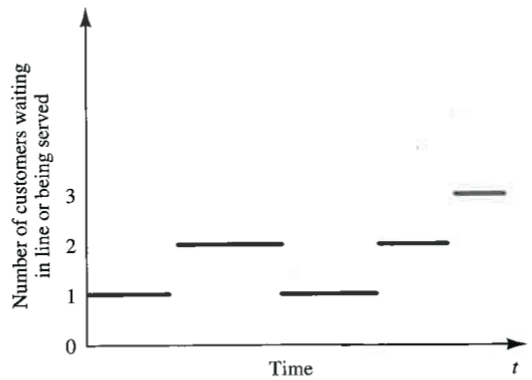

Figure 2.1: Discrete System State Variable.
[6]

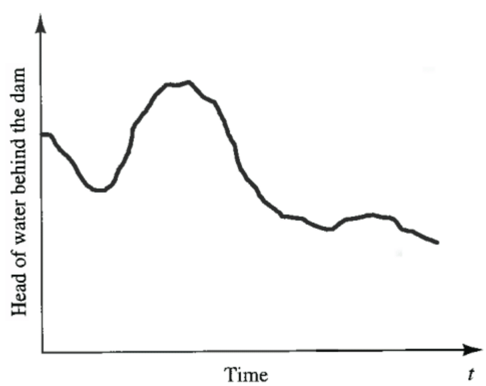

Figure 2.2: Continuous System State Variable.
[6]

A system can be characterised as discrete or continuous. A system is considered discrete when the state variable(s) change only at a discrete set of points in time.

On the other hand in a continuous system the state variable change continuously over time. The figures 2.1 and 2.2 show the state variables in time [5], [6].

2.1.2 The Simulation Process

Is important to define how a simulation process was defined in the study. Law [7] define a seven-steps approach for conducting a successful simulation study (see figure 2.3). This seven-steps are implemented in this case study for the long time credibility that the process has in the field.

The seven-steps will be discussed as follows:

1. **Formulate the Problem**

   The first step consists to know the problem, usually is present for the decision-makers and some questions should be approached: the object of study, why this problem is happening, the system configuration, performance measure evaluate the efficiency of the system [7].

2. **Collect Information/Data and Construct an Assumptions Document**

   The second step is to collect information about the system, the plant characteristics, the number of entities, number and position of the servers, to observe the flow, and take notes of about the working process. If necessary and possible, collect a database the parameters, every inputs and output, the distributions data, opinions of Subject-Matter Experts (SME)s and the time and money constrains [7].

3. **Is the Assumptions Document Valid?**

   The third step is important to evaluate the assumptions of the system, to analyze if they are valid and possibly discover errors [7].

4. **Program the Model**

   The fourth step requires a decision based on knowledge in simulation software frameworks and the most suitable software (e.g. ARENA, ProModel, Simio®, etc) [7].

5. **Is the Programmed Model Valid?**

   The fifth step is one of the most important steps to validate the model and to compare the output of the model simulation with the outputs of the real world. If the results have a good approximation and it is clear that the model represents the real system, then is reliable used it [7].

6. **Design, Conduct, and Analyze Experiments**

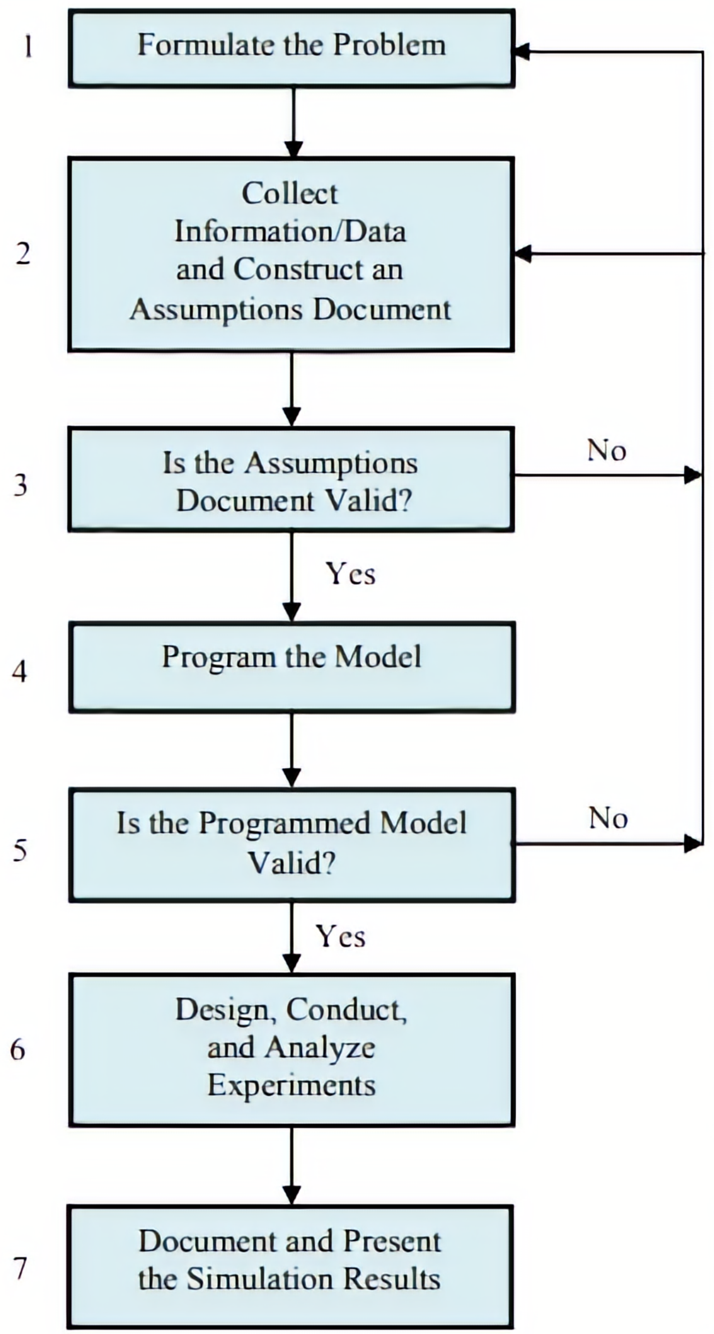

Figure 2.3: A Seven-Step Approach for Conducting a Successful Simulation Study. [7]

The sixth step determines the run parameters, the run length, the number of replications and, after that, to analyze the results, and decide if additional experiments should be run [7].

7. **Document and Present the Results**

   The seventh and last step is the documentation, it is important to register the analysis of the result, leaving suggestions for future changes and to archive images, simulations fields, animations [7].

2.1.3 Advantages and Disadvantages of Simulations

The number of companies and organizations using simulation tools is increasing rapidly. It is more and more common to solve problems and develop methods using computer simulation models. However, like any simulation tool, there are advantages and disadvantages, these are mentioned by authors as Pegden, Shannon and Sadowski [8], Banks [9], Carson and Nelson [6], Law and Kelton [10] and Schriber [11].

- The simulation allows the user to perform better decisions. Once hard decisions have been made, simulations tests avoid unnecessary costs with changes.

- Systems with wide information flows can be tested without many resources, manipulating times like in real system, compressing or expanding the analysis in a few minutes.

- It is possible to obtain insight about the interaction of variables, allowing to identify problems in complex systems.

- Bottleneck analysis can be a key indicator to better performance and to understand and identify the constraints in process, how like the delays in work-in-process.

- A simulation study can help the user to understand how some phenomena happens in the real system, examining and controlling the situation.

- Exploring situations and different scenarios, modifying and testing changes in the model, answering questions "What-If".

Despite many advantages, the simulation tools can also have some disadvantages for the user. The authors mentioned above also corroborate [6],[8],[9],[10],[11].

- Simulations may be used inappropriately, leading to poor results. This is an important point to this study because wrong results it is the higher cause of a deficient simulation and unsatisfactory.
- Simulation may be very expensive and can consume a lot of time and resources to build, to execute, and to analyze.
- A strong and excellent training is necessary for the team who will work with simulation because to build a correct simulation is necessary to make the right decisions and define the right constraints.
- Furthermore, random variables can influence the simulation results outputs and may cause a flawed model.

2.1.4 Discrete-Event Simulation

Discrete-event system simulation is the modelling of the system in which the state variable changes only at a discrete set of points in time [6].

The basic building blocks of a discrete-event simulation model is attributes and entities, events and activities. This section covers the general principles and concepts, definitions and analysis of this methodology and your applications in mathematical models of discrete-event simulation models [6].

Some concepts more relevant to know:

- A **System** is a set of entities that communicate overtime to accomplish one or more goals and explain how to occur the processing of entities in the simulation.

- A **Model** is a representation of a real system that can have in the structure a mathematical logic related to the system entities and their attributes.

- An **Entity** is a name for any object or element in the system that requires notorious representation in the model. They can be classified as dynamics when the entity moves by the system (e.g. customers) or statics when the entity has the function to serve other entities. Moreover, entities can be temporary when they enter, cross and get out of the system permanently when doing their function without leaving the system.

- **Attributes** are the properties of a specified entity (e.g. the path that an entity needs to follow, how long an entity needs to wait, or most common properties like age or height).

- An **Event** is an occurrence that momentarily or permanently changes the state of a system. Events can modify attributes and variables.

- An **Activity** is an established time duration (for example, arrival time or the duration of action), which is known when it starts but can be defined by an automatic distribution [6].

2.1.5 Simulation Tools

The simulations tools are reliable instruments to build models and systems which represents the characteristics and parameters of mathematical modelling of any natural system. The best tool simulation for users and companies depends on your objectives and perspective [12].

The companies are adopting computation simulation to obtain and measure the quality and efficiency of their business, this reflects in performance and organisation [13].

This section will present the most common simulation tools for users who apply discrete event modelling over time, and which can also be applied to continuous event simulation.

AnyLogic®

AnyLogic® is a flexible and dynamic simulation tool developed by The AnyLogic Company [14]. The first version was released in 2000. AnyLogic® 4.0 version used discrete and continuous logic and physical objects (e.g. vehicles, chemical reactions,etc) [15]. The software is generally used in simulating discrete, system dynamics, multi-agent, and hybrid systems like **Xing, Y. and Liu, S. and Wang, H.(2018)** used in their article to simulate emergency organization of mass passenger flow in subway station [16].

Arena®

Arena® is a software of computation simulation that is based on concepts from object-oriented programming [17]. It's widely used on production lines and was released from Rockwell Automation®, but the first software was a combination from CINEMA and SIMAN (languages simulation) in 1993 [18].

Using discrete event simulation, the user is capable to develop a quickly analyse and build a complex process, it has a user-friendly interface which guides the user by the resources and without any write code [19].

ExtendSim®

The system of structure and simulation modelling ExtendSim® was one of the first programs of simulation modelling development by Imagine That Inc. in 1897. Is a simple platform, intuitive and it does not require specifics knowledge and skills for programming [20]. ExtendSim® is a program package used to model continuous, discrete event, discrete rate and agent-based systems [21].

FlexSim

FlexSim® is a powerful simulation software for object-oriented architecture that is used to model and to optimize animation. It has a user-friendly interface and allows developers to quickly build simulations objects (workstations, queues, transporters) [22].

This software is strongly recommended for teachers who used FlexSim® in the classroom because has a strong textbook *Applied Simulation Modeling and Analysis using Flexsim* like support [23].

Plant Simulation

Siemens® developed a collection of application, the modules simulation portfolio Tecnomatix®, this portfolio is composed by Tecnomatix Jack, Intosite, Robcad and Plant Simulation [24]. One of them, Plant Simulation allows simulation and optimization using discrete events. It is a powerful software for building and analyzing material and logistics flows [25].

ProModel

ProModel is a system simulation software and open architecture with a graphical interface and object-oriented modeling [26]. Using discrete-event, it was released by ProModel Corporation and is a common tool for designing, modelling and optimizing manufacturing process, the logic is easy to learn and use. ProModel simulation software, it is a powerful tool for reducing costs, increase production capacity and services and accelerate production cycles [27].

Simio LLC Software

To understand why this software was a tool important to develop this thesis, it is necessary to know how intelligent objects works and why is the future of the simulation [28]. Simio® is an acronym of Simulation Modelling framework based on Intelligent Objects. The intelligent objects are set up in Simio LLC to model and by combining many objects that represent the physical components of the system and may be used in other projects [5], [28].

An object-oriented system is modelled by specifying the details of the objects, once they are the more common framework used to build a model [28]. The Simio LLC

Software allows you to set up your model using the Standard Object Library or creating your library. The objects have their behaviour and they can respond to events defined by the system [5].

Simul8

Simul8 simulation software was developed and released in 1994 by American firm Simul8 Corporation [29]. Initially, this software was intended to didactically assist the construction of models and production systems at the University of Strathclyde (Scotland) [30]. Intuitively and professionally, Simul8 software is suitable for simulating 3D production processes, with the 2D environment used to visualize the process [29].

Witness™

Witness™ is a modern and powerful tool developed by Lanner Group in 2000s [31]. This software has an environment that allows "What If" analysis, a tool used in Six Sigma method and Lean Techniques with several applications in Industrial Enterprises to analyze and to optimize bottlenecks in processes [31], [32].

2.1.6 Applications of Simulations Tools in Healthcare Environments

Simulation is applied in wide areas in science, some examples are Manufacturing Systems, Publics Systems, Transportations Systems, Constructions Systems and Hospital environments systems. The following studies show recent research in healthcare/hospital environments.

Bahou, Nicolas *et al.* [33], published an article in 2017 using Simul8 software to model a healthcare system. The Golden Jubilee National Hospital had a problem in increasing demand for scheduled patients and agglomerations in an emergency, resulting in increasing waiting times and patient cancellation. The problem was caused by a bottleneck in the High Dependency Unit (HDU) beds. By modelling the system and improving the scheduling by the day which the patients arrive, was possible to reduce 20,7% of patients cancellations [33].

Dos Santos, Adna Amorim *et al.* [27], published an article in 2019 using discrete-event simulation in ProModel software to solve a problem in a Family Health Program (FHP) which had a large number in waiting lines. One of the patients had to wait 29 days to have a consultation with a cardiologist. Using the modelling of the real system the author was able to predict that the problem would be solved by increasing the frequency of cardiologist consultations and adding one more professional to this area, thus the waiting times would be reduced to 10 days [27].

2.2 Queueing Theory

Queueing theory has been studied since 1909, at first by mathematician A.K. Erlang, one of the creators of the queueing theory and the Erlang distribution method [6], [34].

It was while working on the Copenhagen Telephone Exchange that Erlang solved the company's phone line congestion problem [6], [34].

He was able to determine the number of circuits needed to provide telephone services to a local village, describing the total traffic volume of telephone calls at a fixed time of operation and the number of operators that were needed to handle this volume of calls [6], [34].

The basics of queueing theory were important for the development of the queueing model's analysis, the mathematical formulas can also prove valuable for verification of simulation models and to determine if the simulations are correct [34].

2.2.1 Queueing-System Structure and Terminology

Healthcare often uses queueing models, and it needs to know the process from arrival to exit. However, during this path, it is necessary to define some questions for design and operation, like the facility, the staff, the periods, how big the waiting room should be, how comfortable and what is the best communication between the nurses/medical

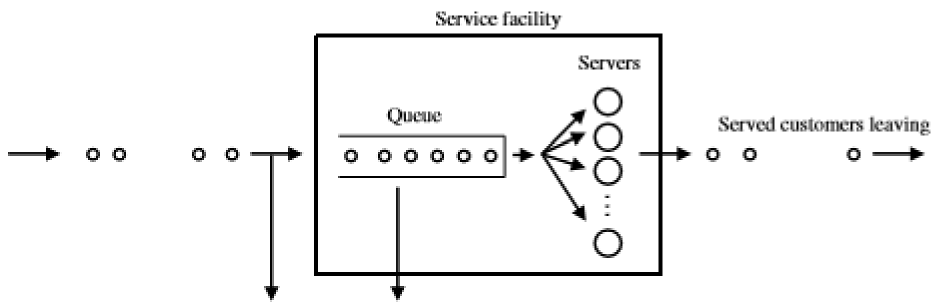

Figure 2.4: A Typical Queueing System.
[34]

doctors/clerks and patients/customers. Is important to have a database about these characteristics, and by using previous simulations knowing how to administrate eventual issues, the impacts are reduced substantially, for example, if the system is overcrowded which 10% additional patients [6], [34].

Queueing System Structure

In a queue system, the entity arrives and wait for service, moves to a single or multiple-station, receive the service and then may leave the system or not [34].

In healthcare, as figure 2.4 shows, the patients need to wait as little time as possible, whence the entities and servers are the keys elements of a queueing system [6], [28].

Arenales (2007) [35] identifies that a queuing system can be classified into 4 types:

a. single queue and a server;

b. single queue and multiple servers in parallel;

c. multiple queues and multiple servers in parallel;

d. single queue and multiple servers in series.

Between the types of queuing systems, there are 2 basic differences: number of servers and the number of queues. As for the number of servers, type a, b and c have a single server and type d there are multiple servers, this means that the user needs to go through more than one server before leaving the system. This type is widely applied in a drive-in in fast-food restaurants, where the customer passes through a server to order and make the payment and then passes through another one to receive the goods [35].

As for the number of queues, single-server systems may have a single queue as in a and b, which is widely applied in banks and post offices, or multiple queues as in c, like in supermarkets and service counters. In particular, single or multiple parallels (b and c) queuing systems are widely applied in hospitals and healthcare [35].

The system of multiple queues and multiple servers in parallel (type c) can also be defined as a dedicated queuing system, in which each server receives the user for a specific type of service. Figure 2.5 shows the different types of queuing systems that can be implemented according to the need for operation and application [35],[36].

Characteristics of Queueing System

A queueing system is composed by entities (customers, people, machines, planes - anything that arrives in a system and needs a service) and servers (clerks, buses, nurses, check-in/check-out station - or any resource that provide a service) [6].

To be able to evaluate a queueing system, quantifying the inputs and outputs, it is necessary to define some characterizations that will assist in the modelling of the system. There are six basic characteristics according [34]:

1. Arrival pattern of customers, this is a measure or rate of arrival of customers to know the distribution between the time arrival of one entity and another.

2. Service pattern of servers, is a measure or rate of the time service, for this, it is important to know the service sequence and the number of the services of the system.

3. Number of servers is a characterization that influences in-service time because depending on the number of servers the system will cost more or have more delays in time of service. Also, is significant to define the types of queue, if the system has a simple queue or multiple queues.

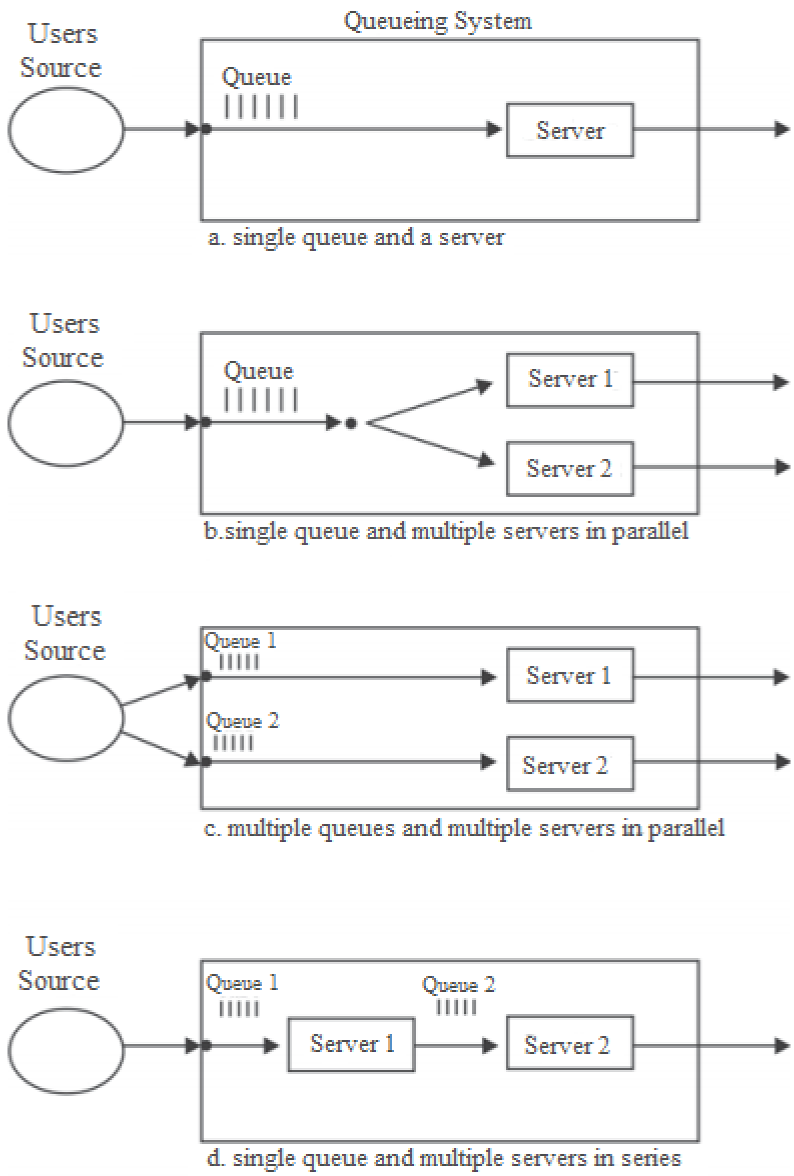

Figure 2.5: Classification of Queue Types.
Adapted from ARENALES [35]

4. System capacity is a measure or rate, that define the space for the entrance of entities. In some situations, this number must be limited but there are many circumstances where it is unknown, thus the rate is unlimited.

5. Queue discipline, this refers to queue behaviour based on customer actions, when entering on the server and waiting for service. The most common queue discipline is a First-In, Fist-Out (FIFO), but there are Last-In, First-Out (LIFO), Service in Random Order (SIRO), Shortest Processing Time First (SPT) and a Priority Service (PR).

6. Number of service stages, this characteristic can be a single number of stages, like in an Automated Teller Machine (ATM) or a multiple stages like in a bank, where there are queueing networks and the servers need to communicate between them.

Queueing Notation

The queueing notation is important to describe how a queue system is classified. A few authors can classify in different ways, but there is a standard notation that describes multiserver queueing stations, and it is known as *Kendall's Notation*. The table 2.1 present the most common and important notation to classify this study [5],[6],[34].

Where A denotes the interarrival-time distribution, B denotes the service-time distribution, c denotes the number of parallel servers, Y denotes the system capacity and Z denotes the queue discipline (some authors may drop the queue discipline notation, even as the system capacity notation when this is unlimited). Some examples may help to better understand [5],[6],[34].

The queueing system $M/M/1/\infty/FIFO$ indicates a single-server system with unlimited capacity, the interarrival-time and service time is exponentially distributed and fist-in, fist-out queue discipline [5],[6],[34].

Table 2.1: Queueing Notation A/B/c/Y/Z

Adapted from [5], [34]

Characteristic	Symbol	Explanation
Interarrival-time distribution (A) / Service-time distribution (B)	M	Exponential
	D	Deterministic
	E_k	Erlang type k (k = 1, 2, . . .)
	H_k	Mixture of k exponentials
	PH	Phase type
	G	General
Parallel servers (c)	1, 2, . . . , ∞	
System capacity (Y)	1, 2, . . . , ∞	
Queue discipline (Z)	FIFO	First in, first out
	LCFS	Last come, first served
	RSS	Random selection for service
	PR	Priority
	GD	General discipline

2.2.2 Stochastic Process

In a stochastic process is common to used normal, exponential or Poisson distribution. There are many probability distributions. In this section, it will be present some of the most important ones and the probability distributions used in this study.

Exponential Distribution

It is common to use an exponential distribution to build a model applying the queueing theory, it is common to use an exponential distribution for models that have particular and independent events. For example, the arrival time between a large number of customers is an event which occurs independently of each other [6], [34].

Exponential distribution is a type of continuous probability distribution with probability density function (PDF):

$$f(t) = \lambda e^{-\lambda t} \quad (t \geq 0), \tag{2.1}$$

where $\lambda > 0$ is a constant [34].

Poisson Distribution

Similar to the Exponential Distribution, Poisson Distribution is a probability of several independent events occur in a specif time or a sample space and be independent one of each other [6], [34].

Poisson distribution has a discrete random variable with probability mass function:

$$p_n = \frac{e^{-\lambda}\lambda^n}{n!} \quad (n = 0, 1, 2, ...) \tag{2.2}$$

where $\lambda > 0$ is a constant [34].

Triangular Distribution

A random variable X has a triangular distribution if it is PDF is given by

$$f(x) = \begin{cases} \frac{2(x-a)}{(b-a)(c-a)}, & a \leq x \leq b \\ \frac{2(c-x)}{(c-b)(c-a)}, & b < x \leq c \\ 0, & elsewhere \end{cases} \tag{2.3}$$

where $a \leq b \leq c$. The mode occurs $x = b$. The parameters (a, b, c) can be related to others measures, such as the mean and mode, as follows:

$$E(X) = \frac{a + b + c}{3} \tag{2.4}$$

From equation 2.4 the mode can be determined as

$$\text{Mode} = b = 3E(X) - (a + c)$$

Since $a \leq b \leq c$, it follows that

$$\frac{2a+c}{3} \leq E(X) \leq \frac{a+2c}{3}$$

The mode is used more often than mean to characterize the triangular distribution [34].

Chapter 3

A case study: Health Care Unit

In this chapter will be described the case study and introduce the object Health Care Unit (HCU). The information has been collected on spot in the HCU and employees report.

Observations and data collected during visits to the HCU are presented, identifying potential problems encountered and characterizing the process flows of services provided at the HCU. This characterizing process is an important part to further apply the seven steps and modelling the system.

3.1 Health Care Unit History

The HCU was opened in 2012 in the district of Bragança, Portugal. It is private health care responsible for the largest number of services in the north of Trás-os-Montes.

With the mission of offering excellent services, with high quality and social awareness, it has the vision to create value for users assisting in support services and specialized medicine and as their main values trust and proximity to the user, professionalism and respect for values of human life. The Health Care Unit serves about 45.8% of the entire northern part of the country, receiving daily users from the districts of Bragança, Vila Real, Viseu and Guarda.

In 2017, it obtained the ISO 9001 Quality Management System Certification, which certifies the quality of services in the HCU.

3.2 Analysis of Processes in the Health Care Unit

The HCU is a building composed of 4 floors, the first floor is responsible for welcoming new patients, the check-in and check-out areas, the Children's and Women's Health Clinic, the waiting rooms and the lift for the second and third floor. In the second floor, it is possible to find doctors' offices, exam rooms, a waiting room and treatments rooms. On the third floor, one can find a waiting room, exams rooms, doctors' offices and the surgery area.

It is important to highlight that in the second and third floors it is possible to do the check-in and check-out.

The other areas that were not described are not relevant to this study and are omitted for simplification.

34 medical specialities are offered at the HCU, including cardiologists, neurologists and ophthalmologists. The professional team includes medical doctors, nurses, technicians and management team.

3.2.1 Characterization of the System

All real system parameters that are necessary to perform a simulation will be described to build the model using Simio®.

First, some elements of the language widely used in the Simio® software environment will be declared with labels for a clear understanding.

ENTITY $\longmapsto$ Patient, Customer.

PATH $\longmapsto$ Path followed by the entities.

WORKSTATION $\longmapsto$ Service Desks, Doctor's Offices, Totems, Exams Rooms.

All data presented in this case study is based on the data collected at the HCU. It is important to make clear that they do not represent the reality of the HCU, but have the purpose of expressing the problems that occur in overcrowded areas.

Three types of probability distribution were used: Poisson, Exponential and Triangular. The use of these types of probabilities is justified according to the literature, which advises the use of the Poisson Distribution to characterize arrival rates. For service rates or server processing times, Exponential Distribution is advised. And for the use of rates in which minimum, average and maximum values are estimated, the Triangular Continuous Probability distribution is applied.

1. **Arrival pattern of patient**

   According to observations made on spot was noted that the arrival number of patients for the day is about 300 patients. The arrival rate can be calculated using the queueing formulas. This parameter will be classified considering the arrival number of patients for the period of 10 hours (8 am. - 6 p.m).

2. **Service pattern of servers**

   For this parameter will be used the inputs analyzed to calculate each rate of service/server using the queueing formulas. The service rates are presented in chapter 4 as processing times, each check-in area has different service rates due to the differences in the number of patients and the number of workstations.

3. **Number of servers and service channels**

   This parameter is essential to calculate and model the simulation. For this study, will be consider 2 totems (Totem01,Totem02), 4 desks (Desk_01, Desk_02,Desk_05, Desk_06), 15 medical rooms and 9 exams rooms. The labels were describe in table 4.1, 4.2, 4.3 and 4.6.

4. **System capacity**

   The system capacity can be considered as unlimited, but this parameter is important to know because the number of patients is a known value in the sample.

5. **Queue discipline**

Overall, all HCUs have FIFO queueing discipline. All workstations are configured with this queue discipline rule, except for workstations in check-in area 1 with labels for DeskP0_01, DeskP0_02 and later workstations added in alternative scenarios. In these workstations, the FIFO queue discipline associated with the PR queue discipline is configured, that is, the entry of patients obeys a priority attendance if necessary, and if not, it obeys the first in first out.

6. **Number of service stages**

   It is common in healthcare that all services are integrated, thus the number of service stages depends on the type of server.

Arrival rates and services are described in the Simio simulation environment as Interarrival Time and Processing Time. The estimated arrival rate between patients was 4.0 minutes. Service rates or Processing Times are shown in chapter 4 and differ depending on the workstation.

Flow Process

The flow process in figure 3.1 begins when the patient arrives in the HCU. If it has a Medical Appointment, need an Information, wants to do a Scheduling, has an Exams (Neurography, Stress Test, Lung Function Test), needs to get an exam and analysis, or make a payment, the patient should remain in check-in area 1. It is necessary to take a number in Totem01 finds in the entrance. There are 4 options to choose:

- Letter A - General Service
- Letter B - Analysis and Examination Survey
- Letter C - Payment
- Letter D - Priority Service

If the patient has any other type of exam or will perform a procedure for collecting clinical specimens, the patient should go to the check-in area 2 and also needs to take a number in the Totem02. There are 3 options to choose:

- Letter A - Private Health Insurance (Multicare, Médis, etc.)
- Letter B - National Health System (NHS)
- Letter C - Analysis Collection

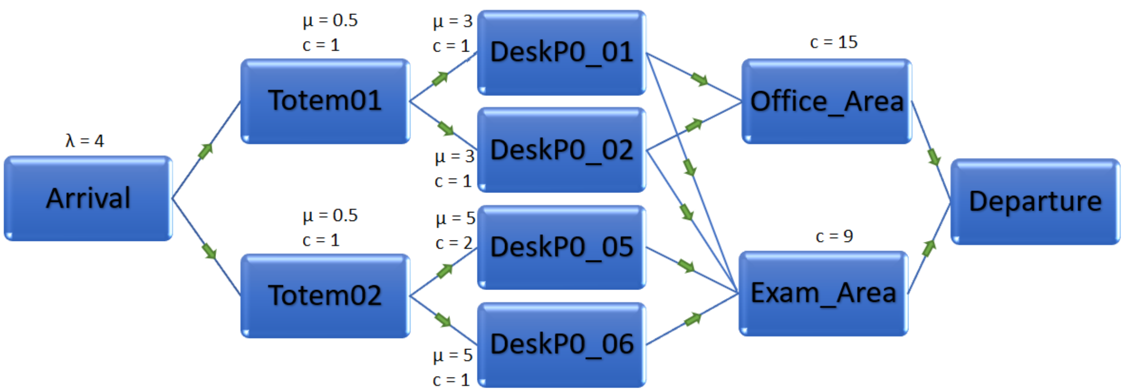

Figure 3.1: Flow Process.

The HCU serves a percentage of patients from Portugal's NHS, which is a network of institutions and services provided to the entire population and financed by taxes.

Considerations

Some considerations were made about elements that may hinder the resolution of problems or were not considered in this study. These are the differential times (weekdays and weekends), changes on schedule and employee shifts.

For perform a model simulation, it was considered that the entity inputs followed an estimated probability, which is presented in table 3.1.

Table 3.1: Probability of Entity Entry

Entity Type	Probability (%)
PatientA1	30
PatientB1	5
PatientC1	5
PatientD	2
PatientA2	20
PatientB2	30
PatientC2	8

3.2.2 Problem Statements

At the beginning of this study, the HCU goal was to reduce the customer's claims minimizing the waiting times in queues and maximizing the flows. The HCU has a large number of people waiting for a long time to be attended and that it is directly reflected in the service quality perception.

The first analysis shows that some problems are related to waiting in queues. Due to that the proposed solutions are directly related to the problems and will be discussed in the next chapter.

Bottlenecks were observed in both check-in areas on the first floor. It was noted:

- The patient arrives long before their scheduled time and occupies the waiting system, presupposing that this is due to anxiety about being in the HCU environment.

- The patient arrives at the HCU and feels the lack of guidance to go to the place where he/she should be heading, which implies that he wrongly takes the number, occupying the system and delaying the service.

- The HCU serves a percentage of patients referred from the National Health System. It was observed that there is a large number of patients for only one attendant, that is responsible for the check-in of these patients. This may be one of the reasons for bottlenecks route cause in the check-in areas.

- On the other floors problems were found in the services desks because the possibility to do the check-in in each floor confuses the system.

The HCU offers several services, which are: Medical Appointment, Information, Scheduling, Analysis Collection, Exams (Neurography, Stress Test, Lung Function Test, among others), exams withdrawal exams and analysis.

Chapter 4

Modelling and Simulation

This chapter will present all the development of the model that intends to simulate the real world of the Health Care Unit. All configurations, properties and processes were referenced in the book Simulation Modeling with Simio: A Workbook, by the authors Jeffrey Allen Joines and Stephen Dean Roberts [37].

4.1 Modelling of Simulation

When a new project is created, automatically is created two new models, one is the *ModelEntity* which represents the entity, and the other is the *Model* that represents the own model. In this simulation, the model is the HCU and the entity are the patients.

The HCU facility is defined 4 zones in the model, the check-in area 1, the check-in area 2, the exam area and the office area. The model does not follow the layout of the HCU to simplify and make the operation of the HCU understandable. The figure 4.1 show the 3D model.

The arrivals of each entity are estimated according to the probability of the event occurring, this means that entities have different probabilities to check-in. The results will be compared in chapter 5. The model was set using the Table tool that allows data simulation.

To insert the estimated probabilities in the model, the Tables tool was used in the

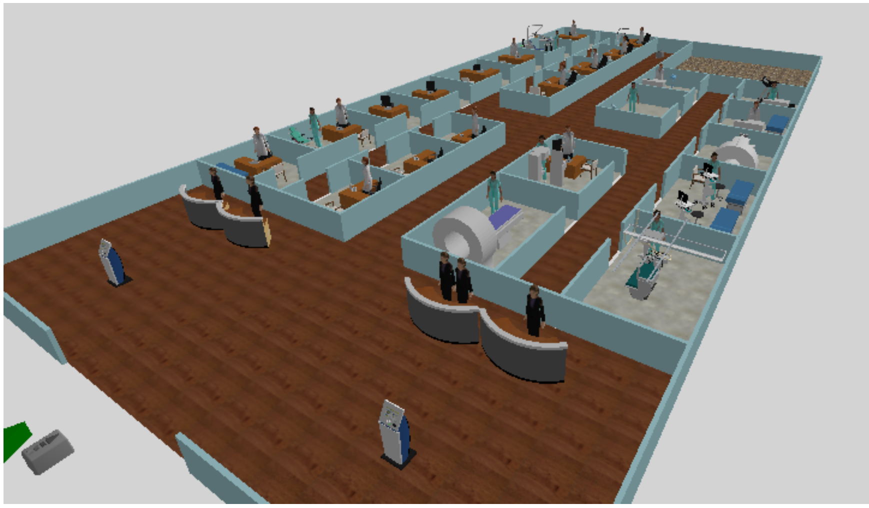

Figure 4.1: Develop 3D Model.

Data tab, as shown in figure 4.2. The first step was to create 2 tables and rename them as Patient Type and Patient Type C2. In both tables were insert an Entity type of Object Reference Property and an Integer type of Standard Property. In Patient Type table were set 6 types of entity. In Patient Type C2 was set 1 type of entity. This was done due to a property configuration that did not allow limiting the number of entities of type PatientC2 without an error.

Patient Type | Patient Type C2

	Patient Type	Patient Mix
1	PatientA1	30
2	PatientB1	5
3	PatientC1	5
4	PatientD	2
5	PatientA2	20
6	PatientB2	30

Patient Type | Patient Type C2

	Patient Type	Patient Mix
1	PatientC2	8

Figure 4.2: Configuration of the Probabilities of Entities' Entries.

The next step was to associate the tables with the Sources. The Source is the object responsible to create entities according to probabilities. It was created 2 Sources. Source named Arrival has to assign Patient Type table and Source named Arrival1 has to assign Patient Type C2. Entity Type, Maximum Arrivals and Table Row References were changed in the Property tab. The first change allows the source to create several types of

ModelEntity at the same time. The second change allows to set a maximum number of entries during the simulation time. The last one allows the source to associate the type of entity with the respective row number and thus its probability of entry (see figure 4.3).

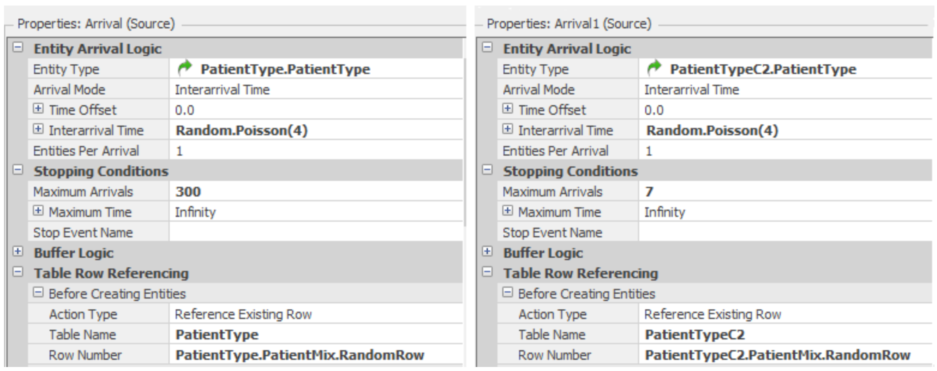

Figure 4.3: Source Arrival and Arrival1 Properties.

The parameters Arrival Rate and Service Rate were set according to the data provided by the HCU. In the model, these parameters correspond to Inter Arrival Time and Processing Time, respectively.

Some features were considered when the model was designed and will be discussed in this section.

4.1.1 Check-in Area 1

The layout was simplified to make easy the simulation. The patients' flow is exactly like in the HCU, the distributions of probability were simulated using Poisson Distribution and Exponential Distribution. The table 4.1 is introduced the objects represented is the check-in area 1 and their parameters.

Only 2 services desks were simulated, even though the original layout in HCU having 4 services desks most of the time only 2 services desks are open.

The entities PatientA1, PatientB1, PatientC1 and PatientD are inputs of the check-in area 1 and the selection will be explained in a later section.

Development of Simulation Model

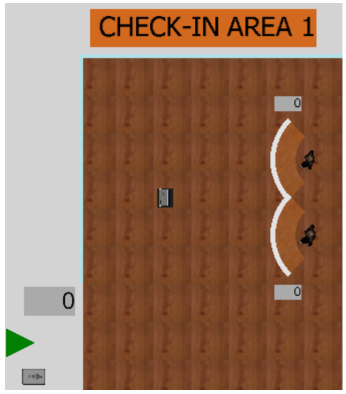

Figure 4.4: Check-in Area 1 in 2D View.

When arriving at the HCU, it is expected that the patient knows where is the service scheduled or intended to be to choose between the check-in area 1 or 2.

In the simulation, this is inferred with an Add-on Process Logic named DecideTotem, where entities PatientA1, PatientB1, PatientC1 and PatientD are directed to Totem01 in check-in area 1 for taking a number. Entities PatientA2, PatientB2 and PatientC2 are directed to Totem02 in check-in area 2 for the same goal. The process is shown in figure 4.5.

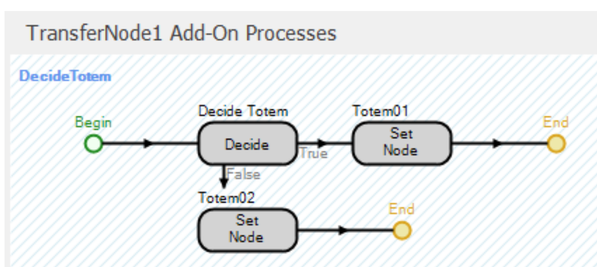

Figure 4.5: Process Logic DecideTotem

After the entities choose to take a number, they will be attended by one of the 2 workstations.

In the table 4.1 is possible to identify Simio® objects, the Labels, Initial Capacity and Processing Times.

These inputs were simulated according to spot visits. The arrival time and service time are simulated in minutes. It was calculated evaluating the number of arrivals in a period

Table 4.1: Check-in Area 1 Properties

Label	Simio Object	Initial Capacity	Processing Time (min)
Arrival	Source	-	Poisson(4.0)
PatientA1	ModelEntity	-	-
PatientB1	ModelEntity	-	-
PatientC1	ModelEntity	-	-
PatientD	ModelEntity	-	-
DeskP0_01	Server	1	Exponential(3.0)
DeskP0_02	Server	1	Exponential(3.0)
Totem01	Server	1	Exponential(0.5)

and the waiting time of a patient. Poisson Distribution is the distribution probability most used to specify an arrival time. For time services the most used one is Exponential Distribution as shown in the figure 4.6.

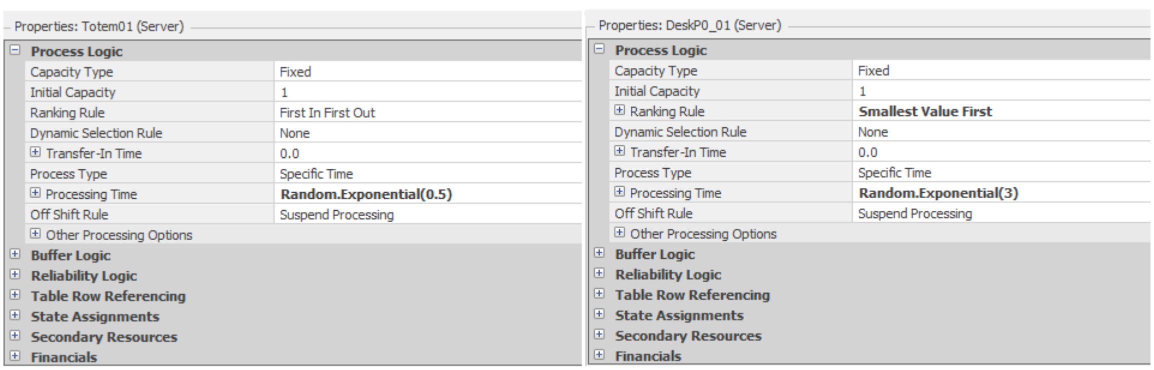

Figure 4.6: Properties of Totem01 and DeskP0_01

The workstations DeskP0_01 and DeskP0_02 did not follow exclusively the queue discipline FIFO. It is a characteristic of the real system where there is a priority entity named PatientD. This entity has an allocate priority above the other entities because this represents a priority number to attend.

During the developing the simulation model, this characteristic was represented by changing the Ranking Rule on Process Logic of both workstation from **First In First Out** to **Smallest Value First** (see figure 4.6).

After this is necessary to change the Initial Property on Routing Logic for all the entities to **2.0** and the entity PatientD to **1.0**, making PatientD a higher priority patient in the Ranking Rule as shown in figure 4.7.

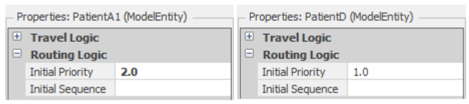

Figure 4.7: Initial Priority of Entities.

4.1.2 Check-in Area 2

The layout was simplified to make it easy to simulate the check-in area 2.

The flow of patients is exactly like in the HCU. The distributions of probability were simulated using Poisson Distribution and Exponential Distribution. In the table 4.2 the objects in Check-in Area 2, as well as their parameters, are introduced.

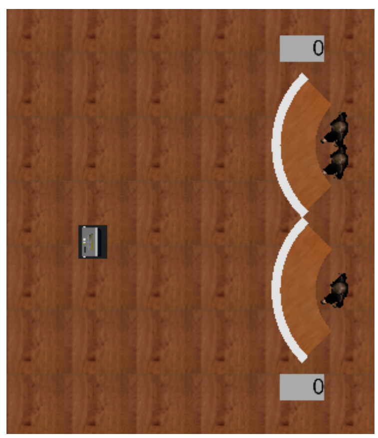

Figure 4.8: Check-in Area 2 in 2D View.

To do a better approximation 2 services desks were simulated, as well as the original layout. In the Check-in Area 2, only patients who will undergo exams or analysis collection are treated. At DeskP0_05 patients are treated with Private Insurance and has Initial Capacity of 2 attendances per entry. At DeskP0_06 only NHS patients are served and have 1 attendance per entry of capacity.

The entities PatientA2, PatientB2 and PatientC2 are inputs of the Check-in Area 2 and the selection will be explained in a later section.

Development of Simulation Model

Table 4.2: Check-In Area 2 Properties.

Label	Simio Object	Initial Capacity	Processing Time (min)
Arrival	Source	-	Poisson(4.0)
PatientA2	ModelEntity	-	-
PatientB2	ModelEntity	-	-
PatientC2	ModelEntity	-	-
PatientD	ModelEntity	-	-
DeskP0_05	Server	2	Exponential(5.0)
DeskP0_06	Server	1	Exponential(5.0)
Totem02	Server	1	Exponential(0.5)

A Process Logic was used for the entity to decide the intended workstation to specific services. Using this tool is possible to show that if the entity belongs to the Private Insurance or will perform an analysis collection, it will take a number in Totem02 and after that, will be attending in a DeskP0_05. If the entity belongs to the NHS, it will choose the DeskP0_06 (see figure 4.9).

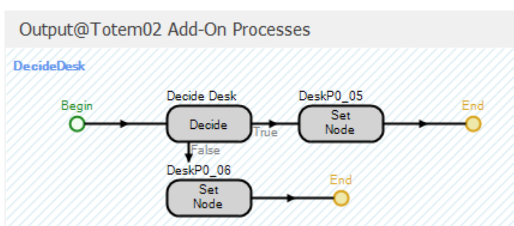

Figure 4.9: Process Logic to Decide Service Desk.

4.1.3 Office Area

The original layout has several medical doctor's offices distributed in 3 floors. Given that, as a way to make the modelling process easier and more comprehensible, all medical doctor's offices were simulated in the same place (see figure 4.10).

This study was done considering a model for each day of the week, in other words, 6(six) models were made to represent Monday, Tuesday, Wednesday, Thursday, Friday and Saturday. This was necessary because the HCU has many specialities working on different days of the week, some in the morning shift, some in the afternoon shift and

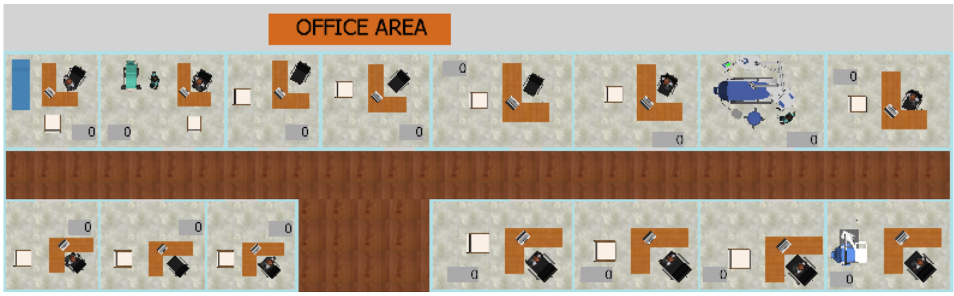

Figure 4.10: Office Area in 2D View.

some all day.

The labels, Initial Capacity and Processing Time are shown in table 4.3. For the simulation, it was considered that each workstation can process one entity at a time and the processing time is a Triangular Distribution of 10, 15, 18 (min, mode, max) minutes.

Table 4.3: Office Area Properties.

Label	Simio Object	Initial Capacity	Processing Time (min)
Pediatrics_Office	Server	1	Random.Triangular(10,15,18)
Gynecology_Office	Server	1	Random.Triangular(10,15,18)
Cardiology_Office	Server	1	Random.Triangular(10,15,18)
Gastro_Office	Server	1	Random.Triangular(10,15,18)
Dentist_Office	Server	1	Random.Triangular(10,15,18)
Ophthal_Office	Server	1	Random.Triangular(10,15,18)
Doctor_OfficeP1_01	Server	1	Random.Triangular(10,15,18)
Doctor_OfficeP1_02	Server	1	Random.Triangular(10,15,18)
Doctor_OfficeP1_03	Server	1	Random.Triangular(10,15,18)
Doctor_OfficeP1_04	Server	1	Random.Triangular(10,15,18)
Doctor_OfficeP1_05	Server	1	Random.Triangular(10,15,18)
Doctor_OfficeP2_01	Server	1	Random.Triangular(10,15,18)
Doctor_OfficeP2_02	Server	1	Random.Triangular(10,15,18)
Doctor_OfficeP2_03	Server	1	Random.Triangular(10,15,18)
Doctor_OfficeP2_04	Server	1	Random.Triangular(10,15,18)

Development of Simulation Model

In order to build the Office Area it was important to define differents *WorkSchedules* with *OnShift* and *OffShif* hours according the speciality and occurrences numbers. This data was collected in visits on spot and through a schedule available on the HCU. The results will be discussed in Chapter 5.

After the entity is processed by the servers in the Check-in Area 1, they follow a path to the TransferNode. This object helps to include an Add-on Process Logic to differentiate the path in which each entity should follow, figure 4.11.

The Processing Logic decides to where the entity will assign it to, if the entity is type PatientB1 or PatientC1 it must follow to Departure, otherwise if it is type PatientA1 or PatientD, it will be reassigned to the Office Area.

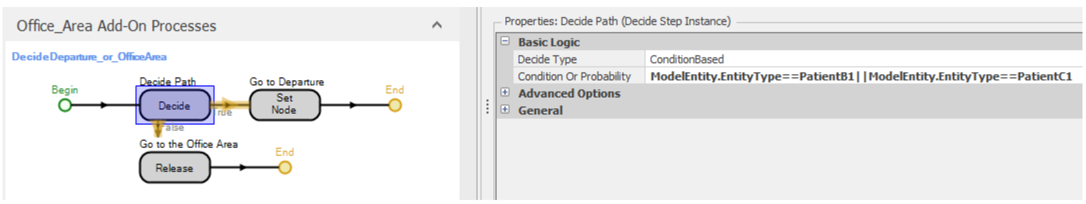

Figure 4.11: Entity Process Logic to Decide Departure or Office Area.

Work Schedules

Work Schedules allows to model resources capacities that change over time. A pattern-based work schedule is comprised of a repeating based pattern with superimposed exceptions.

A table-based work schedule allows defining the schedule information in a data table with rows in a table defining a series of work periods [5]. The table 4.5 shows the work schedule of each day of the week.

Table 4.4: Subtitles WorkSchedule

Collection3hours	(red)
Office_WorkScheduleM	(yellow)
Office_WorkScheduleA	(blue)
Office_WorkScheduleM_A	(green)
Office_OffShift	(purple)

Work schedules are set with a parameter Value, this ensures that the entity will not enter in a workstation and fill idle time. The Value equals 1 means the workstation is On Shift and the Value 0 means the workstation is Off Shift, for this property to be fulfilled,

Table 4.5: Weekly WorkSchedule to Office Area.

	WorkSchedule					
Label	**Monday**	**Tuesday**	**Wesneday**	**Thursday**	**Friday**	**Saturday**
Pediatrics_Office	[light blue]	[purple]	[light blue]	[purple]	[purple]	[purple]
Gynecology_Office	[purple]	[light blue]	[purple]	[yellow]	[light blue]	[purple]
Cardiology_Office	[purple]	[light blue]	[purple]	[light blue]	[green]	[purple]
Gastro_Office	[light blue]	[purple]	[purple]	[purple]	[purple]	[purple]
Dentist_Office	[purple]	[purple]	[purple]	[purple]	[purple]	[light blue]
Ophthal_Office	[yellow]	[green]	[green]	[light blue]	[green]	[purple]
Doctor_OfficeP1_01	[green]	[yellow]	[light blue]	[green]	[green]	[light blue]
Doctor_OfficeP1_02	[green]	[green]	[yellow]	[yellow]	[green]	[green]
Doctor_OfficeP1_03	[yellow]	[light blue]	[light blue]	[light blue]	[yellow]	[yellow]
Doctor_OfficeP1_04	[light blue]	[green]	[light blue]	[green]	[green]	[yellow]
Doctor_OfficeP1_05	[light blue]	[green]	[purple]	[green]	[yellow]	[green]
Doctor_OfficeP2_01	[green]	[green]	[green]	[purple]	[yellow]	[purple]
Doctor_OfficeP2_02	[yellow]	[yellow]	[light blue]	[purple]	[purple]	[purple]
Doctor_OfficeP2_03	[light blue]	[light blue]	[green]	[purple]	[purple]	[purple]
Doctor_OfficeP2_04	[light blue]	[yellow]	[light blue]	[purple]	[purple]	[purple]

another property in a path that connects the entity to a server is needed, this property is named Entity Routing Logic and it changes from 1.0 to 0.0 or vice versa as shown in figure 4.12.

The *WorkSchedule Table* (figure 4.13) was used to simulate the shift in an HCU, in which the medical doctor's appointment can have different schedules. Considering if the doctor's office has a *Office_WorkScheduleM* it will work from 8:00 am to 12:00 pm with value 1 and from 12:00 pm to 6:00 pm the value 0. If the doctor's offices have a *Office_WorkScheduleA* schedule it will work from 8:00 am to 2:00 pm with value 0 and 2:00 pm to 6:00 pm with value 1, If the doctor's offices have a *Office_WorkScheduleM_A* schedule it will work from 8:00 am to 12:00 pm and 2:00 pm to 6:00 pm with value 1 and last If the doctor's offices have a *Office_OffShift* schedule this means there is no shift in this office, so the value is 0.

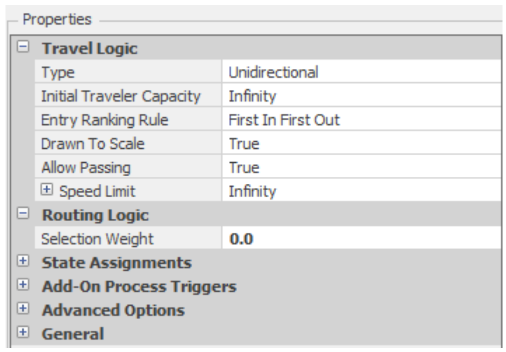

Figure 4.12: Travel Logic Settings.

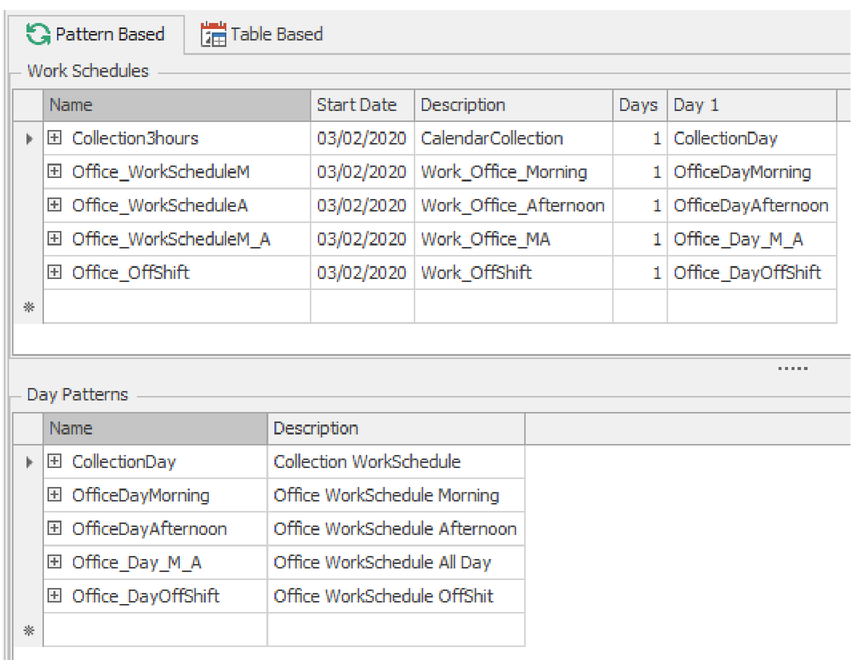

Figure 4.13: WorkSchedules Settings.

4.1.4 Exam Area

The Exam Area is an area where the patient can do specif exams. There are 9 rooms. The exams available in the HCU are X-ray, MRI (Magnetic Resonance Imaging), Lung Test Function, Stress Test Function, CTE (Computed Tomography Exam or X-ray Computed Tomography), Analysis Collection, Mammography, Ultrasound and Electrocardiogram. Each type of exam is represented by a workstation (figure 4.14).

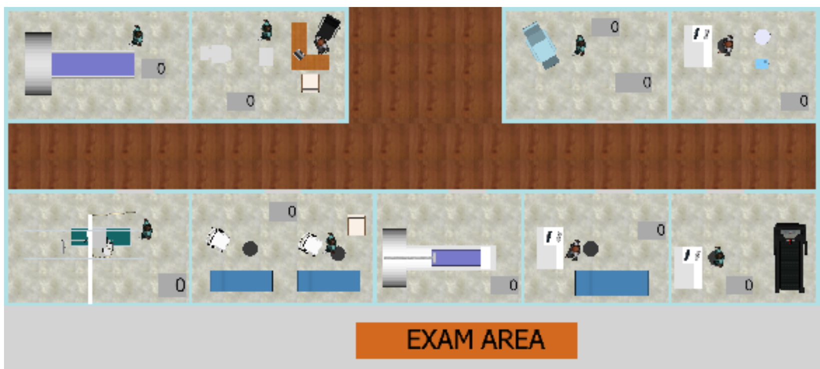

Figure 4.14: Exam Area in 2D View.

The Exam Area different from the Office Area has no working schedule, in their exams are performed every day of the week but Sundays. The table 4.6 show the labels and properties of each workstation in Exam Area. The Processing Time property was set in a Triangular Distribution, this choice is due to the Triangular Distribution that allows average times to perform each exam. The time considering each exam was simulated according to the data collection provided by the HCU.

Development of Simulation Model

Collection_Room Server

The server *Collection_Room* has a Work schedule called *Collection3hours* which the starting time set to 8:00 am and end time set to 10:00 am with Value 1, after this time there are no more collections and the server closes, that is the value is 0.

Table 4.6: Exam Area Properties.

Label	Simio Object	Initial Capacity	Processing Time (min)
X_Ray_Room	Server	1	Triangular(10,13,15)
Ultrasond_Room	Server	2	Triangular(20,30,40)
MRI_Room	Server	1	Triangular(40,50,60)
Mammography_Room	Server	1	Triangular(10,12,15)
Eletro_Room	Server	1	Triangular(14,17,20)
Collection_Room	Server	1	Triangular(5,7,9)
Cte_Room	Server	1	Triangular(10,15,20)
LungFT_Room	Server	1	Triangular(10,12,15)
StressT_Room	Server	1	Triangular(08,10,13)

Furthermore, there is a Process Logic to set entrance logic of the entities in the server. This processing logic only allows the entity PatientC2 to enter and must follow the Work schedule (see figure 4.15).

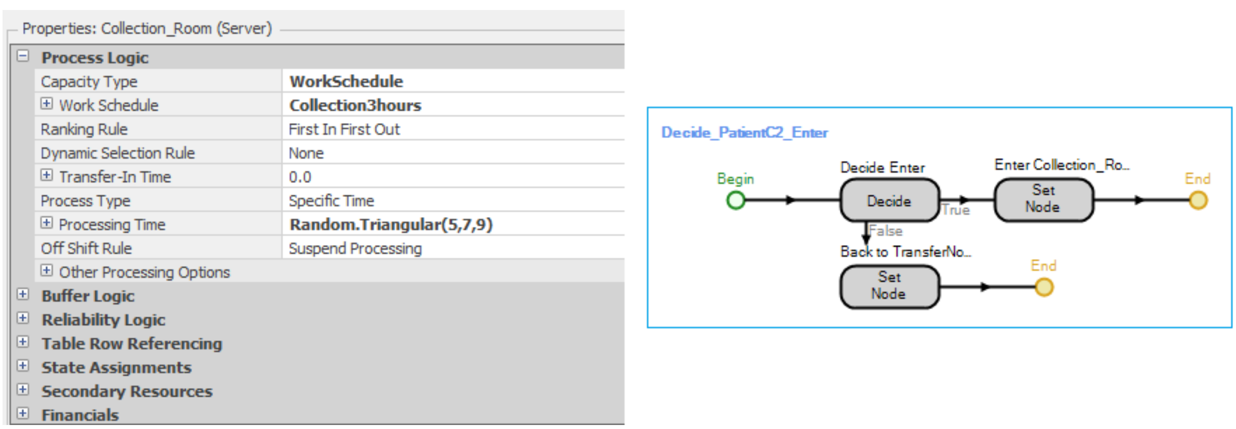

Figure 4.15: Collection_Room Server Settings.

4.2 Validation

The verification for the simulation is important to ensure that the model is functional and has the performance according to the real world.

The validation was performed running the model for 10 hours and observing the behaviour of entities, workstations, paths and the responses of each intelligent object.

The validation was done with the data collected on the spot. The main performance measure to validate the model is the time between the entity started to be processed in workstation Totem01/Totem02 until the entity finished to be processed in the workstations.

The average time between the workstation Totem01 and DeskP0_01 and DeskP0_02 is 10.18 minutes and the average time between the workstation Totem02 and DeskP0_05 and DeskP0_06 is 14.25 minutes. The tables below show the 6 scenarios with different replications and the error between the average real-time and the average simulated time.

The table 4.7 shows for Check-in Area 01that the smallest value of error is 1,36% for 10 replications, considering the average time of 10,31 minutes.

The table 4.8 shows for Check-in Area 02 that the smallest error is 0,99% for 150 replications, considering the average time of 14,31 minutes. This values validated the model based on the fact that the results are very similar to the real world values.

Table 4.7: Model Validation Data of Check-in Area 1

Check-in Area 1 Data		
Replications	Average Time (Minutes)	Error (%)
10	10,31	1,36%
25	10,65	4,64%
50	10,85	6,64%
75	10,57	3,83%
100	10,55	3,72%
150	10,38	1,96%

4.2.1 Performance Measures

The performance measure is collected and present the model results. Simio® environment has many properties to define and to tally statistics that help the analysis and conclusions. Some of these properties that were used in this study are present and discuss in Chapter 5. The Performance Measures are the same for all the simulation models described previously.

Table 4.8: Model Validation Data of Check-in Area 2

Check-in Area 2 Data		
Replications	Average Time (Minutes)	Error (%)
10	15,43	6,82%
25	15,98	10,56%
50	14,91	3,18%
75	14,97	3,58%
100	14,15	2,04%
150	14,31	0,99%

State Variables and State Statistic Elements

State Variables are definitions within an object to hold the value of something that might change while a model is running. Also, a state variable can be associated as an attribute of the entity.

In this study were defined some state variables to analyse time results. This states variables are defined below:

Number In System

This state variable collects the inputs and outputs of all the entities, this means it is possible to know how many entities were created, destroyed and how many stayed in the system after the simulation finished. The result named *NumberInSystem* is set using a state variable created in *Model* (see figure 4.16).

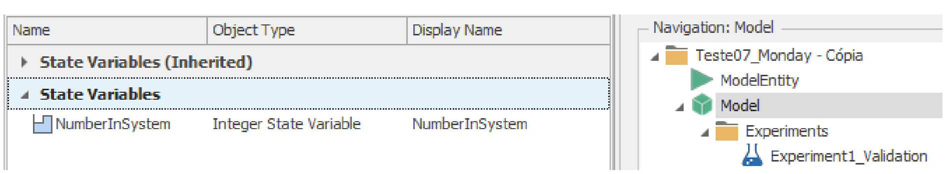

Figure 4.16: State Variable NumberInSystem.

First, a state variable is defined as a to a *Model*. After this, the state variable is set in "State Assignments" property (Before Existing) on Arrival (Source workstation) (see figure 4.17). It this means that when an entity is created the state variable NumberInSystem hold an increment (+1). Also, this step was set on the Departure (Sink workstation) to decremented (-1) when an entity leaves the system.

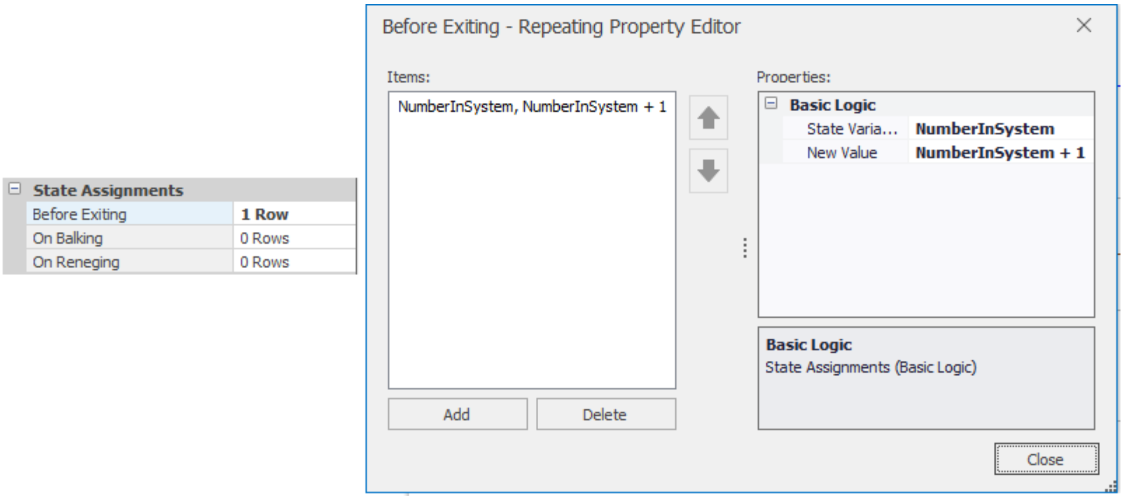

Figure 4.17: State Assignments Settings.

The results are held in a "State Statistic Element" created in the "Definitions" tab and associated with the NumberInSystem State Variable after the simulation is finished, it is possible to see the results in Pivot Grid table.

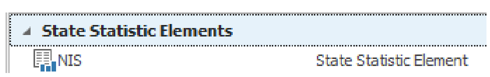

Figure 4.18: State Statistic Elements NIS.

In the model used to validate the system, the final value in the system was 63, that is, when the system was running after 10 hours, there were still 63 entities in the system and the number of entities created and destroyed confirm that value.

NIS	Average	38,9529
	FinalValue	63,0000
	Maximum	65,0000

Figure 4.19: State Statistic Elements NIS Value.

Number In Queue

This state variable collects the inputs and outputs in the queue, this means it is possible to know how many entities were waiting in a queue in each workstation through the state

Departure	InputBuffer	NumberEntered	Total	253,0000
		NumberExited	Total	253,0000
Arrival	OutputBuffer	NumberEntered	Total	316,0000
		NumberExited	Total	316,0000

Figure 4.20: Number of Entities Created and Destroyed.

value NIQ. For each respective workstation, there is a register, NIQ01 to DeskP0_01, NIQ02 to DeskP0_02, NIQ05 to DeskP0_05 and NIQ06 to DeskP0_06.

This property was set in the same way as the property Number In System (NIQ). The figure 4.21 show the state variables and state elements .

State Variables		
NumberInSystem	Integer State Variable	NumberInSystem
NumberInQueue01	Integer State Variable	NumberInQueue01
NumberInQueue02	Integer State Variable	NumberInQueue02
NumberInQueue05	Integer State Variable	NumberInQueue05
NumberInQueue06	Integer State Variable	NumberInQueue06

State Statistic Elements	
NIS	State Statistic Element
NIQ01	State Statistic Element
NIQ02	State Statistic Element
NIQ05	State Statistic Element
NIQ06	State Statistic Element

Figure 4.21: Number in Queue Settings.

After running the simulation, in the Pivot Grid tab is possible to follow the standard results of the model and the ModelEntity. Analysing the number in queue, it is noticed that DeskP0_01 had a maximum of 13 entities waiting in the queue to be processed at the same time, DeskP0_02 had a maximum of 7 entities waiting in the queue at the same time, DeskP0_05 had a maximum of 3 entities at the same time, and DeskP0_06 had a maximum of 16 entities waiting at the same time. The last result is the most worrying number, interfering directly with waiting time, service time and the total time that each entity has in the system.

NIQ01	StateValue	Average	4,1092
		FinalValue	3,0000
		Maximum	13,0000
NIQ02	StateValue	Average	1,9454
		FinalValue	0,0000
		Maximum	7,0000
NIQ05	StateValue	Average	0,1705
		FinalValue	0,0000
		Maximum	3,0000
NIQ06	StateValue	Average	7,1512
		FinalValue	1,0000
		Maximum	16,0000

Figure 4.22: Number in Queue Results.

Tally Statistics

Tally Statistics is a property that is used as a parameter, used to collect and tally information in interarrivals time. This property was used to tally the time in the system, the queueing times and to validated the models with the time between 2 workstations, as it was discussed in the previous section.

State Variables		
Picture	Real State Variable	Picture
Animation	String State Variable	Animation
ArrivalAtTotem01	Real State Variable	ArrivalAtTotem01
ArrivalAtTotem02	Real State Variable	ArrivalAtTotem02

Figure 4.23: States Variables in ModelEntity.

The first step as showed in figure 4.23, it is created 2 states variables in *ModelEntity*. These states were assigned to the workstation Totem01 and Totem02, respectively, after that, it was selected the input nodes where it was created a process in "Add-On Process Triggers" (Entered) (see figure 4.24) for each input node workstation.

In the Process tab, it is used the step "Assign", where is possible to assign a new value to a state variable that can be changed over time. In this step is assign "New Value" to the corresponding state variable and set as TimeNow, this property set the current time simulation in hours (see figure 4.25).

After tallying the statistics about the settings in the simulation, it was created 2 tally

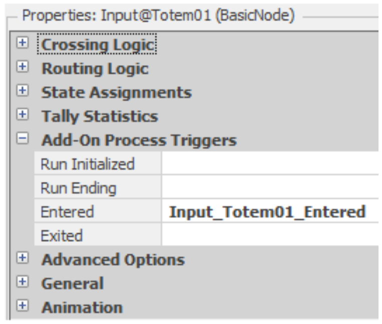

Figure 4.24: Add-On Process Triggers Settings.

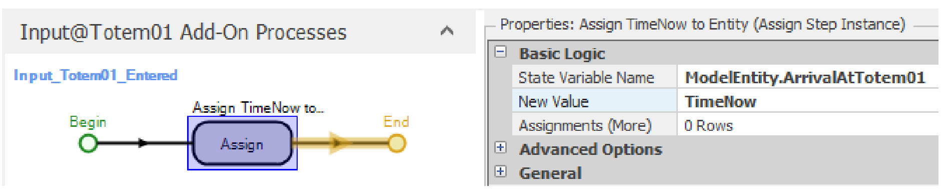

Figure 4.25: Process Logic Input Node Totem01.

statistics elements to register the time in system (see figure 4.26), then it was chosen 2 Transfernodes to be a final point for the tallies, being those, the Transfernode DecideDeparture_or_OfficeArea and Exam_Area. In both cases it was created an "Add-On Process Triggers" (Entered) and set 2 steps, first a "Decide" step to ensure only the *ModelEntity* associated with the State Variable and this value needs to be greater than 0 to enable to register the time and the "Tally" step to associate an expression value to the Tally Statistic Elements **TimeBetweenTotem01toTransfernode**.

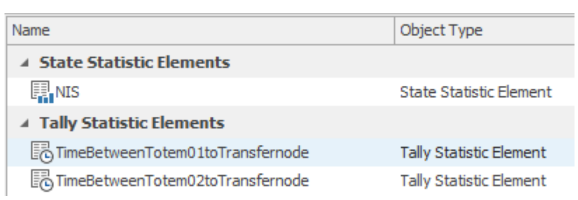

Figure 4.26: Tally Statistic Elements.

The expression value "TimeNow - ModelEntity.ArrivalAtTotem01" calculate the current time assigned to an entity when it enters in the input node and the time tally when it enters on Transfernode and leaves this small control volume studied (see 4.27).

Another tally statistic

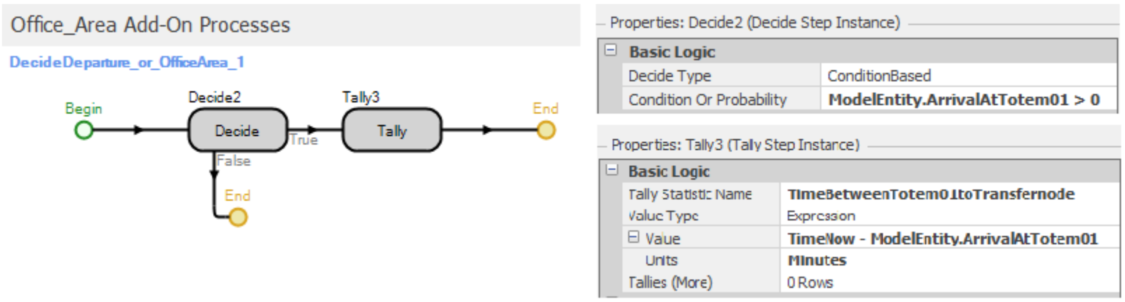

Figure 4.27: Process Logic Step Settings in Office Area.

Pivot Grid

The Pivot Grid reports is an interactive tool that presents the default results of the system. For this study was analyzed some outputs in the *Results* tab on the tab bar, where it was possible to monitor the data and find more information about the performance metrics. The results in the Pivot Grid tab can be viewed in a very dynamic way, to show specific results for analysis, the type of object, category and statistics can be filtered.

Object Type	Object Name	Data Source	Category	Data Item	Statistic	Average Total
ModelEntity	PatientA1	[Population]	Content	NumberInSystem	Average	8,3382
			FlowTime	TimeInSystem	Average (Hours)	0,6808
					Observations	86,0000
	PatientA2	[Population]	Content	NumberInSystem	Average	5,3062
			FlowTime	TimeInSystem	Average (Hours)	0,6939
					Observations	58,0000
	PatientB1	[Population]	Content	NumberInSystem	Average	0,0820
			FlowTime	TimeInSystem	Average (Hours)	0,1367
					Observations	6,0000
	PatientB2	[Population]	Content	NumberInSystem	Average	16,0355
			FlowTime	TimeInSystem	Average (Hours)	1,6332
					Observations	72,0000
	PatientC1	[Population]	Content	NumberInSystem	Average	0,3026
			FlowTime	TimeInSystem	Average (Hours)	0,1681
					Observations	18,0000
	PatientC2	[Population]	Content	NumberInSystem	Average	8,3781
			FlowTime	TimeInSystem	Average (Hours)	0,2956
					Observations	8,0000
	PatientD	[Population]	Content	NumberInSystem	Average	0,2322
			FlowTime	TimeInSystem	Average (Hours)	0,3870
					Observations	6,0000

Figure 4.28: Comparison Statistics Parameters Between Entities in Model Standard.

The figure 4.28 shows that the average time that an entity spent in the simulation model in interarrival is 10 hours. Analysing this results it is important to observe that the average time spend each entity validate the probability of the entities is created.

Status Pie Graphics

The Status Pie Chart is a resource to better understand results about the comparison between expression values. This tool was used to compare the efficiency of work time during the 10 hours run between the workstation DeskP0_05 and DeskP0_06, once of the difference in Initial Capacity between this workstations.

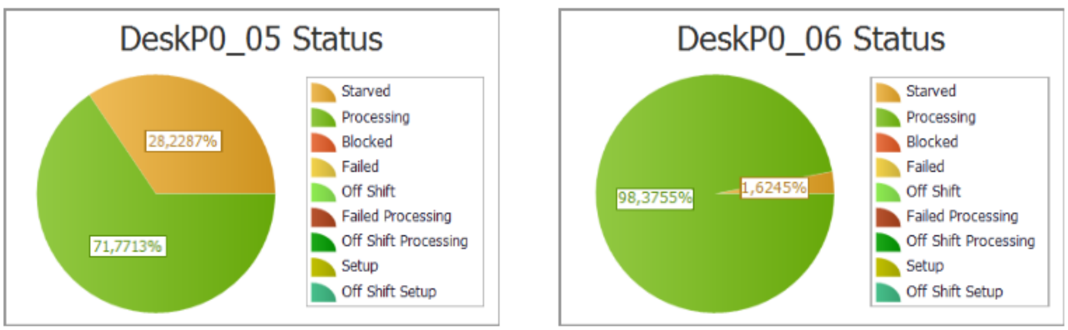

Figure 4.29: Pie Charts Comparing DeskP0_05 and DeslP0_06.

The workstation DeskP0_05 has an Initial Capacity of 2 staff members and the DeskP0_06 has an Initial Capacity of 1 work. As it was observed in figure 4.29 for an interarrival of 10 hours the DeskP0_05 was 71,77% of the time processing, this means 7,18 hours while DeskP0_06 had 98,37% of the time, that is 9,84 hours in processing. Because of the work numbers, the workstation DeskP0_05 is 26,60% lower than DeskP0_06, this means 2,66 hours. In Chapter 5 these results will be compared with other scenarios.

Chapter 5

Simulation Results & Discussion

In this section will be presented the results of 4 simulated alternative scenarios with different configurations.

5.1 Alternative Scenario 01

The scenario 01 has the goal to verify if there is time reduction by adding a new workstation. this new workstation DeskP0_03 have the same properties that DeskP0_01 and DeskP0_02 (the properties described in Chapter 4).

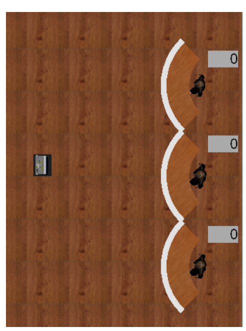

Figure 5.1: Check-in Area 01 With 3 Desks.

To record the variables times also was created a State Statistic for this workstation.

When analyzing and comparing the obtained results from the **TimeBetweenTotem01toTransfernode** statistics and the scenario 01 it turns out that, by adding one

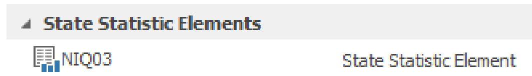

Figure 5.2: DeskP0_03 Properties.

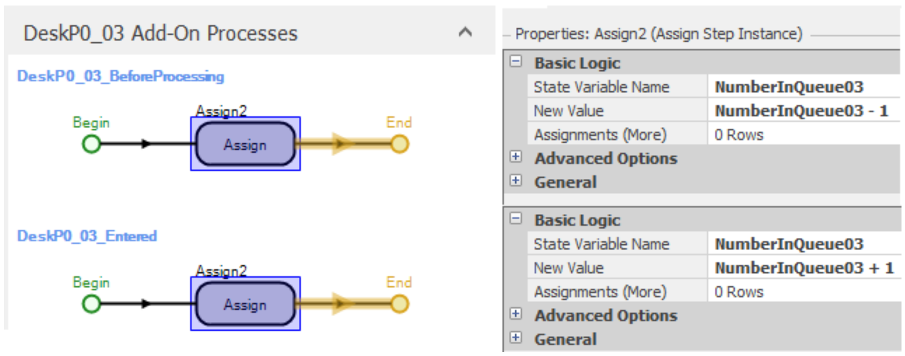

Figure 5.3: DeskP0_03 Settings.

workstation the waiting time is reduced by 20,81% on average, being 10,18 minutes the collected data to be compared with. As shown in table 5.1 the best result occurred for 50 replication, in which there was a 26,47% reduction.

The figure 5.4 shows the chart of the simulated data in the table 5.1.

In figure 5.5 it is also noticed that the number in queue registered by the NIQ01, NIQ02 and NIQ03 reduced from 13 to 1 entity in DeskP0_01, from 7 to 3 in DeskP0_02 and to 2 in DeskP0_03 entities waiting in the queues.

Table 5.1: Comparison of Times in Scenario 01 in Minutes.

Check-in Area 1 Data			
Replications	Average Time Validation	Average Time Alternative Scenario 01	Reduction (%)
10	10,31	8,36	18,93
25	10,65	8,02	24,67
50	10,85	7,98	26,47
75	10,57	8,01	24,19
100	10,55	8,03	23,93
150	10,38	7,96	23,25

This means that the implementation of 3 desks instead of 2 desks in check-in area 01 may reduce 26,47% in the best results and 18,93% in the worst results, for the patients'

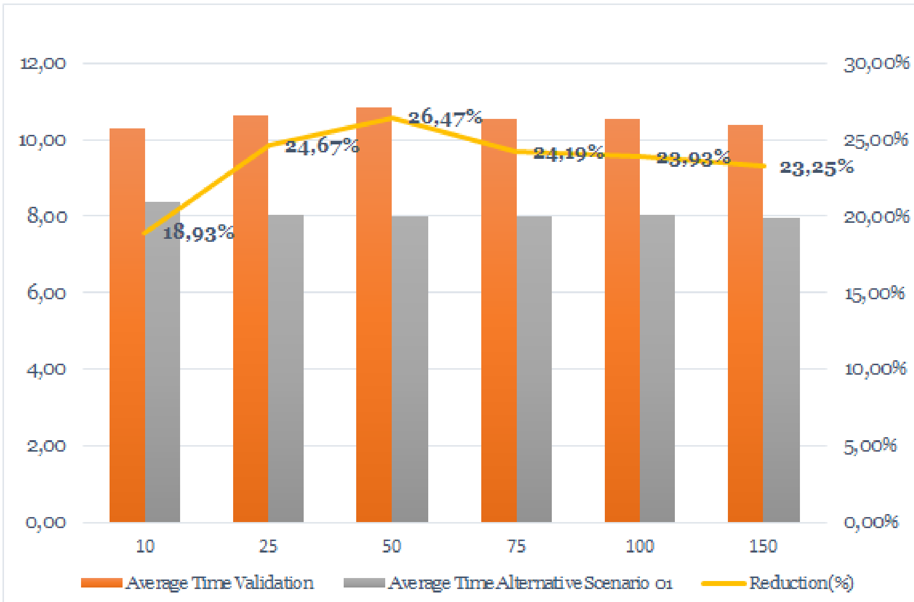

Figure 5.4: Chart of the Results of the Comparison of Scenario 01.

NIQ01	StateValue	Average	0,0300
		FinalValue	0,0000
		Maximum	1,0000
NIQ02	StateValue	Average	0,1222
		FinalValue	0,0000
		Maximum	3,0000
NIQ03	StateValue	Average	0,1205
		FinalValue	0,0000
		Maximum	2,0000

Figure 5.5: Number in Queues for DeskP0_01, DeskP0_02 and DeskP0_03.

check-in. This is a reduction between 1,95 minutes and 2,87 minutes of the time spend per patients in the check-in area 01.

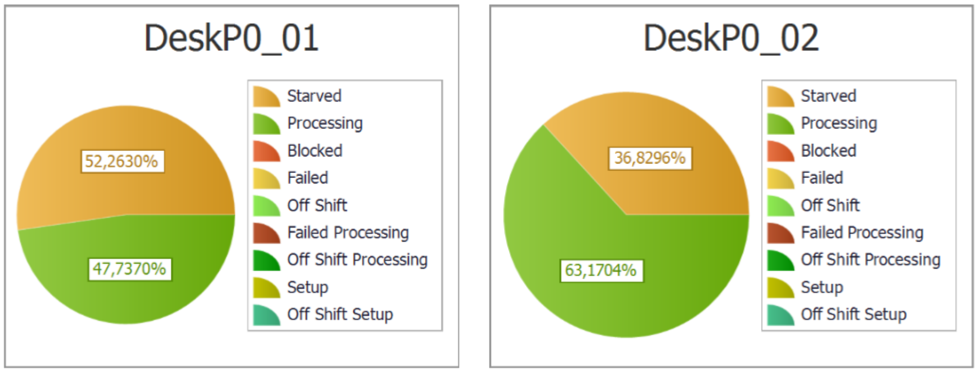

Figure 5.6: Pie Charts Comparing DeskP0_01 and DeskP0_02 in Validation Model.

When the processing time of this 3 workstations is analyzed (see figure 5.9) and compared with the validation model, where there were 2 workstations (see figure 5.6), a reduction of 47,73% to 22,17% is observed in workstation DeskP0_01, from 63,17% to 31,79% in workstation DeskP0_02 and in the new workstation DeskP0_03 37,60% of the time was under processing.

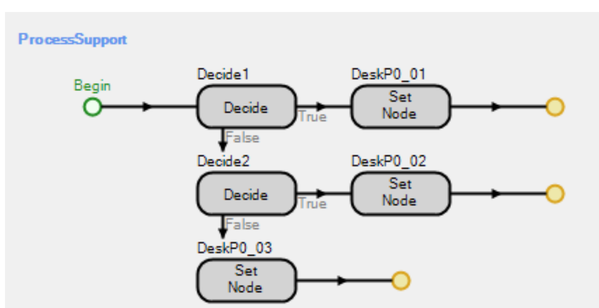

Figure 5.7: Process Logic to Decide Desk Based on Number Waiting in Queue.

The time reduction on DeskP0_01 and DeskP0_02 is justified by the logic of model (see figure 5.7). As the model describes the DeskP0_03 only opens when the number of patients waiting on DeskP0_01 plus the number of patient waiting on DeskP0_02 is greater than 4.

The decision condition expression used in Decide1 Step is shown in figure 5.8.

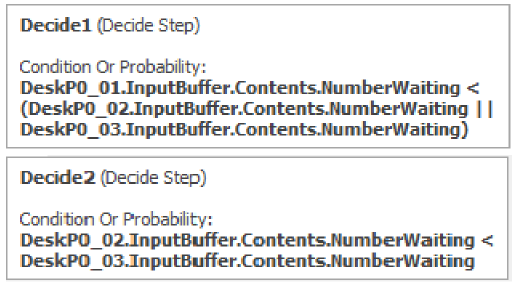

Figure 5.8: The Decision Condition Expression.

However, it is possible to analyze the periods of the day when the longest queues occur and to direct the shift of this third workstation only during the occurrence of these events.

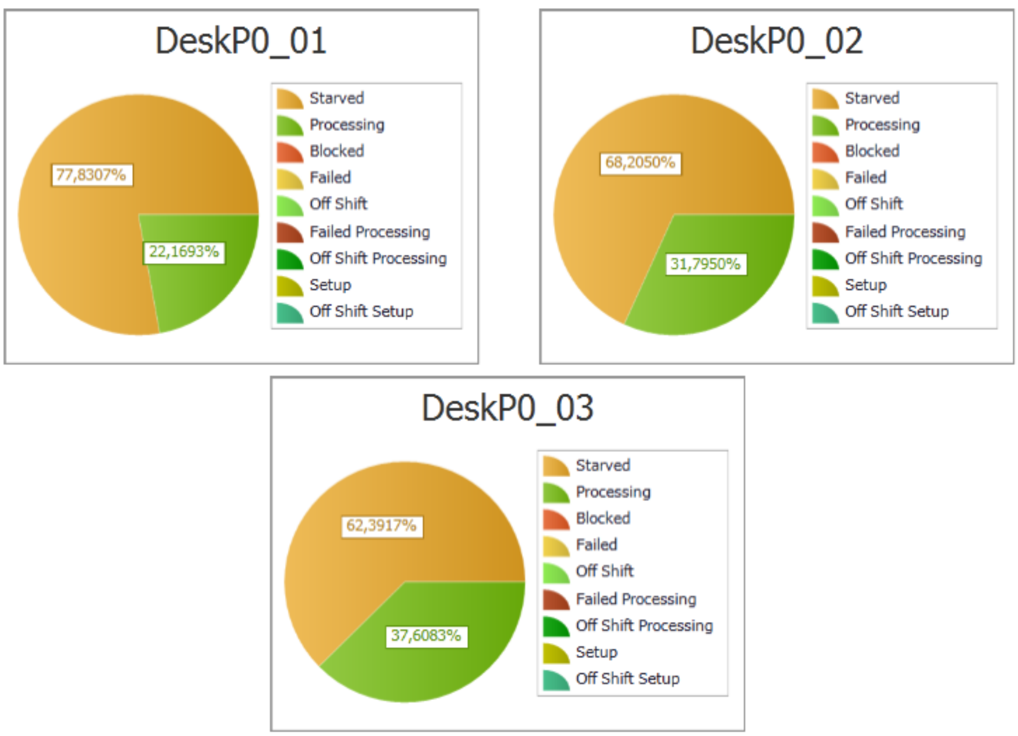

Figure 5.9: Pie Charts Comparing DeskP0_01, DeskP0_02 and DeskP0_03.

5.2 Alternative Scenario 02

The scenario 02 has the same goal of scenario 01, but in this case, was used 4 desks to analyze if was possible a further reduction on the waiting time in check-in area 01. For this, it was repeated the same process for scenario 01 and simulated the model.

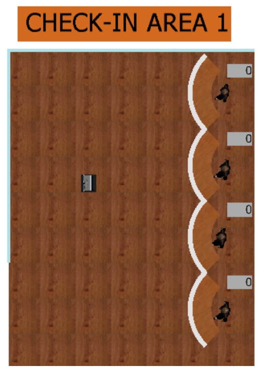

Figure 5.10: Check-in Area 01 with 4 Desks.

The properties and processes used to define this scenario were the same as in scenario 01. The properties were reproduced and verified to guarantee the accuracy of the model, without harming the results.

When analyzing and comparing the results obtained from the **TimeBetweenTotem01toTransfernode** statistics and the scenario 02 it turns out that to add two workstations concerning Validation Model reduces in average 30,21% on the waiting times concerning the real-time of 10,18 minutes and 11,84% concerning scenario 01 with 3 desks. When the replication of the model was simulated, as shown in table 5.2 the best result occurred in 50 replication, when there was a reduction of about 35,09%.

Table 5.2: Comparison of Times in Scenario 02 in Minutes.

Check-in Area 1 Data			
Replications	Average Time Validation	Average Time Alternative Scenario 02	Reduction (%)
10	10,31	7,07	31,48
25	10,65	7,13	33,02
50	10,85	7,04	35,09
75	10,57	7,08	32,96
100	10,55	7,12	32,56
150	10,38	7,18	30,79

The figure 5.11 shows the chart of the simulated data in the table 5.2.

In figure 5.12 it is also noticed that the number in queue registered by the NIQ01,

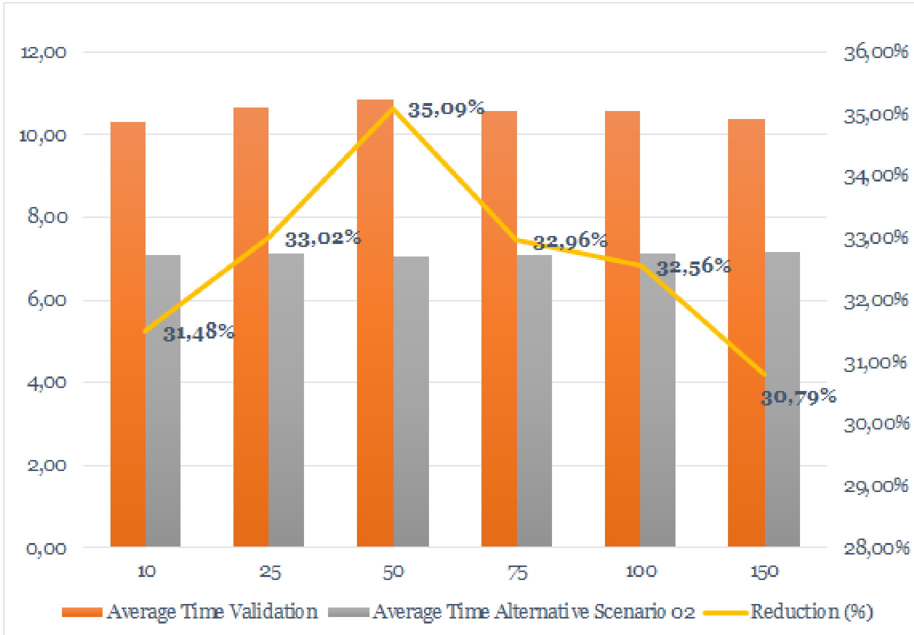

Figure 5.11: Chart of the Results of the Comparison of Scenario 02.

NIQ02, NIQ03 and NIQ04 reduce from 13 to 1 entity in DeskP0_01, from 7 to 2 in DeskP0_02, the number in DeskP0_03 remained the same with 2 entities and to 2 entities in DeskP0_04 considering the maximum number of entities waiting in queues.

This means that the implementation of 4 desks instead of 2 desks in check-in area 01 reduces in 35,09% in the best result and 30,79% in the worst waiting time result that patient has in check-in. This is a reduction between 3,20 minutes and 3,81 minutes of the time spend throughout the time it remains in check-in area 01.

When analyzing processing time of this 4 workstations (figure 5.13) and comparing with the validation model where there were 2 workstations (figure 5.6), it is observed a reduction of 47,73% to 17,81% in workstation DeskP0_01, a reduction of 63,17% to 34,04% in workstation DeskP0_02, a reduction of 37,60% to 16,70% in workstation DeskP0_03 and the new workstation DeskP0_04 30,61% of the time was in processing.

The scenario with 4 workstations allows to observed that the waiting time in the queue and the number in the queue were reduced and it was efficient the management of 4 workstations.

The logic used to simulate this alternative scenario, when the DeskP0_04 is open is

NIQ01	UserSpecified	StateValue	Average	0,0185
			FinalValue	0,0000
			Maximum	1,0000
NIQ02	UserSpecified	StateValue	Average	0,0927
			FinalValue	0,0000
			Maximum	2,0000
NIQ03	UserSpecified	StateValue	Average	0,0531
			FinalValue	0,0000
			Maximum	2,0000
NIQ04	UserSpecified	StateValue	Average	0,0515
			FinalValue	0,0000
			Maximum	2,0000

Figure 5.12: Number in Queues for DeskP0_01, DeskP0_02, DeskP0_03 and DeskP0_04.

the same time as the previous model. The process logic and the decision condition can be visualize in figure 5.14 and figure 5.15.

5.3 Alternative Scenario 03

The alternative scenario 03 has the goal to verify if there is a reduction in the waiting time and number in the queue in check-in area 02. This scenario presents the results when DeskP0_06 in Check-in Area 02 has a dedicated queue to attend patients belonging to the National Health Service and only the entity PatientB2 can do check-in. Also, DeskP0_05 workstation has a dedicated queue to serve patients belonging to the Private Insurance and Collect Analysis, where only the entities PatientA2 and PatientC2 can be attended.

The strategy is to optimize the waiting times simulating the DeskP0_05 as a support desk to the DeskP0_06. Then when the DeskP0_05 has a Starved Status, this means, when there is no entity in processing or the queue, the workstation can attend the entity PatientB2 and that way releasing the entities waiting in DeskP0_06 queue.

For this simulation was applied the logic of process shown in Alternative 02 and 03 as it is possible to emphasize in figure 5.16.

Check-in Area 02 has an important specification regarding the entry of entities in each desk. Each counter has a dedicate queue where the entity arrives to take a number on

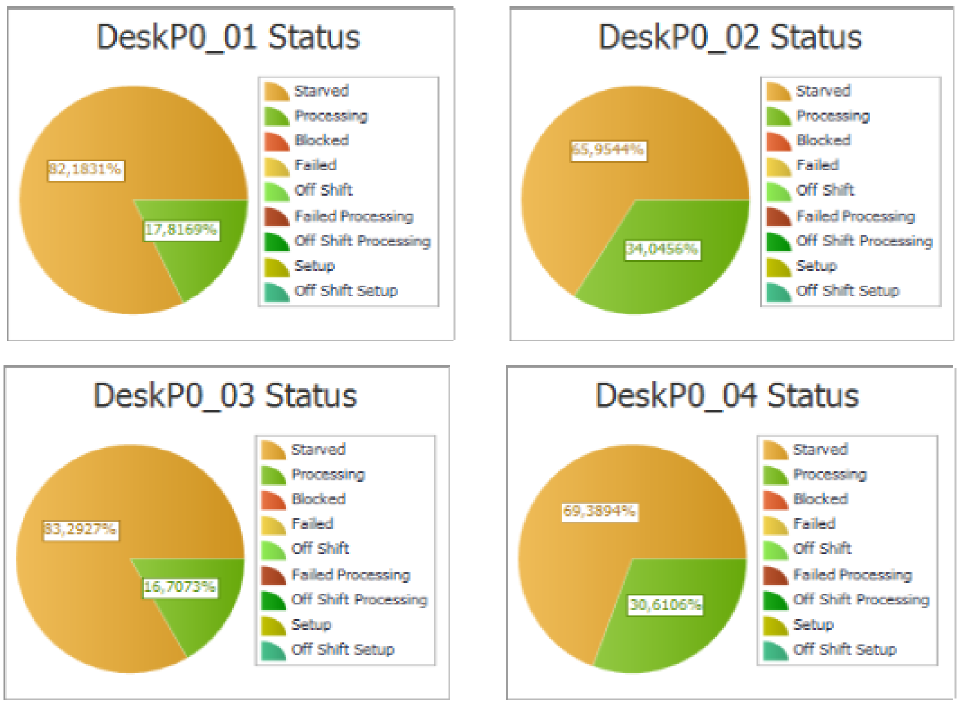

Figure 5.13: Pie Charts Comparing DeskP0_01, DeskP0_02, DeskP0_03 and DeskP0_04.

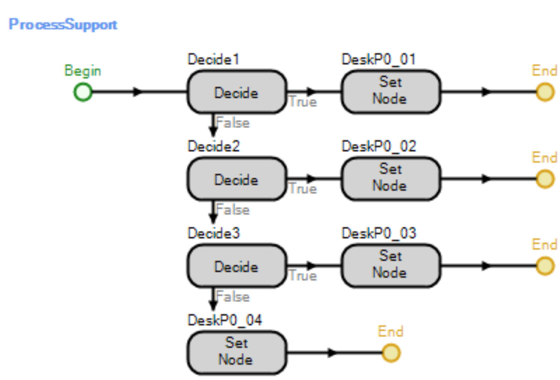

Figure 5.14: Process Logic to 4 Desks.

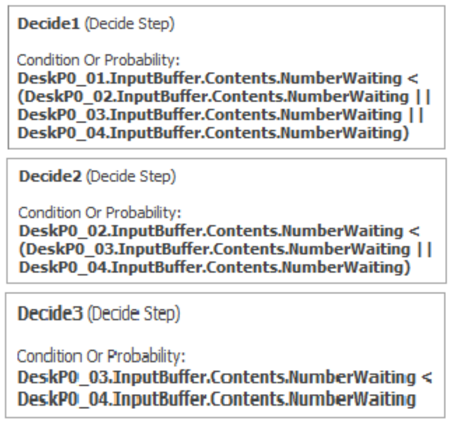

Figure 5.15: The Decision Condition Used in Process Logic ProcessSuport.

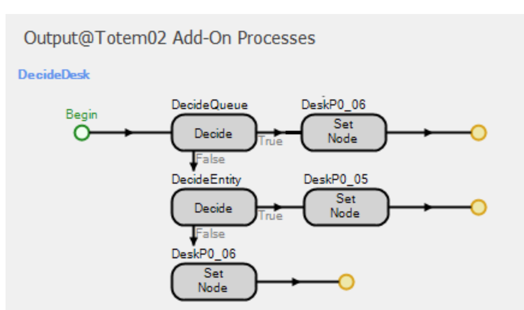

Figure 5.16: Process Logic in Output Totem02.

Totem02. The first decision step verifies that the number of entities waiting in the queue at DeskP0_06 is less than the number of entities waiting in the queue at DeskP0_05 AND if the entity is identified as PatientB2. If this condition is True, the entity must go to the DeskP0_06 desk. If this condition is False the entity goes to the next step decision.

The second decision step verifies if the entity identified is PatientA2 or PatientC2. If this condition is True the entity must go to the DeskP0_05. If this condition is False the entity must go to the DeskP0_06.

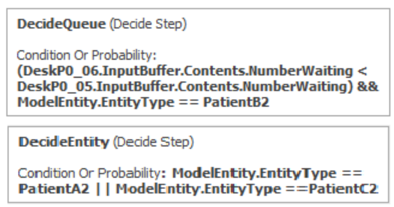

Figure 5.17: The Decision Condition Steps Used in Process Logic DecideDesk.

The table 5.3 show the results after 10 hours of simulation.

Table 5.3: Comparison of Times in Scenario 03 in Minutes.

Check-in Area 2 Data			
Replications	Average Time Validation	Average Time Alternative Scenario 03	Reduction (%)
10	15,43	12,62	18,27
25	15,98	12,83	19,72
50	14,91	12,39	16,92
75	14,97	12,27	18,00
100	14,15	12,60	10,98
150	14,31	12,53	12,43

Check-in area 02 waiting times presented a reduction of 19,72% in the best scenario for 25 simulations and 10,98% in the worst scenario for 100 replications when compared to the average time in the validation model.

Comparing these results with the real system was observed an average reduction of 16,13%. This percentage of reduction represents a significant value in minutes between 1,55 and 3,15.

The figure 5.18 shows the chart of the simulated data in the table 5.3.

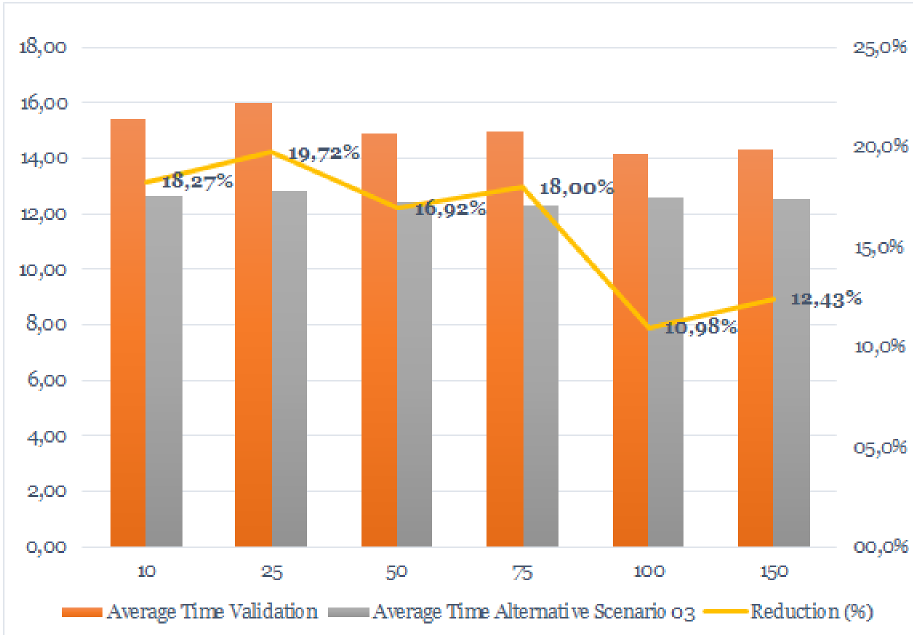

Figure 5.18: Chart of the Results of the Comparison of Scenario 03.

Check-in Area 02 also has a problem in the relation of workstations resource utilization. There was a high percentage of utilization in DeskP0_06 when the Initial Capacity has a value of 1. After the simulation, there was a reduction of 12,94% in DeskP0_05 and 43,33% in DeskP0_06. It is important to point out the DeskP0_06 capacity utilization had a satisfactory reduction and has a good approximation to DeskP0_05. It can be caused by an improvement in the processing in both workstations decreasing the entity waiting times in queues and the time utilization of each workstation.

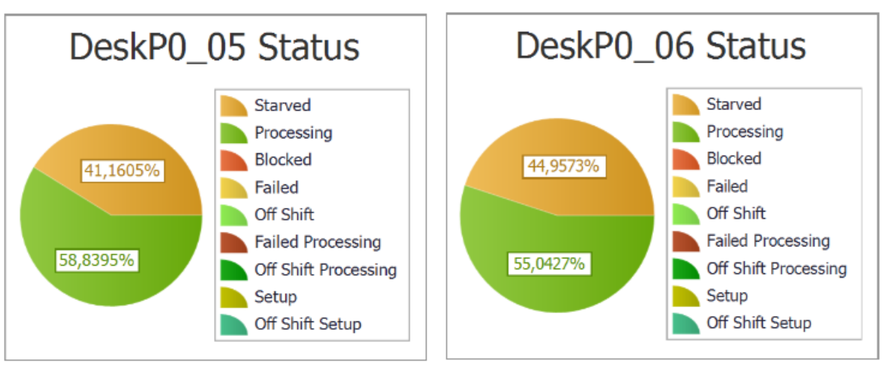

Figure 5.19: Pie Charts Comparing DeskP0_05, DeskP0_06 in an Alternative Scenario 03.

5.4 Alternative Scenario 04

The alternative scenario 04 goal is to verify the time in a system that entities take from entry to leave the system, considering the schedule of the HCU characterized in Chapter 4.

This scenario consists of 6 sub-models. Each model simulated the schedule of medical appointment doctor's for the workstations in Office Area. The exams area will not be modified, as it will be considered that the exams can be performed during the 10 hours of simulation and 6 days a week, from Monday to Saturday.

The table 4.5 is repeated in this section to make the analysis of the results clearer to the reader.

As the workstations follow a work schedule in which they define their working time, it was found necessary to adjust a configuration in the Paths that connect the Check-in Area 1 with the workstations in the Office Area. Workstations that have been configured with the WorkSchedule Office_OffShift have a value of 0.0 in the Selection Weight in each path property, and the workstations that are configured with the other WorkSchedules have been configured with a value of 1.0.

The simulation model used to evaluate this scenario is a new model that has all the tools of the Simio® software development environment. Therefore, this new model that simulates the alternative scenario 04 is a combination of the applications of scenarios 01 and 03. Scenario 01 have been chosen instead of scenario 02 taking into account that it has obtained good results in reducing waiting times, this model is closer to implementation in the real system.

To analyze and evaluate the performance of the simulation model that represents scenario 04, a registration statistic called Time In System was used. The development and application of this statistic was presented in Chapter 4, section 4.2.1.

After running and analyzing the 6 simulation models, the results collected in the Pivot Grid are shown in table 5.5. Comparing the statistics between the validation model and the 6 models it is noted that the response Time In System in all of the results is less than

Table 5.4: WorkSchedule Office Area.

	WorkSchedule					
Label	**Monday**	**Tuesday**	**Wesneday**	**Thursday**	**Friday**	**Saturday**
Pediatrics_Office	Cyan	Purple	Cyan	Purple	Purple	Purple
Gynecology_Office	Purple	Cyan	Purple	Yellow	Cyan	Purple
Cardiology_Office	Purple	Cyan	Purple	Cyan	Green	Purple
Gastro_Office	Cyan	Purple	Purple	Purple	Purple	Purple
Dentist_Office	Purple	Purple	Purple	Purple	Purple	Cyan
Ophthal_Office	Yellow	Green	Green	Cyan	Green	Purple
Doctor_OfficeP1_01	Green	Yellow	Cyan	Green	Green	Cyan
Doctor_OfficeP1_02	Green	Green	Yellow	Yellow	Green	Green
Doctor_OfficeP1_03	Yellow	Cyan	Cyan	Cyan	Yellow	Yellow
Doctor_OfficeP1_04	Cyan	Green	Cyan	Green	Green	Yellow
Doctor_OfficeP1_05	Cyan	Green	Purple	Green	Yellow	Green
Doctor_OfficeP2_01	Green	Green	Green	Purple	Yellow	Purple
Doctor_OfficeP2_02	Yellow	Yellow	Cyan	Purple	Purple	Purple
Doctor_OfficeP2_03	Cyan	Cyan	Green	Purple	Purple	Purple
Doctor_OfficeP2_04	Cyan	Yellow	Cyan	Purple	Purple	Purple

the validation model response. This was expected due to the configurations applied to the 6 simulated models, that showed results in reducing waiting times in check-in areas 1 and 2 and, consequently, influenced the result of reducing the total times spent by entities when created by Source until leaving the system in Sink.

Table 5.5: Comparison of Statistics in Scenario 04.

Model	Time In System (Minutes)	Reduction (%)	Number In System	Number Observation
Validation	58,78	-	45	262
Monday	48,51	17,47	23	284
Tuesday	47,65	18,93	15	292
Wednesday	50,77	13,63	14	293
Thursday	40,85	30,49	26	281
Friday	39,91	32,10	19	102
Saturday	44,24	24,72	16	291

Analyzing also the number of entities that remain in the system after finishing running the model, there was a very significant reduction in the results of the Number In System

Response, this is justified by the fact that reducing waiting times at workstations, either in the check-in areas 1 and 2 reduce the total amount of time, that is, in the areas of exams and office. The results show the waiting times reduction in the queues provides better development of the system, optimizing its functioning and improving the processing of all models.

Chapter 6

Conclusion and Future Work

This chapter aims to complete this study, summarizing and highlighting the most important points in the characterization and development of simulation models, evaluating the results obtained and the initial objectives of the study, and ending with the proposals for the continuation of this case study in future works.

6.1 Synopsis of The Work Developed and Conclusion

The case study of how the waiting time in queues is managed at a Health Care Unit proved to be a great challenge to be performed. The development, execution and analysis of all phases were performed using all the knowledge acquired about queueing management and queueing systems, as well as the use of simulation and modelling software based on intelligent objects, Simio® was extremely important and a great ally for the execution of this work.

After modelling the system in the Simio®, the simulation, verification and validation of the model were essential for the continuation and performance of the simulation models in alternative scenarios.

To seek solutions to the problems presented in chapter 3 and fulfil the objectives described in chapter 1, it is essential to emphasize that the literature review is the basis for the development of this work, all the concepts presented during this study are supported by the analyzes and allowed the use of many tools from the Simio® environment.

Finally, 4 alternative scenarios were built presenting solutions to optimize the validation model, aiming to reduce the waiting times in the check-in queues in areas 1 and 2, the number of patients waiting for the service and the average total time that the patient takes from the entrance to the exit considering 4 steps: the withdraw number, the check-in at the services desks, the execution of the requested service and the departure. After observing the system's behaviour and applications for improvement, the results and conclusion are presented below.

The first simulated model had as the main objective the reduction of waiting times for patients in the Check-in Area 01. On this model a new working station was added, having the same configuration as the others. After simulating and analyzing the results, it was concluded that there was a reduction of 26.47% for 50 replications, this being the best result for waiting times.

This result had a direct impact on reducing the number of patients waiting in the queues at each workstation and on the processing time at each workstation.

For this last result, there was a reduction of 25.56 % in the workstation DeskP0_01 and 31.38% in the workstation DeskP0_02. This reduction meant an improvement in the processing times, that is, by adding a third workstation, service time would be improved, fulfilling the goal of optimizing waiting times.

The second simulation model is an improvement of the first model, allowing the evaluation of use 4 workstations and comparing the processing and waiting times with the models that have 2 and 3 workstations, respectively. When the waiting time parameter was analyzed, the model had an average reduction of 35.09% when compared to 2 workstations and 11.84% when compared with 3 workstations. This scenario is important to analyze if the decision to implement 4 workstations is viable.

In the third simulation model, the main objective was to check if by opening the DeskP0_05 work station as a support workstation, the waiting times and the numbers of patients waiting in the queues were reduced.

When simulating this process, without changing the behaviour of dedicated queues, the data shows that there was an average reduction of 19.72% in waiting times for 25 replications. When analyzing the workstations processing, the result was quite significant, with a reduction of 43.33% for the DeskP0_06 workstation and also a reduction in the DeskP0_05 workstation.

This model leads to the conclusion that one possible solution to the problem of overcrowding and long waiting times in check-in area 2 is to open the DeskP0_05 workstation as support.

The fourth and last simulated model aimed to analyze the performance when a schedule for medical specialities attendance is configured. This schedule was applied to 6 submodels following work schedules in different shifts.

The main result obtained from this simulation was a reduction in the total time spent by the patient from the moment he enters the system until the moment he leaves it. The analysis shows a reduction in all 6 submodels when compared to the validation model. Besides, it was found that, as the total times were shorter, the number of patients that remained in the system after the completion of the models' run was also significantly lower.

6.2 Proposals for Future Work

The proposals for future works based on this study are divided into the characterization of the real world and the development of alternative scenarios in the simulation models.

As a suggestion, the study to be done should not need a new data collection on spot, due to restricted laws to protect costumers in the healthcare system, the data is very hard to be collected and any missing data can give a misleading result, such as a study on the distribution of objects in the physical space, that is, the simulate layout, analyzing how changes in the layout influences the waiting time, can be as easily done and still give important data to be used by the HCU.

It is also recommended a study on the implementation of scenarios 01 and 02, analyzing how the modification of the layout by adding workstations interferes with the waiting time in the check-in area 01.

Although this case study does not consider the development of scenarios simulating the costs involved in the changes, it is suggested that the cost of the employees' hour of work is estimated and calculated.

Finally, for the development of simulation models, it is suggested to analyze the processing times about the staffs work shifts, as this parameter can influence the processing times and waiting times of the patients.

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Appendix A

Original Project Proposal

Proposta de Trabalho Dissertação de Mestrado em Engenharia Industrial

Estudante: Janaina Cristina Ferreira (Estudante de Dupla Diplomação IPB-UTFPR, Brasil)

Orientadores: João Paulo Almeida (IPB), Carla Alexandra Soares Geraldes (IPB), Marjorie Maria Belinelli (UTFPR)

Título: *Análise de sistemas de filas de espera – um caso de estudo*

Resumo: Este trabalho tem como objetivo a análise e otimização de um sistema de filas de espera numa unidade de saúde do distrito de Bragança, Portugal. Em particular, será analisado o processo desde o *check-in* dos pacientes/utentes na unidade de saúde para a realização de exames complementares de diagnóstico, tratamentos e consultas externas nas diferentes especialidades médicas até à consclusão do respetivo episódio.

Atualmente, a unidade de saúde depara-se com tempos de espera do período compreendido entre o *check-in* e a conclusão do episódio superiores ao desejado, pelo que se pretende com este trabalho encontrar soluções que permitam aumentar a eficiência do sistema. Para esse efeito, serão abordados e estudados modelos quantitativos para a gestão de filas de espera com o propósito de indicar o desempenho esperado do sistema sem que seja necessário quantificar o custo de espera.

Dada a complexidade do sistema a analisar será usada a técnica de simulação para o desenvolvimento de diferentes tipos de modelos matemáticos e lógicos que reproduzam o comportamento do sistema em estudo. O sistema será modelado utilizando o *software* Simio®, que é uma ferramenta de modelação de eventos discretos por simulação, baseada em objetos inteligentes [2]. O trabalho a desenvolver terá por base a abordagem apresentada por Law [1] para a realização de um estudo de simulação bem sucedido e que contempla as seguintes sete fases:

1. Formulação do problema em análise;
2. Recolha de informação/dados e construção de um modelo conceptual;
3. Validação do modelo conceptual;
4. Programação do modelo;
5. Validação do modelo programado;
6. Conceção, realização e análise de diferentes cenários;
7. Documentação e apresentação dos resultados de simulação.

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