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Using Computer Simulation to Study a Hospital Patients' Admission Process

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Master Thesis

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It is my deepest gratitude and warmest affection that I dedicate this thesis to my family especially Mohammad and Amirreza for their endless love, support, and encouragement.

Abstract

Hospital performance is an important issue today and is greatly dependent of how the internal processes are implemented. One critical process at hospitals is the patients' admission process. Some of the aspects that should be considered in this process are layout definition, the number of receptionists, patients' flow and the use of technology.

In the use of technology, solutions such as self-check-in machines and information displays need to be evaluated. Due to the highly combinatorial nature of the problem is quite difficult to select adequate tools to evaluate the alternatives. Computer simulation has become widely used in the analysis of complex problems and seems to be the adequate tool for this project. The objective of the work is to analyse a hospital patients' admission process in order to improve its performance, particularly by evaluating the effect of introducing self-check-in machines and information displays. The work involves the development of a simulation model that characterizes the current situation (as-is) and the new proposed scenarios (to-be) for the patients' admission. These models are created in Arena simulation tool which is a discrete simulator. The model is then used to evaluate and compare the different scenarios in order to decide the best one based on the decision criteria's which are defined. The work involves 1) collecting and validating data; 2) simulating model development, verification, and validation; 3) analysing and evaluating of the different scenarios.

We proposed several scenarios for the to-be. The results of the simulation show that the scenario with two self-check-in machines and two receptionists is the best in term of the patient's satisfaction and resource utilization. By reducing the number of receptionists, the hospital has more freedom to use them for the improvement of current services or the development of new services.

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List of abbreviations

DES: Discrete-event simulation

ED: Emergency department

UK: United Kingdom

LOS: length of stay

JCAHO: Joint Commission on Accreditation of Healthcare Organizations

ICU: Intensive care unit

ROI: Return on Investment

1 Introduction

Over the past years, the dramatic increase in the cost of healthcare has compelled researchers and healthcare professionals to examine ways to improve operational efficiency and reduce costs.

Hospital performance can play an important role in the patient satisfaction as well as in the hospital utilization. One of the important issues at a hospital is the patients' admission process where the patients spend a long time waiting for their turn for an appointment. In the traditional approaches, the patients should check-in at the reception and then wait for their turn to be consulted by a doctor. Due to the number of patients, there may be a long queue in front of the receptionists and also in the waiting room where patients wait for a doctor. These are the foundation of the problem in this study.

1.1 Project background

In this regard, there are several factors that can impact the performance of the hospital regarding the patients' admission process: the layout definition, number of receptionists, patients flow, and the use of technologies.

In spite of the fact that technology and medical services are being made at unbelievable rates, the health care services are still inefficient because the delays in queues and waiting rooms occur regularly. Hospitals have tried to solve this problem by adding more resources such as staffs to alleviate the delays which cannot be an efficient answer. But it seems that understanding the patient flow in the hospitals can help to serve the patients receiving timely healthcare services (Haraden and Resar, 2004).

The study of the admission process at a hospital can help decreasing the overcrowding and also the hospital staff's utilization. This study can reveal the bottlenecks and help reduce the queue size as well as the queue time which increases the patient's satisfaction by decreasing the total waiting time of patients at the hospital. There are two queues at the hospital that can be problematic: the queue for receptionists and the waiting room's queue. The reception's queue can be reduced by increasing the number of receptionists which may not be an economic solution. Therefore, the hospitals have a trade-off between the patient's satisfaction and increasing the number of staffs which has a direct effect on their budget.

As hospitals respond to higher patient expectations and a tighter budget, many are looking to self-service technologies such as self-check-in machines and information displays as a way to improve the efficiency and the patients' satisfaction. Recent improvements in touchscreens and high-resolution displays have made the self-check-in machines as an attractive option for the hospitals. Using these technologies is costly and should be evaluated beforehand to reduce the hospital's costs.

1.2 Discrete Event Simulation

Computer simulations are considered to be a promising tool which can be used for the improvement of different processes without affecting the existing services for patients or needing significant financial investments (Khare et al. 2009). In recent years the application of simulation in healthcare has become increasingly more popular. It has several benefits including cost savings of applying different scenarios and finds the best one without actually deploying them and expends money for the implementation.

The patient's admission process involves several inputs and variables that can influence the performance of the process. These variables are patient's arrival rate, reception's queue, and the doctor's service time. Therefore, a discrete-event simulation (DES) software can be used which provides flexible models for all of the variables.

DES software is also used by the researchers to ask several what if questions and test different scenarios while assessing the efficiency of the proposed services (June et al. 1999). DES models also provide more flexibility by being able to define custom parameters in comparison to the traditional queuing theory approach. We choose ARENA student version 14.7 created by Rockwell Automation Inc.

1.3 Problem Description

In this project, we dealt with two main problems: Patient waiting in a queue and hospital's staff's utilization. Long waiting queues are symptomatic of inefficiency in hospital services. Patients usually wait in a long queue to being served by a receptionist or wait for a doctor for their consultation. In this case, the hospital managers can either increase the number of receptionists which is a costly action for the hospital or try to increase the staff performance by the extra hour which again causes staffs dissatisfaction. On the other hand, staff's utilization is a very important factor for the hospitals, in which increasing it gives extra opportunities to the hospital's managers to offer more health service to their patients using existing staff, therefore, increasing the hospital profits.

1.4 Research Questions

One of the most important issues at a hospital is the patient's satisfaction. The patients at a hospital should wait in several places for their turn due to the limitation in the hospital's resources. This limitation can be in the number of staffs or equipment. Therefore, a study of the best configuration for the hospital's resources while reaching a high patient's satisfaction is desirable.

In this project, we intend to study the effect of the number of receptionists at a hospital on the patient's waiting time in different places in the hospital. The use of the self-check-in machine is also studied. Therefore, we are going to investigate the below important research questions:

- Do the current receptionists can reach to a high patient's satisfaction?
- Using self-check-in machines, does the patient's satisfaction improve?
- What are the best combination of the number of the receptionists and the number of the self-check-in machines?

1.5 Study and Project Development at the Hospital da Prelada

The consultation service is selected for this project at the hospital da Prelada. The patient's consultation is arranged either by a family doctor from the Centro de Saúde or by making a call to the hospital by the patients. In both cases, they should go to the hospital in their scheduled consultation time. The patient arrival process is started by entering a patient to the hospital and then it is finished when a doctor finishes visiting the patient.

In this period of time, the patients should wait to do the check-in. There are two places for the patients to wait for check in 1) the first place in the receptionists' queue and 2) a waiting room to avoid a long queue in front of the receptionists.

In addition, the patients are also waiting in a second waiting room for their turn for the doctors. The waiting time in these queues and waiting rooms has a direct influence on the patient's satisfaction.

On the other hand, increasing the number of receptionists is not an option for the hospital to improve the patient's satisfaction due to high involved cost. We suggest the use of self-check-in machines to improve the patient's satisfaction. But it also has its own cost of implementation which can be justified for the hospital to buy them. To solve this problem, we proposed to use the self-check-in machines while simultaneously we reduce the number of receptionists to compensate the self-check-in machine's cost.

The evaluation of the proposed scenarios is done by using the Arena simulator and the results of this evaluation are presented in Section 5.

1.6 Report outline

Section 1 presents an introduction to this project. In Section 2, we review the state of the art related to the analysing the patient's arrival process at a hospital. In section 3, we explain the problem that the hospital facing in more detail and explain the objectives of the project. The methodology that we use for this project is described in Section 4. The results of the evaluation of proposed solution and the comparison of the scenario are presented in Section 5. Finally, Section 6 concludes the report and presents the lines of research as future work.

2 Literature Review

Nowadays, health care costs have dramatically increased while the health service providers try to improve the quality of health cares for their patients. The discrete-event simulators are cost-saving tools that can reduce the implementation costs while improving the patient satisfaction. Therefore, a discrete-event simulation can help the healthcare decision-makers to assess the current services ("as-is") and also design new services ("to-be") or improve the existing ones without actually implementing a new solution, so, reducing costs. Discrete-event simulation can also be used to predict the impact of any change in current services and resource (Human resources/physical resources) requirements. Having this information by means of simulation, hospital managers can easily decide about reconfiguring existing services or plan new services.

2.1 Admission Scheduling

Lobo et al. (2011) studied the operating theatre based on a simulation model in the biggest hospital in the north of Portugal. Their focus was on the critical planning problem of the operating theatre, the allocation of medical services to operating rooms and shifts. They found that the increasing patient waiting lists trend can be reversed by modifying the allocation of some surgical specialties and utilizing free shifts of the schedule. However, their configuration requires extra-time which would have a financial impact for the hospital.

Helm et al. (2011) simulated a partner hospital through a custom designed C++ program. The group studied the effects of zone based admission control using one year of historical data of arrival rates, the length of stay distributions, and transfer probabilities. In the study, expedited patients were identified within the emergency department (ED) as a third class of patients. Patients who are being admitted through the ED that are able to delay their admission 1-3 days but unable to wait and be admitted as an elective patient due to excessive waiting times are the types of patients which fit the expedited patient category. This study provides a call-in mechanism to serve this third class of patients which allow the reduction of excess load that is placed on the ED during peak congestion periods. Helm et al. (2011) also suggest in their study a Markov decision process model which focuses on using the expedited patient category and elective admission cancellations to create a balance between bed utilization and hospital congestion to provide an optimal admission policy.

Helm et al. (2009) also studied patient flow and admission control and found that hospitals are able to improve hospital occupancy and alleviate congestion by reducing variability through a more flexible system. It was found that many hospitals make decisions independently without considering the downstream effects on workload strain and costs of hospital resources. High variability of elective surgeries due to the independent scheduling of each surgeon creates blockages for ED inpatients beds, increases ED waiting times and lowers the quality of health care. Using a patient flow simulation framework of a 160 bed hospital with three main units; surgery, medicine, and intensive care unit (ICU) beds, they showed that level loaded scheduling with call-in and cancellation thresholds compared to a hospital with the typical front-loaded scheduling without daily control thresholds provided a dramatic reduction in the number of cancellations and reduction in variability by 27%. Such improvements could provide healthcare facilities with a means to efficiently staff hospitals to match workload and patient demand with an overall improvement in the quality of care and cost savings from the reduction of understaffing and overstaffing.

Haraden and Resar (2004) discuss the importance of patient flow in hospitals as a major area to study for understanding and improving patient wait and cancellations. Hospitals have responded by adding more resources to more beds, larger facilities, and increased staff numbers but have seen that just increasing resources does not solve the common occurrences of waiting. Interventions that smooth the flow of elective surgery, reducing waits for inpatient admission through the ED is critical in that understanding variation is the first step in providing a timely flow of patients.

Lowery (1996) explains that when creating a hospital admission scheduling system through simulation, the simulation model should be able to be easily applied to multiple hospitals, be valid, representing an actual system, and be able to show improvements in variability. Some of the input variables that are highlighted include a number of beds, average standard deviation of length of stay (LOS), arrival rates of emergency patients by day of the week, and distribution of elective admits. Using a graphical approach is the most common method of validating a model and explained how understanding the admission process would prove to be invaluable to explaining how the system behaves.

Table 1: The comparison of the state of the art related to the admission scheduling

Reference	Topic	Contribution	Method	No. of citation
Lobo et al. (2011)	allocation of medical services to operating rooms and shifts	Decrease the patient waiting time	Simulation	1
Helm et al. (2011)	Elective patient distribution in ED	Create a balance between bed utilization and hospital congestion	Simulation	42
Helm et al. (2009)	Patient flow and admission control	Match workload and patient demand	Simulation	7
Haraden and Resar (2004)	Discussion of the importance of patient flows in hospitals	Increasing resources do not solve the common occurrences of waiting	Review	131
Lowery (1996)	Evaluate hospital admission scheduling system	Create a graphical approach for admission process	Simulation	47
Kloehn (2004)	Address how problems with patient throughput cause a wide array of unsolved issues		Executive summary	2

Kloehn (2004) in an executive summary tries to address how problems with patient throughput cause a wide array of unsolved issues in overcapacity, diversions, excessive wait times, bed placement control, and discharge process. A facility over 85% occupied is considered to have a high chance of throughput issues and delays in the ED. Throughput is also to have an impact in how patients are admitted and cause unnecessary delays and excessive wait times.

2.2 Elective Admission

Bowers and Mould (2002) conducted a study on reducing waiting time through "deferrable elective patients" to maximize utilization and still ensuring the quality of care for orthopaedic patients in the UK. "Deferrable elective patients" are elective patients given the opportunity to receive earlier care with the possibility of postponement based on the event that the demand for care needed for that day is high. Using this policy would allow for patients to be seen earlier having an impact on waiting time but with the cost of 19% probability of treatment being deferred.

Gupta and Denton (2008) summarized key issues in the health care field using different kinds of models to help represent a scheduling system. There was concern that existing manufacturing, transportation, and logistics models are not able to easily fit into the health care field due to the nature of the health care industry. There are many issues that must be addressed such as patient and provider preferences, stochastic and dynamic nature of multi-priority demand, technology changes, and soft capacities to name just a few. The paper also describes the challenges and future opportunities to implement novel industrial engineering and operation research techniques to hospital appointment scheduling systems.

May et al. (2011) reviews the problem of surgical scheduling by surveying past work and suggesting potential future research on capacity planning, process reengineering, surgical services portfolio, procedure duration estimation, scheduled construction, and scheduled execution, monitoring, and control. Surgical scheduling was considered to deviate significantly from even a detailed plan through the course of a surgical day due to the stochastic elements of arrivals, cancellations, and duration of the surgical procedures. However, the study concluded with the idea that a better guide will allow operational management to use their resources more effectively and efficiently with the economic and project management aspect of surgical scheduling having the greatest potential for relevant research.

Min and Yih (2010) studied patient priority within the elective surgery scheduling problem. Using a stochastic dynamic programming model, patients with the highest priorities were selected to be scheduled for surgery when capacity became available. The study showed that using patient priority had significant impacts on surgery schedules.

Bekker and Koeleman (2011) assessed a study on scheduling elective admissions that minimized the target and offered a load of patients in order to maintain more consistent bed occupancy levels. Target load levels were determined based on the capacity in relation to the variability in offered load as well as incorporating weekly patterns of bed availability. Smoother admission best stabilizes bed occupancy levels. The more even distribution of elective admissions throughout the week provided the most stable time performances by decreasing variability in bed demand and the probability of refusals. The article also found that patients with longer LOS scheduled on Fridays provided a more optimal schedule while higher admissions on Mondays with shorter LOS also were found to be advantageous. The model in this study, however, does not capture the discharge process.

Table 2: The comparison of the state of the art related to the elective admission

Reference	Topic	Contribution	Method	No. of citation
Bowers and Mould (2002)	Deferrable elective patients	Maximize utilization by ensuring quality of care	Simulation	14
Gupta and Denton (2008)	Introduce key issues in the health care field	A road map of the state of the art in the design of appointment management systems	Survey	366
May et al. (2011)	Surgical scheduling	Reviews the general problem of surgical scheduling	Survey	89
Min and Yih (2010)	Patient priority within the elective surgery	Minimized the target and offered load of patients in order to maintain more consistent bed occupancy levels	Theoretical	33

2.3 Emergency Department

Fone et al. (2003) studied the effects of hospital occupancy on emergency department length of stays and patient disposition. They conducted an observational study of a 500-bed acute care to teach hospital which showed that increased hospital occupancy seemed to be a major indicator of increased ED LOS for admitted patients. A threshold of 90% bed occupancy appeared to indicate an extensive increase in ED length of stay which is believed to be an important determinant of ED overcrowding. Also, although there is little data verifying the claim, they suggested increasing hospital bed availability might contribute to less ED overcrowding especially when at the 90% bed occupancy threshold.

Han et al. (2007) assessed a study on the effects of expanding the emergency department and its effects on overcrowding. An increase in ED bed capacity had little effects on ambulance diversion and increased the length of stay for admitted patients due to other bottlenecks within the hospital network.

Olshaker and Rathlev (2006) explored how emergency department overcrowding and ambulance diversion impacts boarding times of patients waiting to be admitted to the hospital. The inability to admit ED patients have been highlighted by the Joint Commission on Accreditation of Healthcare Organizations (JCAHO), the General Accounting Office, and others as the leading factor contributing to ED overcrowding. Olshaker and Rathlev (2006) also covers the causes of overcrowding through the development and changes within the health care industry as there is an increase in ED visits due to a number of ED closures, a greater percentage of patients not having health insurance, and a number of laws and programs affecting increased volumes.

Liu et al. (2012) conducted a study through a survey on the effects of reducing crowding in the emergency department through crowding initiatives like vertical patient flow, a method of evaluating and managing patients without using an ED room. Further study was suggested in examining the effects of such crowding initiatives in patient outcomes (safety, LOS, satisfaction) as there is yet a widespread support system in place to create enough momentum to see improvements in ED crowding.

Table 3: The comparison of the state of the art related to the emergency department

Reference	Topic	Contribution	Method	No. of citation
Fone et al. (2003)	Study effects of hospital occupancy on ED	A narrative systematic review	Simulation	324
Han et al. (2007)	Expanding the ED	ED expansion appears to be an insufficient solution to improve diversion without addressing other bottlenecks in the hospital	Simulation	86
Olshaker and Rathlev (2006)	ED crowding	Indicate the causes of overcrowding of ED	Review	165
Liu et al. (2012)	Review the physician leadership of all U.S. academic EDs		Online survey	15

2.4 Computer simulation of health care processes

The use of simulation is growing and is seen as a powerful tool within the health care industry being able to model a wide range of topic areas and answer a variety of research questions as explained in the systematic review regarding computer simulation in health care done by Fone et al. (2003). The review also discusses how computer modelling should provide valuable evidence in how to deal with stochastic elements within the industry. However, it is still yet to be seen the effects and the true value of modelling such processes due to the lack of model implementation on real systems.

Duguay and Chetouane (2007) modelled the emergency department using discrete event simulation and found DES to be an effective tool due to the complexity of healthcare systems. They suggested the combination of total quality management and continuous quality improvement techniques to especially be useful in combination with DES. The group studied a regional hospital to improve the current process through data collection and the use of control variables (physicians, nurses, and examination rooms). Analysis of waiting times and best staffing scenarios was conducted by adding and reducing staff and exam rooms within budget limitations.

Kumar and Mo (2010) provide three different methods of bed prediction models, one of which was simulated through ARENA 10.0 to model bed occupancy levels for 3 different awards for three different types of patients. Data was collected from a hospital for values on the daily number of admissions, the average length of stay over one year, and an average number of beds for each patient type. The simulation showed to be a useful tool in predicting bed occupancy levels for coming weeks and actual values fell within the 95% confidence interval of the model.

Sargent (2011) discusses verifying and validating simulation models through different approaches, graphical paradigms, and various techniques. The author mentions that there is yet to be a set of specific tests that easily applies to the validity of a model giving every new simulation project unique challenges.

Eddy et al. (2012) conclude the importance of creating a model that is transparent, showing how the model is built and valid in reproducing reality to become successful within the health care industry. Face, internal, cross, external, and predictive validity are all a means to validate a model with the latter two being the strongest forms. Validation of a model is also suggested with 4 criteria in mind: rigor of the process, quantity and quality of sources used, model's ability to simulate sources with detail, and how closely match observed outcomes results.

In most of the studies, the use of a self-check-in machine for patient arrivals at the ED is not considered. Therefore, the existence of a self-check-in machine will be evaluated through the simulation and hopefully, the effect on the patient's arrival will be positive.

3 Problem Characterization

3.1 Hospital da Prelada

The construction of the Hospital da Prelada began in 1971. However, the project definition occurred in 1961, the year that the Mesa da Santa Casa da Misericórdia do Porto, through the purveyor of Dr. Domingos Braga da Cruz, outlines the execution Centro de Reabilitação to be built on the grounds of Quinta da Prelada. The project aims at the inclusion of certain specialties: Physical Medicine and Rehabilitation, Plastic and Reconstructive Surgery, Orthopedics and also a Burns Unit. On 17th October 1988, the Hospital da Prelada opens its doors and welcomes the first patients in orthopedics services, Plastic and Reconstructive Surgery and Physical Medicine and Rehabilitation.

Figure 1: The Statue of Dr. Domingos Braga da Cruz at the Hospital da Prelada

The Hospital da Prelada has a mission to improve health through quality care, ensuring timely access and optimization of available resources in the community, as well as participate in research and postgraduate education. By positioning (socially responsible, promoting equity of access, non-profit) and the excellent results obtained in the various specialties available to it, the Hospital will be recognized by the community and the other stakeholders as a quality establishment in health, both for care and for their participation in research and postgraduate education. It is the first private hospital in Portugal that receives accreditation in quality.

3.2 Problem description

At the hospital da Prelada, the patient's consultations are scheduled. A patient who needs a consultation, asks a family doctor in a Centro de Saúde to communicate with the Hospital da Prelada and schedule a consultation through the health system. Another way to schedule a consultation is to call to the hospital's call center and ask for a consultation.

In any case, the patients come to the hospital on their consultation's time. Currently, the check-in process is done by a security man and 4 receptionists. The security guides the patients when they arrive at the hospital. The security decides whether the patients should go to the receptionist's queues or go to the first waiting room and wait until the receptionist's queue become uncrowded. The patients also waited in front of each receptionist for their turn. This is the first place that patients should wait before checking-in.

After completing the check-in and the payment process, the patients should go to the second waiting room and wait for a doctor. There is a second set of receptionists who accompany the patients from the second waiting room to the doctor room. Therefore, each patient should wait to be called by one of the second receptionists. Then, this receptionist accompanies the patient to the doctor's room. This process is the second place where a patient should wait.

The problem in the Hospital da Prelada is related to the customer satisfaction in parallel to the financial issues. To improve the patient's satisfaction, the hospital should increase the number of receptionists to reduce the patient's waiting time at the hospital.

Another solution is to use the self-check-in machines to improve the patient's admission process. Figure 2 show a sample of these machines. They are capable of doing all the check-in process and payment.

Patients arriving for their appointments use the self-check-in machines to check themselves in. The self-check-in machine can identify the patients by their unique codes. It also can present demographic information, tells the patients if there is a holding payment. The self-check-in machines can also accept card payments for the payment.

Figure 2: A sample of the self-check-in machines with its dimension [mm]

On the other hand, increasing the number of receptionists or using the self-check-in machines has a high cost for the hospital. Therefore, there is a gap to study this solution and propose a solution with low cost while can increase the patient's satisfaction by reducing their waiting time at the hospital. Both the patients and the hospital benefit from this solution and therefore, the usability of the solution is high. All stockholders are willing to use the solution.

The objective of this project is to help the hospital understanding this gap and all consequences that hospital will have using these solutions. During this project, we study the current scenario (as-is) and provide a detail evaluation for the hospital to understand the bottlenecks and how the hospital can overcome these problems. We also proposed several scenarios as new solutions for the hospital (to-be) for the patient's admission process.

These solutions use the self-check-in machines as a complementary to the receptionists and aim at reducing the number of receptionists. This reduction allows the hospital to use them for implementing new services or improvement of the current services. Therefore, improve the return on investment (ROI) and also patient's satisfaction.

Finally, we suggest the best solution which is a combination of a number of receptionists and self-check-in machines that can satisfy our objectives. These solutions and scenarios are explained in Section 4 and their evaluation results are presented in Section 5.

4 Methodology

We study the patient arrival process by using a discrete-event simulation, the last version of Arena, 14.70. Computer simulation can be a very effective tool to determine a hospital's capabilities and helps to improve the allocation of resources. In addition, computer simulation can assist hospital administrators in the process of establishing a better system to improve the patient service. The patient flow can be controlled and managed better by analysing the hospital's methods, resources, and capabilities, in order to optimize its resources which can reduce waiting time and queue length.

In order to use simulation for analysing several approaches of using self-check-in machines, we need to know the initialization parameter and input data for the simulation. These initial parameters and input data are very important because they make the simulation scenarios more realistic. Therefore, a preliminary action was taken at the hospital for data collection about the patient's arrival time at the hospital and their flow in the hospital.

4.1 Data Collection

The family doctor in a Centro de Saúde asks for this consultation through the National Health System. After receiving this request, the hospital sends a letter to the patient's address using normal post services. Therefore, patients know their consultation beforehand and they come to the hospital for their consultations.

We started by monitoring the patients arriving at the hospital for a consultation. A part of the information exists in the hospital's database but it was not complete and we try to collect the data related to the missing parts. Then we also get the information in the hospital's database and join them using the patient's unique code, called PRO (for the patients who come to the hospital for the first time) and HP (for the other patients).

We also join the information regarding the age and address of patients to their arrival times. Then, this data is used for an exploratory data analysis. The results of this analysis are presented in the results section.

4.2 As-is

We start by analysing the as-is scenario in two part. The first part was to analyse the patient admission process and patient flow at the hospital. The second part was to implement the existing admission process in the simulation. In this section, we start by explaining the hospital layout, and then the patient admission process. Finally, the simulation scenario is explained.

4.2.1 Hospital layout

The existing layout (as-is) in the hospital is shown in Figure 3.

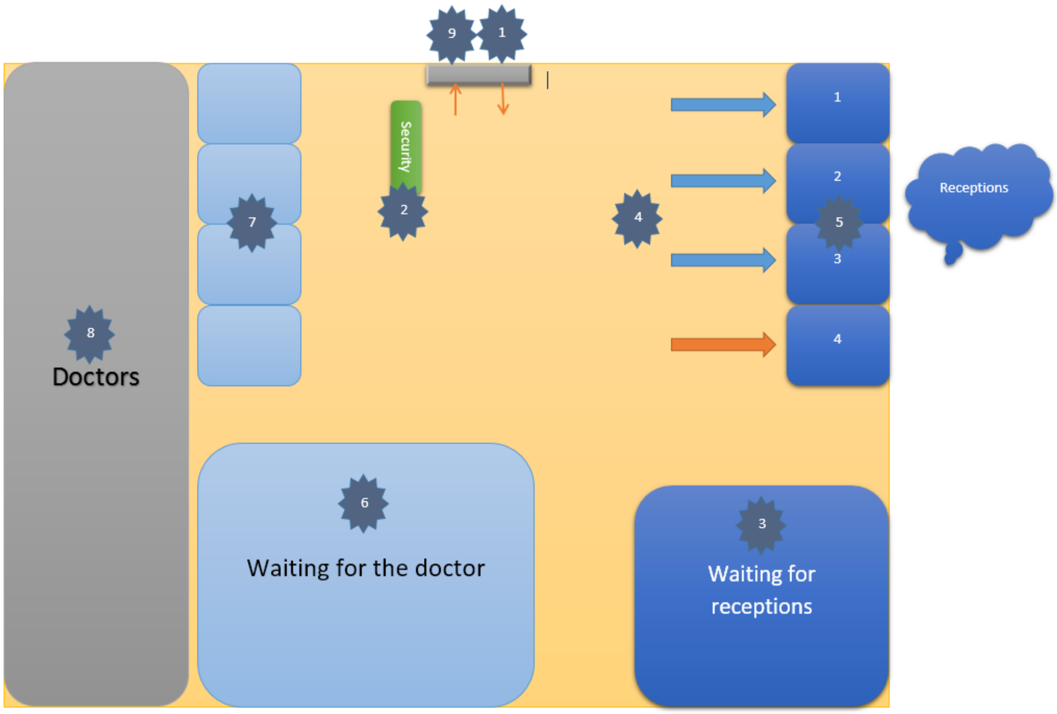

Figure 3: The as-is layout

The security asks the patients for their consultation letters as soon as they arrive at the entrance (location 1 in Figure 3). Then, the security decides if the patient should go to a queue in front of the receptionists (location 4 in Figure 3) or should go to the waiting room (location 3 in Figure 3). This decision is taken based on the number of patients that are currently waiting in those queues. In either case, patients in a queue in their turn go to a receptionist (location 5 in Figure 3) and deliver their consultation letter to the receptionist. The receptionist checks their information in the system. If the information is not correct, then she will ask for more information to complete the information. The receptionist also asks for the payment. After ending this process, the receptionist asks the patients to go and wait in another waiting room (location 6 in Figure 3) and wait for the doctor.

When a doctor can see a patient, one of the second group of receptionists (location 7 in Figure 3) will go to the waiting room (location 6 in Figure 3) to take the patient and accompany him/her to the doctor room (location 8 in Figure 3). At the end of a consultation, the patient either leave the hospital (location 9 in Figure 3) or go to other location within the hospital such as to do an exam or X-ray.

In this layout, the patients can be in a queue/waiting in several locations. In Figure 3, locations 2, 3, 4, 6 are the possible locations that a patient may wait for his/her turn. For all of these locations, we consider a queue in the simulation scenarios. In addition, the main performance gained from the new scenarios, (to-be)'s, is a reduction in the waiting time in these queues. These results are shown in the results section.

4.2.2 The patient admission process

The process of the patient's arrival at the hospital is depicted in Figure 4. As discussed in the previous section, patients arriving at the hospital, deliver their consultation letter to the security and then depending on the length of the queues in front of the receptionists, the security decide if the patients should go and wait in the waiting room or go to the queues. After being attended by the receptionist, the patients do the registration and payment. Then they go to the second waiting room and wait until another receptionist (the second set of receptionists) call them to go to the doctor. Then one of the second receptionists accompanies the patient to the doctor. The patient after visiting the doctor leaves the hospital.

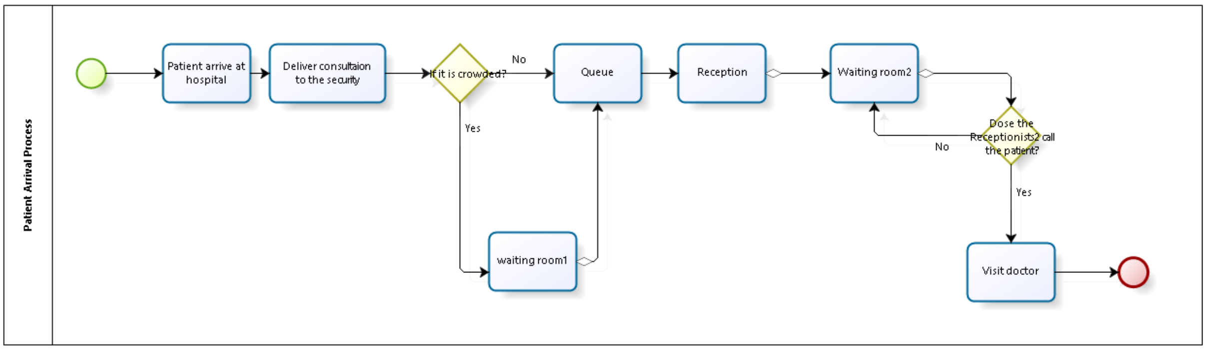

Figure 4: The patient arrival process at the hospital

4.2.3 The patient arrival swim lane

To identify the actors of the actions in the patient's admission process, we also make a swim lane for the process. Figure 5 shows the swim lane for this process. There are five actors in this process which have an influence on the process.

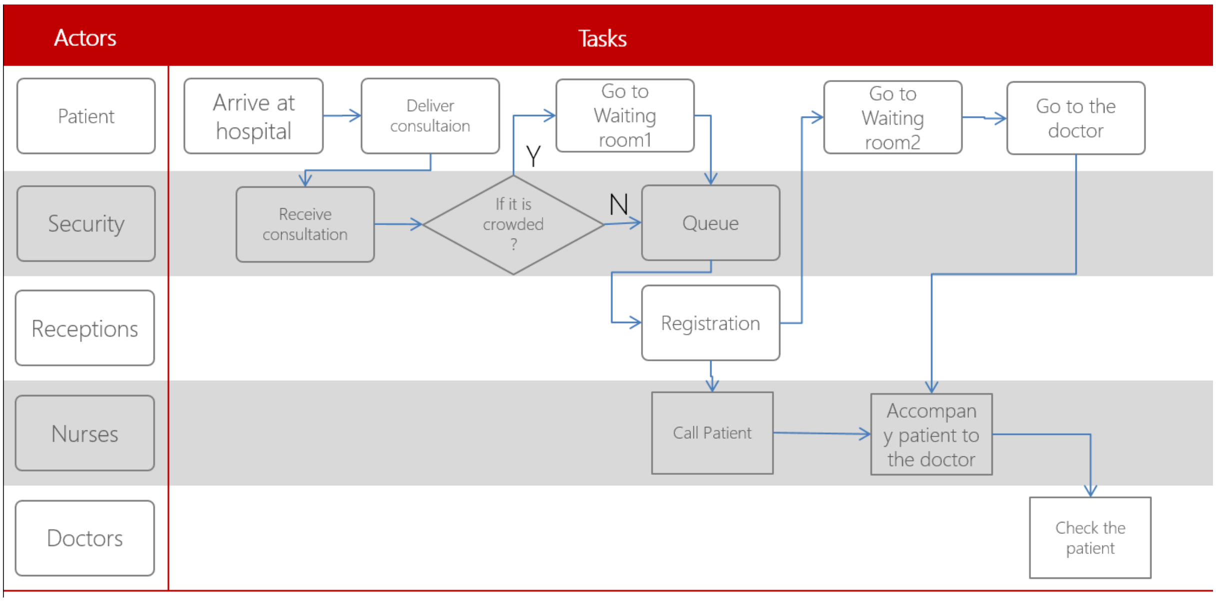

Figure 5: The patient admission swim lane

4.2.4 Validation: Simulation of as-is scenario

The next step was to simulate the as-is scenario to verify the simulation results by matching them to the data collection results. The scenario is discussed in this section while the results of this simulation are presented in the result section.

As mentioned previously, we used Arena simulation tool. The simulation scenario is very complex because we wanted to make it more realistic. Figure 6 shows the simulation layout. Due to having a very large layout, only a small view can be seen. We are going to explain different parts separately so that we can identify all building block of the simulation.

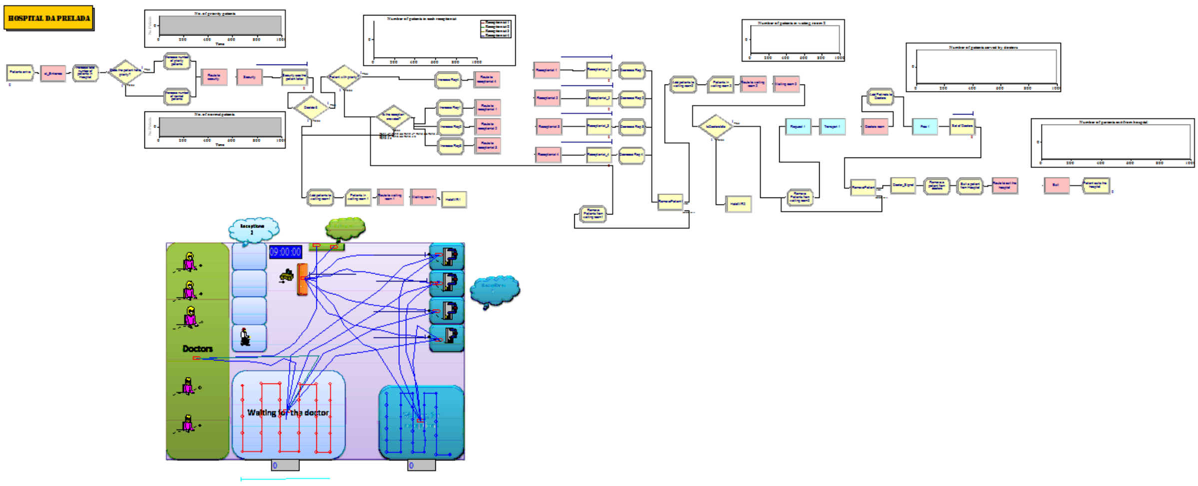

Figure 6: The simulation scenario, as-is

The simulation is implemented according to the process map (Figure 4). The simulation parameters are also set according to the data analysis that we have done on the data collected at the hospital.

To simulate the patient's arrival rate, we use "create" module in Arena.

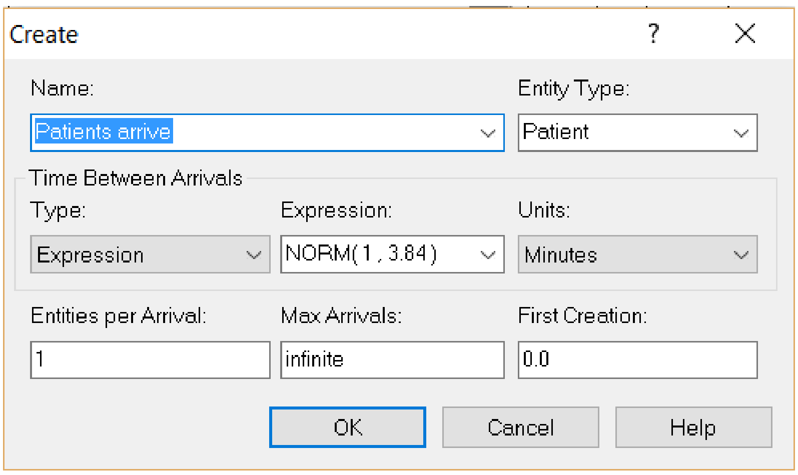

Figure 7: Create module for the patient's arrival

In Figure 7, the patient arrival is considered as a normal distribution with the mean of one minute and standard deviation of 3.84 minutes. These values are obtained from the as-is data analysis.

Then, 5% of all patients are considered as priority patients. These patients go to the special receptionist who is responsible for serving the priority patients. All other patients (95%) are divided between other three receptionists and should wait in the queues. The next actor is the security who checks the consultation letters. For this purpose, we use the "process" module I the Arena simulator (Figure 8).

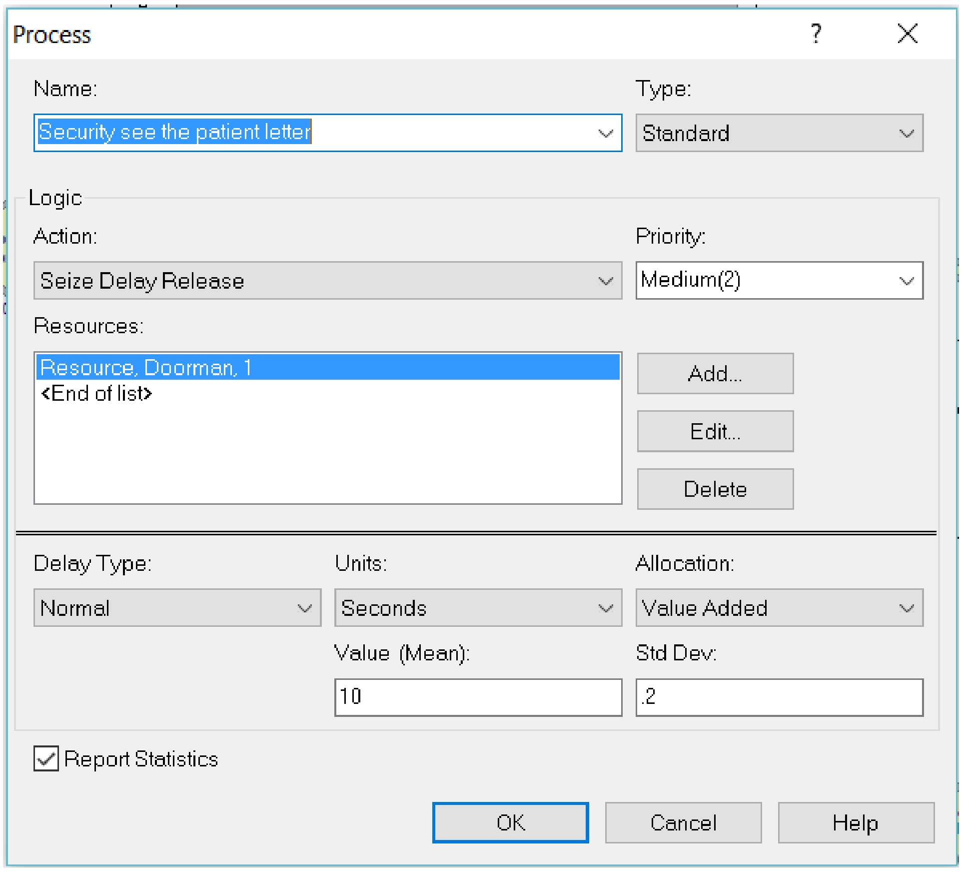

Figure 8: Process module for the security

According to our observation, the security checks the patient's letters very fast. Therefore, we set the average process time to 10 seconds. The security also checks if the patient is a priority patient who needs to go to the receptionist four. The receptionist four is the receptionist who is responsible only for the priority patients. This decision is taken in the simulation based on Priority attribute which is set to 1 for the priority patients (Figure 9).

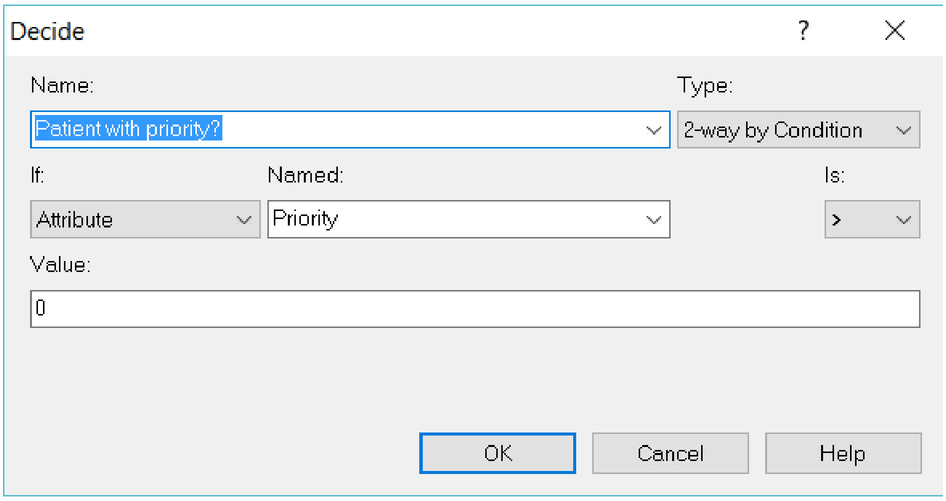

Figure 9: The decide module for separating priority patients

The security also decides if a patient should go to the queue or to the waiting room. This decision making in the simulation is taken by a "Decide" module.

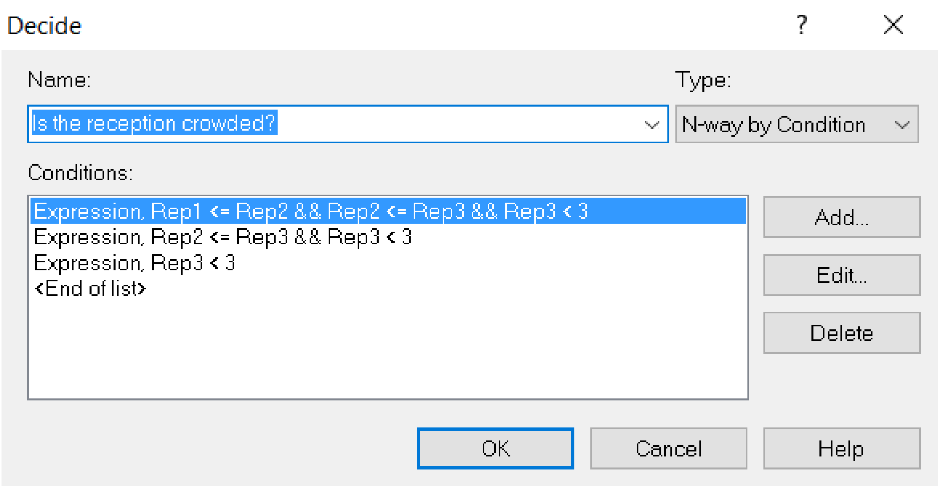

Figure 10: The decide module for the security

As we can see in Figure 10, there are three conditions for the decide module. These conditions make the queues in front of the receptionists to have a length of at most 3 patients. After having 3 patients in each queue for the four receptionists, the security guides the patients to go to the waiting room and wait until one of the queues gets less than 3 patients. Then one of the patients in the waiting room can go to the queue and wait for a receptionist.

For the first waiting room, we use a "Hold" module to make patients waiting until one of the receptionists can serve the patient. Then, a "Remove" module remove a patient from the waiting room and let the patient go to the queue. These two modules are shown in Figure 11 and Figure 12.

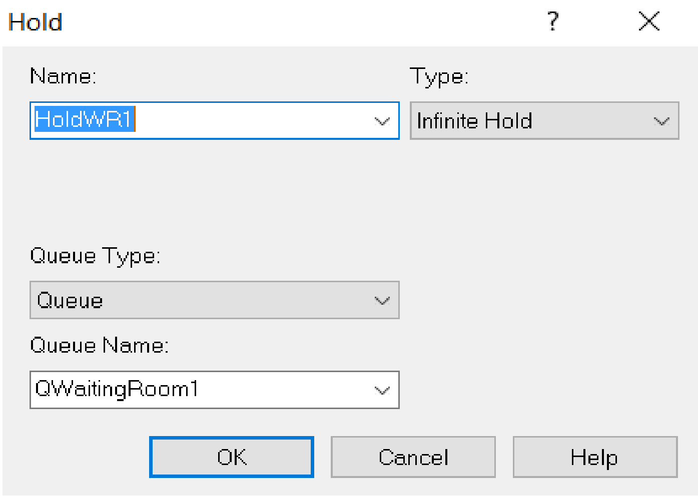

Figure 11: The hold module for the waiting room 1

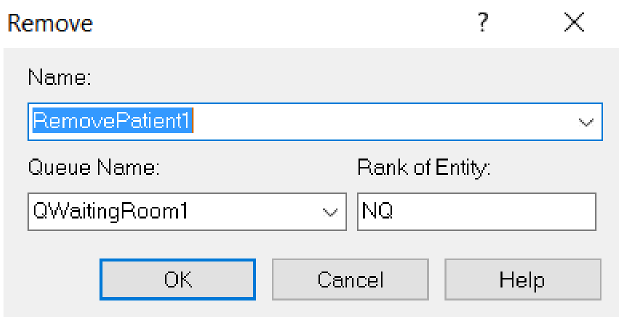

Figure 12: The remove module

After the receptionists, there is another waiting room where the patients wait until the doctor call them. This waiting room has the same module as the previous one (Figure 11).

As soon as the doctor calls a patient, one of the second set of receptionists go to the second waiting room and call the patient. Then this receptionist accompanies the patient to the doctor's room. This setting in the simulation is implemented using the "Advanced transfer" modules. We define four transporters which are the second set of receptionists. When a doctor call patients, in the simulation, a request send to the transporters and one of them accompany (carry) the patient to the doctor's room and then a "Free" module makes the receptionist (transporter) free and ready for the next job.

We define the doctor resource as a set of doctors and their consultation is simulated by using a "Process" module (Figure 13). The doctors are working in a cyclic manner and serve the patients. Their process time is set according to the actual process time which is obtained from the real data collection. Therefore, the consultation is a realistic process for all patients.

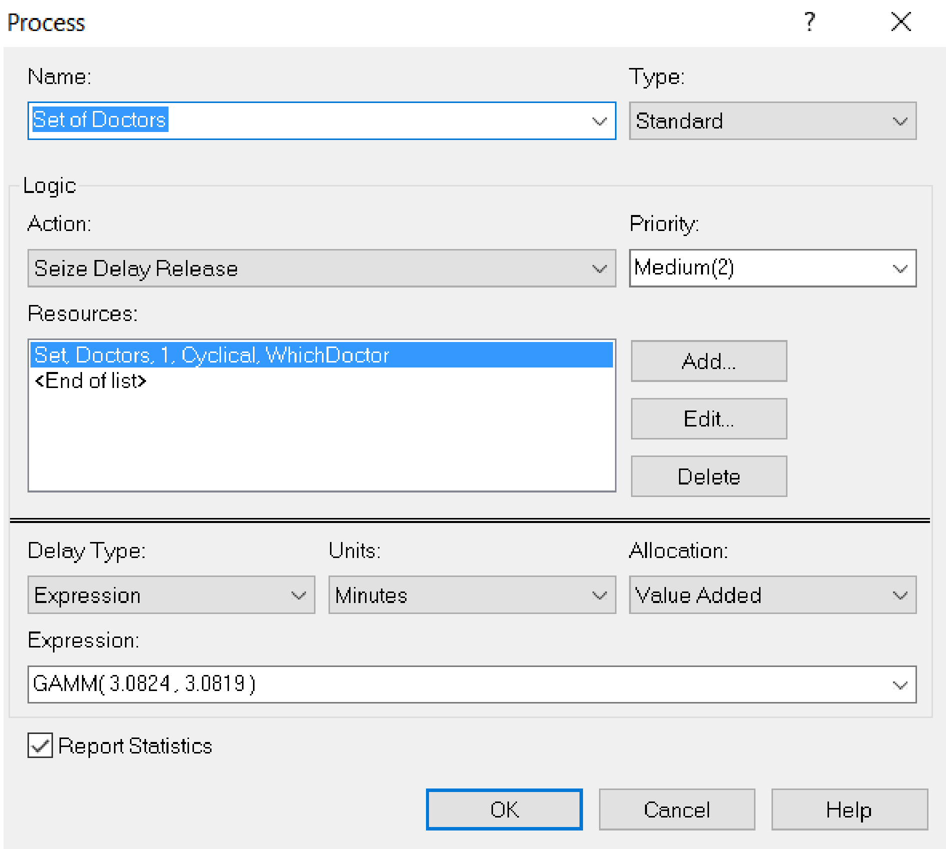

Figure 13: The process module for the doctors

At the end of a consultation, the patient leaves the hospital. In the simulation, we use a "Dispose" module to remove the patient from the simulation and free up the memory.

The results of this simulation scenario are presented in the result section.

4.3 Simulation of to-be scenarios

We use the same parameters as the as-is simulation for the simulation of the to-be scenarios. We proposed three scenarios for the to-be: 1) adding a self-check-in machine with the same number of receptionists, 2) 50% of patient use the self-check-in machines, and 3)66% of patient use the self-check-in machine.

4.3.1 To-be layout

In the as-is layout, we find a location for the self-check-in machine between the entrance and the receptionists. This location is near the entrance door and can be accessible for the patients. Figure 14 shows the to-be layout.

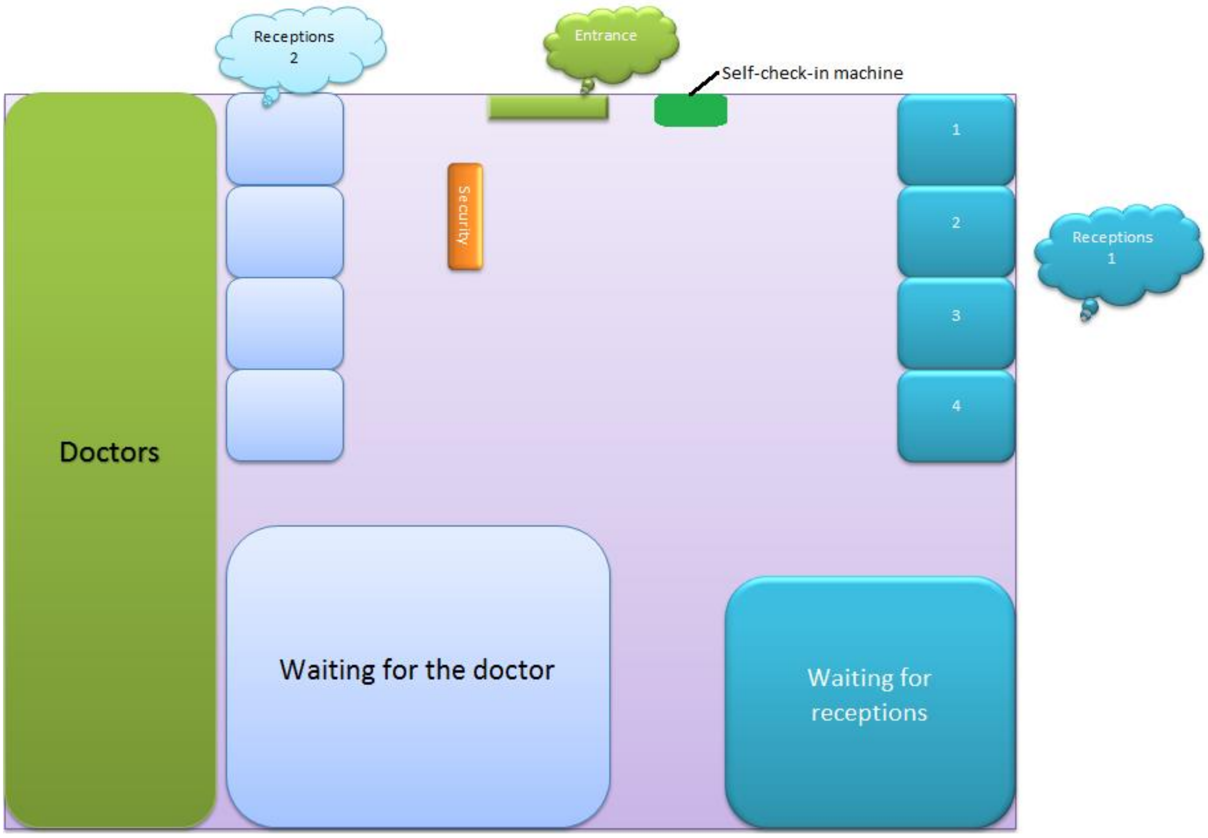

Figure 14: The to-be layout

In this layout, the dark green place is the location of the self-check-in machine. According to the proposed scenarios, we place the self-check-in machines in this location.

4.3.2 To-be swim lane

The new swim lane for the to-be scenarios is shown in Figure 15. In these scenarios, the security and the receptionists help the patients to use the self-check-in machines. In addition, they also do their previous job according to the as-is process.

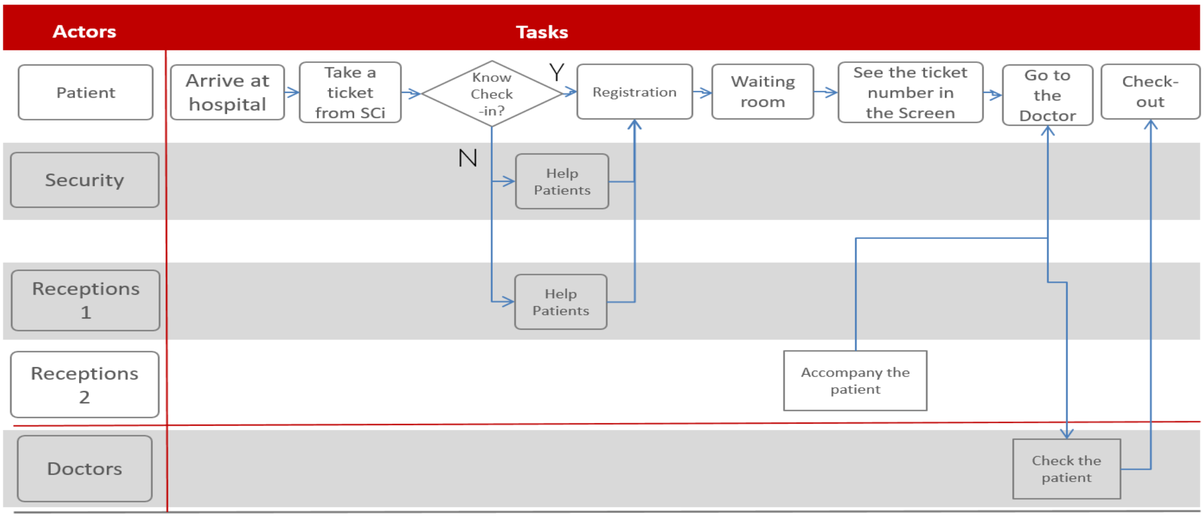

Figure 15: The to-be process

4.3.3 To-be simulation

For simulating the to-be scenarios, we proposed the utilization of self-check-in machines. To simulate this kind of machines, we use a "Process" module in the simulation for each self-check-in machine. There is also a queue for each machine. We also suppose that 50% of patients use the self-check-in machine while other use the previous flow (as-is) at the hospital (using a "Decide" module). The self-check-in machines are modelled by a "Process" module. We consider that each patient spends two minutes on a self-check-in machine, on average. This process is shown in Figure 16.

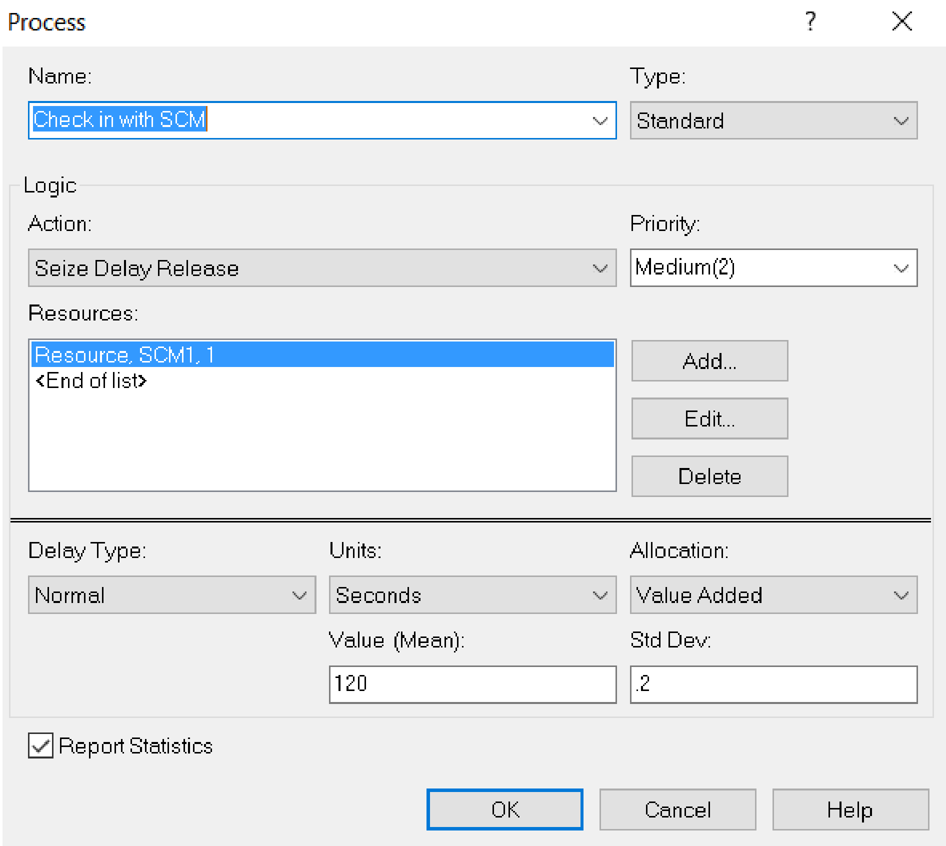

Figure 16: The process module for a self-check-in machine

We have two scenarios for the self-check-in machines: 1) Using one machine with four receptionists, and 2) Using two machines and two receptionists. The use of two machines is also having two different scenarios: 1) Share the patients between self-check-in machines and receptionists equally (50/50), 2) Share the patients between self-check-in machines (66%) and receptionists (34%).

5 Results

Before going to the results, we define a few parameters for our analysis. These parameters and their meanings are listed below:

1- T1: The time difference between patient arrival time to the hospital and the patient being served by a reception,

2- T2: The waiting time of a patient after being served by a reception and before the patient entering the doctor room,

3- T3: The time that a patient being served by a doctor,

4- T4: The total time that a patient is in the hospital.

According to these parameters, we are going to analyse them for different scenarios in the following sections.

5.1 Data analysis of as-is scenario

The first step to obtaining results was data analysis of the as-is scenario. This result is shown in this section.

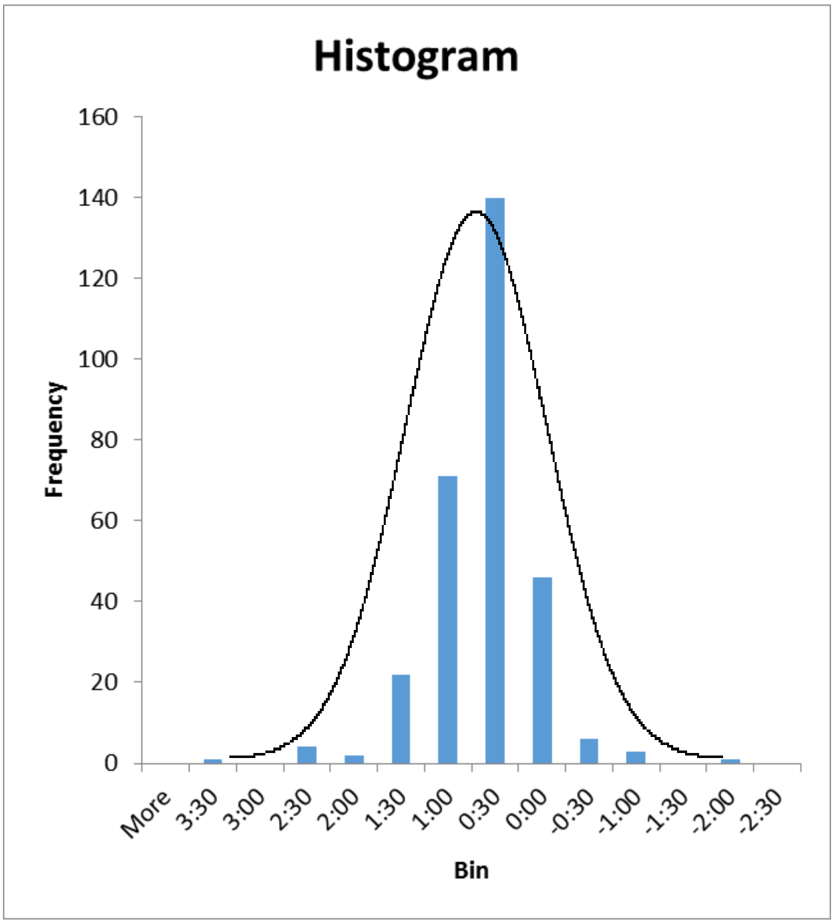

Figure 17: The time difference between arrival and consultation times (hour: minute)

Figure 17 shows the patients' arrival time to the hospital. The x-axis shows the time difference between their arrival time and their consultation time. A positive value shows that the patients arrive sooner than their consultation time while a negative value shows that patients arrive late. The x-axis values are shown in hours and minutes. As it can be seen, a normal distribution is fitted to the arrival time. This allows us to select the same distribution for the patients' creation in the simulation.

In addition, the summary of the analysis for the defined parameters is shown in Table 4.

Table 4: The summary of the data analysis about the collected data in minutes

	T1 (1-5)	*T2 (5-8)*	*T3 (8)*	*T4 (1-9)*
Average	3	42	12	58
Minimum	1	1	2	12
Maximum	25	166	34	181
Standard Deviation	3.86	34.46	6.54	34.33

The values in this table are in hours and minutes. The average time that a patient waits before being served by a receptionist (T1) is 3 minutes. In few cases when there are no other patients in the queues, a patient immediately after arrival to the hospital goes to a receptionist and so the patient's waiting time is less than 1 minute (0:00). During the lunch time, the receptionists leave their chairs to go lunch. Therefore, the patients should wait in the waiting room until the receptionists come back to work. Because of this, the maximum waiting time for a receptionist is around 25 minutes.

The waiting time that the patients wait in the second waiting room (T2) is another metric that we analyse. In Table 4, the average waiting time in the second waiting room is around 42 minutes. This time has a minimum of 1 minute and a maximum of 2 hours and 46 minutes.

The doctors consult the patients (T3) for a minimum of 2 minutes while the maximum visiting time is 34 minutes. The average time that a doctor visits a patient is around 12 minutes.

In a result, the total time that a patient stay in the hospital (T4) has a minimum of 12 minutes and a maximum of 3 hours and 1 minute. The average of T4 is 58 minutes.

In addition to this summary, Figure 18 shows the difference of the patients' arrival time to the hospital and their consultation time for a day and for all patients. Only a few patients have a negative value which means they arrive late.

Another metric that is important for reaching high patients satisfaction is the total time that a patient waits in the hospital before seeing the doctor. Therefore, the waiting time is from the patient's arrival time to the patient entering into the doctor's room. As the waiting time also affects the hospital performance, we calculate it only for the patients that arrive at most 15 minutes before their consultation as these 15 minutes is instructed in their letter. The patients that arrive too soon to the hospital cannot be considered for the calculation of the waiting time.

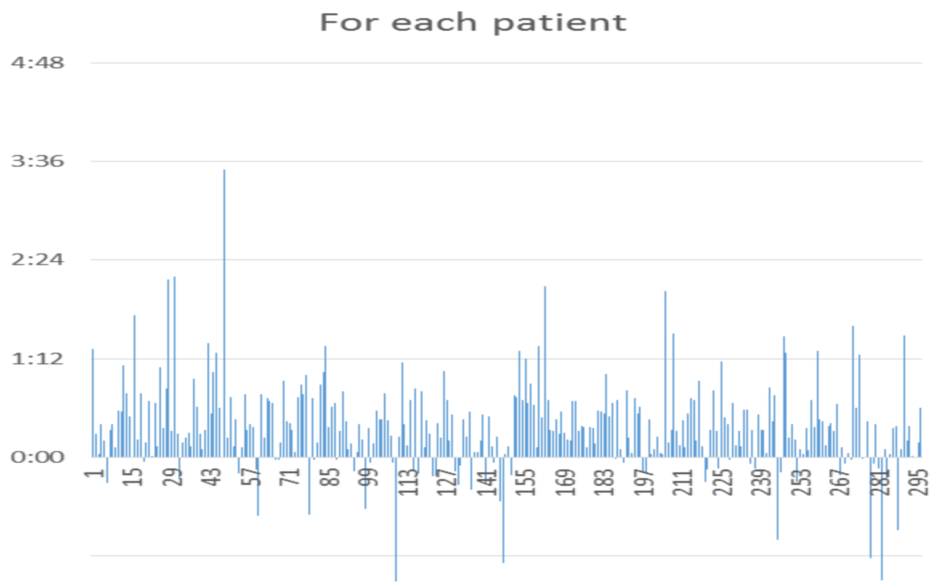

Figure 18: The distribution of the time difference between patients' arrival time and their consultation time

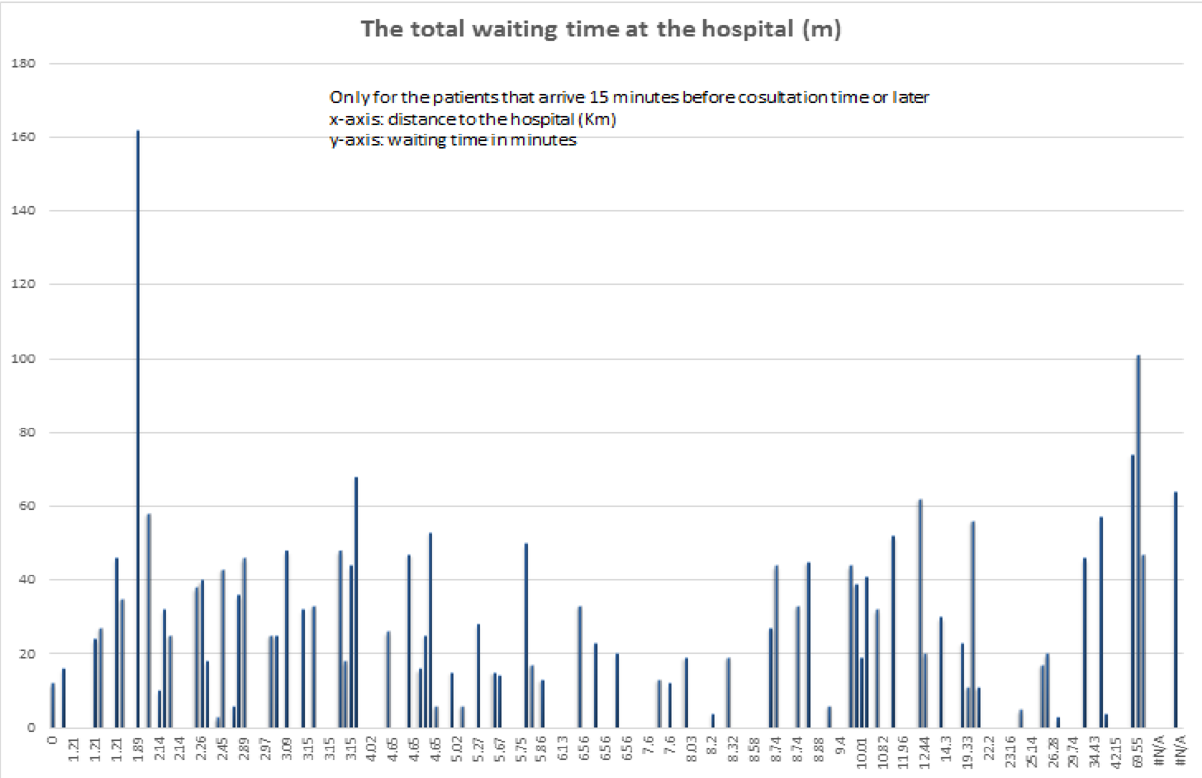

Figure 19: The waiting time for patients arrive at most 15 minutes before their consultation time

Figure 19 shows the waiting time in minutes. The average waiting time for all patients is 31 minutes. This time is compared with the same metric obtained from other scenarios to see the improvement in waiting time.

5.2 Simulation of as-is

For the purpose of the validation of simulator with the real data, we implement the same scenario of as-is and the results are shown in this section. The most important metrics are the metrics in Table 4. Therefore, we calculate the same metric for the simulation of as-is and these results are shown in Table 5. These results especially for the T1, T3, and T4 are the same as real data collection at the hospital. The only difference is for the T2. This happens because there are patients that after check-in at a receptionist go to section like doing an exam and then they come back to the second waiting room. Therefore, in the real data collection, the T2 is longer than the T2 in the simulation.

Figure 20 shows the number of patients that are checked-in by each receptionist in the simulation of the as-is scenario. This behaviour is the same as the real scenario because the security always fills the first receptionist, then the second and the third. Therefore, the number of patients being served by the first receptionist is more than the two other receptionists. The fourth receptionist is also responsible only for the priority patients who are less than the normal patients.

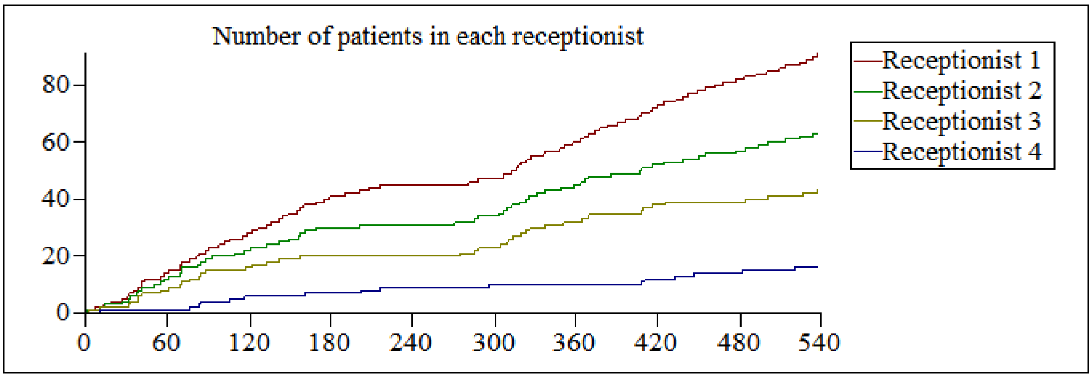

Figure 20: The number of patients being served by each receptionist during the working hours (as-is)

Figure 21 shows the number of patients in the first waiting room. This waiting room is only used when the queues for all receptionists are crowded. In the real scenario, this only happens during the lunch time when the receptionists are left for lunch. As it can be seen, only around 14:00, there are patients waiting for the receptionists to come back to work.

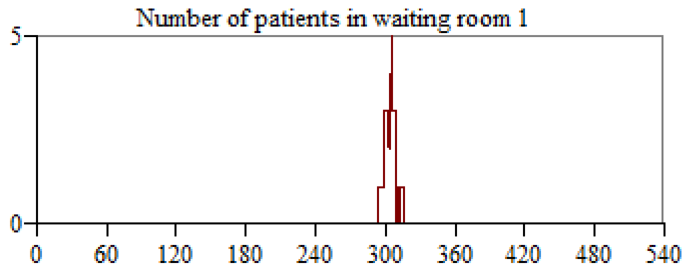

Figure 21: The number of patients in the first waiting room during the working hours (as-is)

Figure 22 shows the number of patients in the second waiting room where patients are waiting for doctors. During the lunch time, the patients are already called and went to a doctor or they didn't come to the hospital for their appointments in the afternoon.

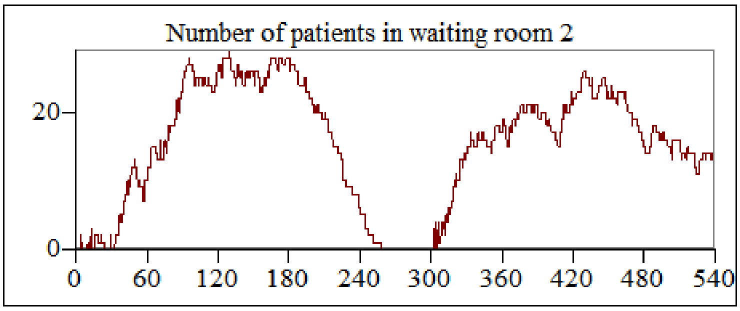

Figure 22: The number of patients in the second waiting room during the working hours (as-is)

Table 5: The result of simulation of as-is scenario

	T1 (1-5)	*T2 (5-8)*	*T3 (8)*	*T4 (1-9)*
Average	2.22	16.9	15.31	40.46
Minimum	0.41	1.08	3.04	9.44
Maximum	43.99	180.56	42.54	217.31
Standard Deviation	2.36	7.37	0.63	6.13

5.3 To-be: the first scenario

In the first proposed scenario, we place one self-check-in machine which works simultaneously with the as-is scenario (four receptionists) to see what are its effect on the timing metrics that we defined, namely, T1, T2, T3, and T4. The patients are divided between the self-check-in machines and the receptionist equally. Therefore, 50% of the patients use the self-check-in machines and 50% of the patients use the traditional as-is approach for check-in. The result of the simulation is presented in Table 6.

Table 6: The results of the first scenario for to-be in minutes

	T1 (1-5)	*T2 (5-8)*	*T3 (8)*	*T4 (1-9)*
Average	0.78	13.54	15.36	34.57
Minimum	0.41	1.08	2.85	7.82
Maximum	11.63	178.7	41.34	200.77
Standard Deviation	0.58	3.47	0.85	3.33

According to the Table 6, the most improvements are obtained on the T1, T2 and T4 which are the time that a patient check-in, the waiting time at the second waiting room and the total time in the hospital, respectively. The check-in time (T1) is reduced to less than a minute while the patients are waiting at the second waiting room 3 minute less. Therefore, these improvements can also improve the patient's satisfaction with the hospital's services.

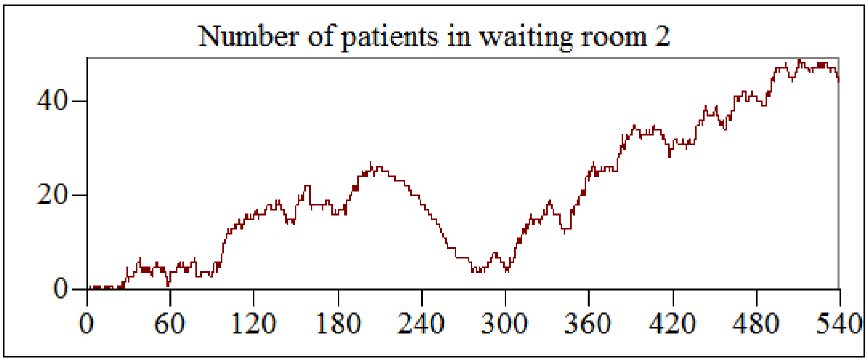

Figure 23: The number of patients in the second waiting room during the working hours

In Figure 23, we can see that the number of patients in the second waiting room is changed during the day. The number of patients is increasing due to fast check-in by a self-check-in machine but still, it has less waiting at this waiting room.

In addition, Figure 24 shows the number of patients being served by each receptionist. According to our observation as well as the simulation scenario, the security always sends the patients to the first receptionist unless it has few (3 patients in the simulation) patients in its queue. Then the security will send the patients to the second receptionist. This scenario is repeated for the second and the third receptionists.

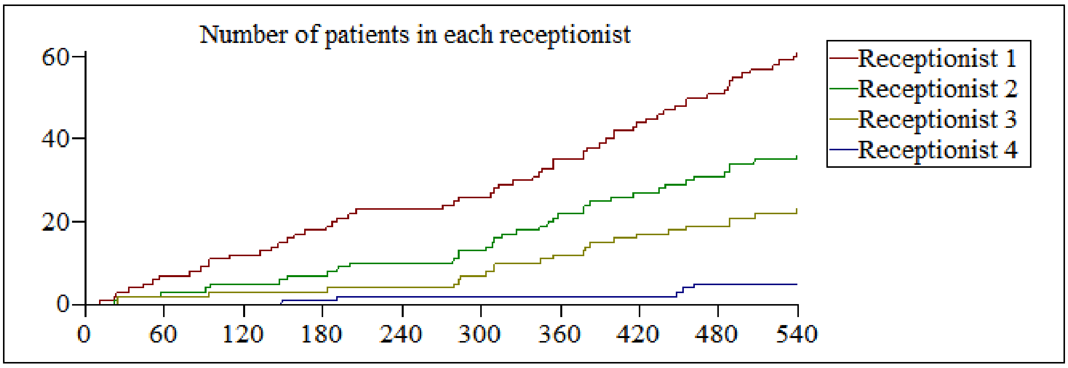

Figure 24: The number of patients being served by each receptionist during the working hours (The first to-be scenario)

Although this approach reduces the waiting time in the second waiting room and the total time in the hospital for the patients, it has a disadvantage which is the high cost due to one self-check-in machine without reducing the number of receptionists. Therefore, we proposed another solution with less number of receptionists who can help the hospital for the development of other services or improvement of the existing ones.

5.4 To-be: the second scenario

In this scenario, we add another self-check-in machine and reduce the number of receptionists to two receptionists. We also share the patients between self-check-in machines and receptionists equally (50/50). The reason for reducing the number of receptionists is to help the hospital using these receptionists for other tasks and services. This is possible by adding self-check-in machines.

Table 7 shows the summary of the results. As it was expected, by reducing the number of receptionists, the check-in time (T1) is increased and in a result, the total time that a patient wait in the hospital (T4) is also increased. This problem can be solved by motivating the patients to use the self-check-in machines more than 50% of the time. We evaluate this scenario in the next section.

Table 7: The results of the second scenario for to-be in minutes

	T1 (1-5)	*T2 (5-8)*	*T3 (8)*	*T4 (1-9)*
Average	5.15	17.22	14.99	40.27
Minimum	0.41	1.08	2.85	8.1
Maximum	85.14	197.62	41.13	244.42
Standard Deviation	3.37	8.66	0.7	8.09

Figure 25 shows the number of patients being served by the receptionists. In fact, we only have one receptionist that can check-in the patients because the second receptionist is only for the priority patients.

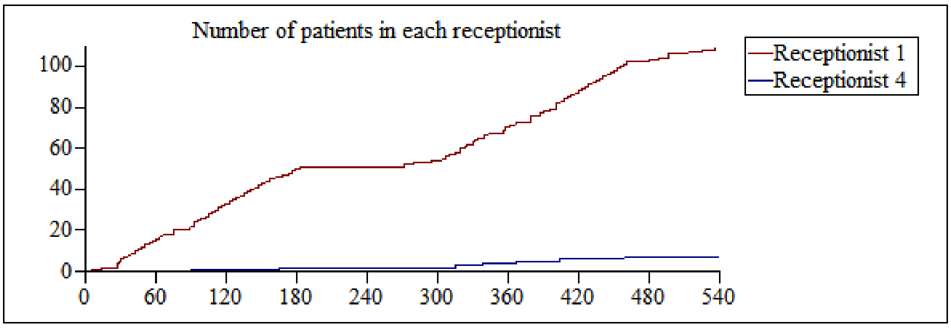

Figure 25: The number of patients being served by each receptionist during the working hours (The second to-be scenario)

Indeed, self-check-in machines are also worked as receptionists. Figure 26 shows the number of patients who used each self-check-in machine. The first machine works more because it is near the entrance door and the patients arrive at the entrance, go to this machine if no other patient using it.

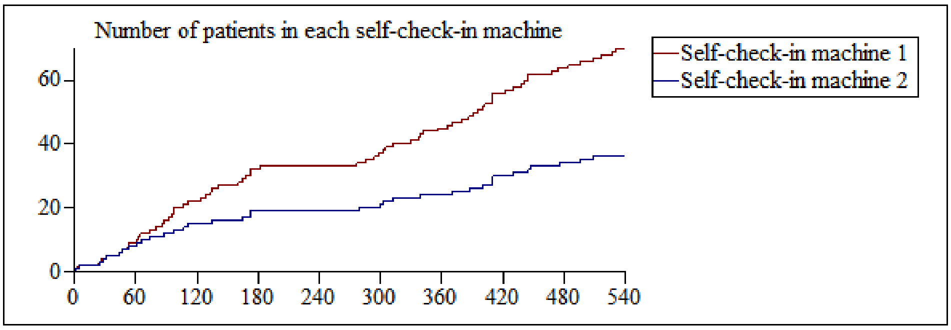

Figure 26: The number of patients using self-check-in machines (the second to-be scenario)

Figure 27 and Figure 28 show the number of patients in the first and the second waiting room. Again, as we expected, these numbers are increased due to less number of receptionists. Although we have two self-check-in machines but only 50% of patients are using them. Therefore, this reduction in the number of receptionist has a negative influence on the waiting time of patients at the waiting rooms and as a result at the hospital. To overcome this problem, we analyse the effect of using the self-check-in machines more frequently by the patients in the next section.

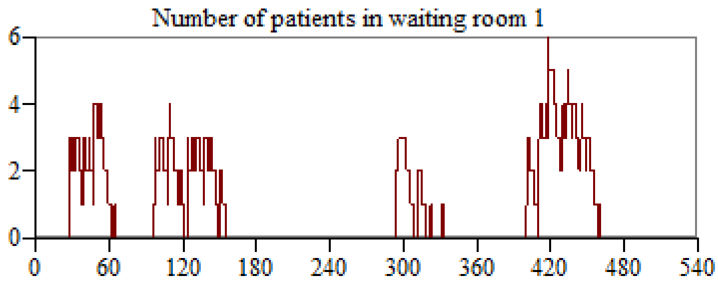

Figure 27: The number of patients at the first waiting room (the second to-be scenario)

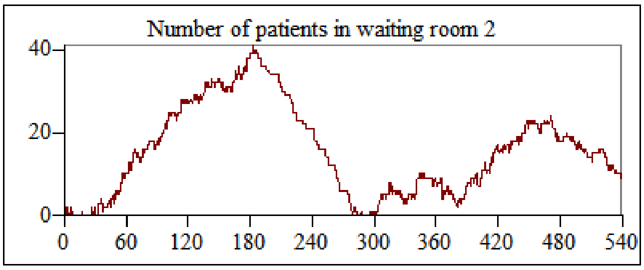

Figure 28: The number of patients at the second waiting room (the second to-be scenario)

5.5 To-be: the third scenario

In the last scenario that we proposed, we have two self-check-in machines that are used by 66% (2/3 of the patients) of the patients and two receptionists. The summary of the result is shown in Table 8.

As it can be seen, the results are positive and we have improvements in all metrics. In this scenario, even with only two receptionists, the total time at the hospital (T4) is reduced while we also have improvement in the patient's waiting time in the waiting rooms.

Table 8: The results of the third scenario for to-be in minutes

	T1 (1-5)	*T2 (5-8)*	*T3 (8)*	*T4 (1-9)*
Average	3.2	12.6	14.39	33.07
Minimum	0.41	1.08	2.58	7.52
Maximum	51.64	163.04	38.98	193.48
Standard Deviation	2.53	4.31	1.22	4.9

Figure 29 and Figure 30 show the number of patients that went to the receptionist or used the self-check-in machines, respectively. In compare to the previous scenario, the number of patients went to the receptionists is reduced while the patients that used the self-check-in machines is increased.

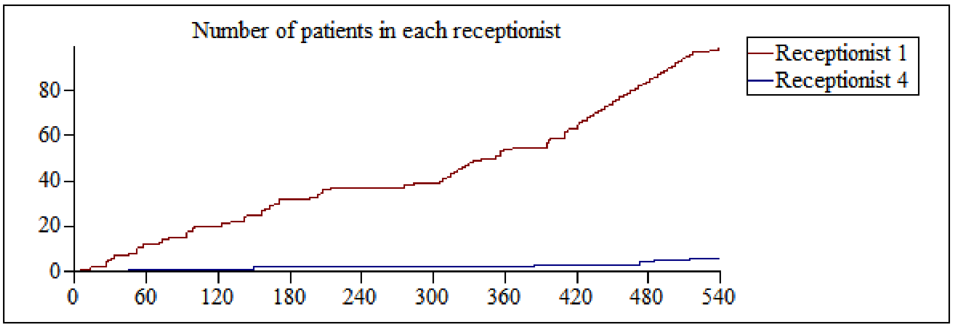

Figure 29: The number of patients being served by each receptionist during the working hours (The third to-be scenario)

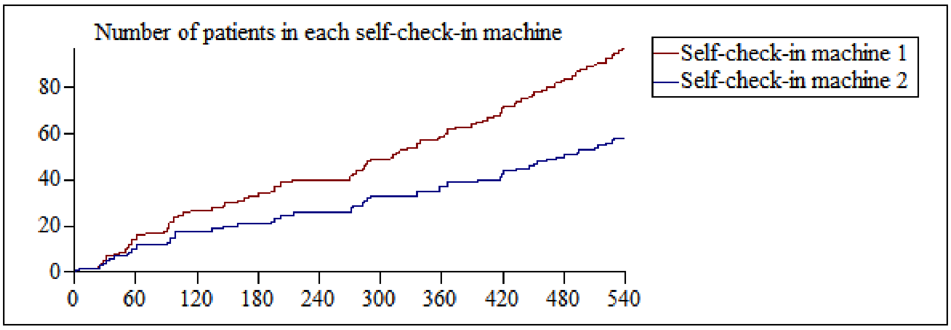

Figure 30: The number of patients using self-check-in machines (the third to-be scenario)

Figure 31 and Figure 32 show the number of patients in the first and second waiting room, respectively. As it is clear, the number of patients at both waiting rooms is also reduced.

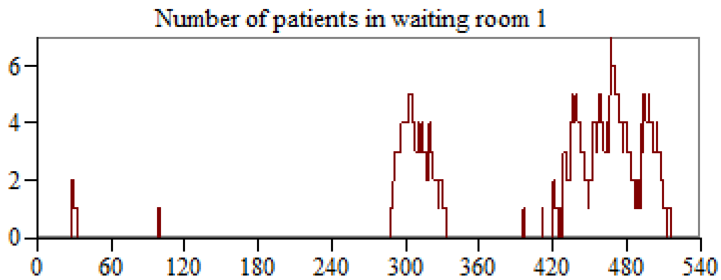

Figure 31: The number of patients at the first waiting room (the third to-be scenario)

These results show that motivating the patients to use the self-check-in machines can reduce their waiting time at the hospital. On the other hand, the hospital also has two receptionists who can be used to improve the current hospital's services or helping the hospital to offer new services to the patients.

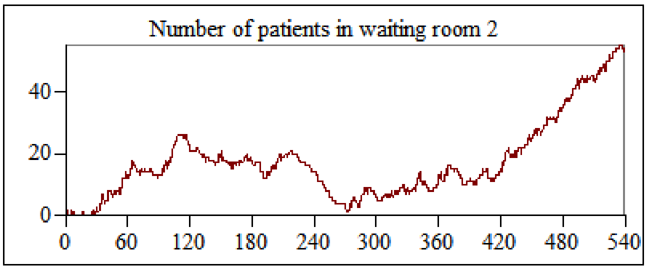

Figure 32: The number of patients at the second waiting room (the third to-be scenario)

5.6 Resource Utilization

We have studied the utilization of receptionists, doctors, and self-check-in machines to present the improvement through using new solutions.

Figure 33 shows the utilization of receptionists, doctors, and self-check-in machines for four scenarios. The doctor's utilization is improved from 90.72% in the as-is scenario to 94.19% in the best solution which is the third to-be scenario.

The receptionist's utilization is also shown that in the as-is scenario, the receptionists are busy only for 40.5% of the time while using the self-check-in machines, they are busy less than 22%. Having this in mind, the receptionists can be used to do other tasks to improve the hospital's services.

On the other hand, at most, the self-check-in machines are also used for 22%. Therefore, there is a possibility of serving more patients by these self-check-in machines. The best setting for the hospital is to use the self-check-in machines and the receptionists with high utilization.

Therefore, to improve the self-check-in machines, we can still increase the use of self-check-in machines for more than 66%. In reality, the hospital can increase the use of self-check-in machines by using advertisements and motivate the patients to use the machines.

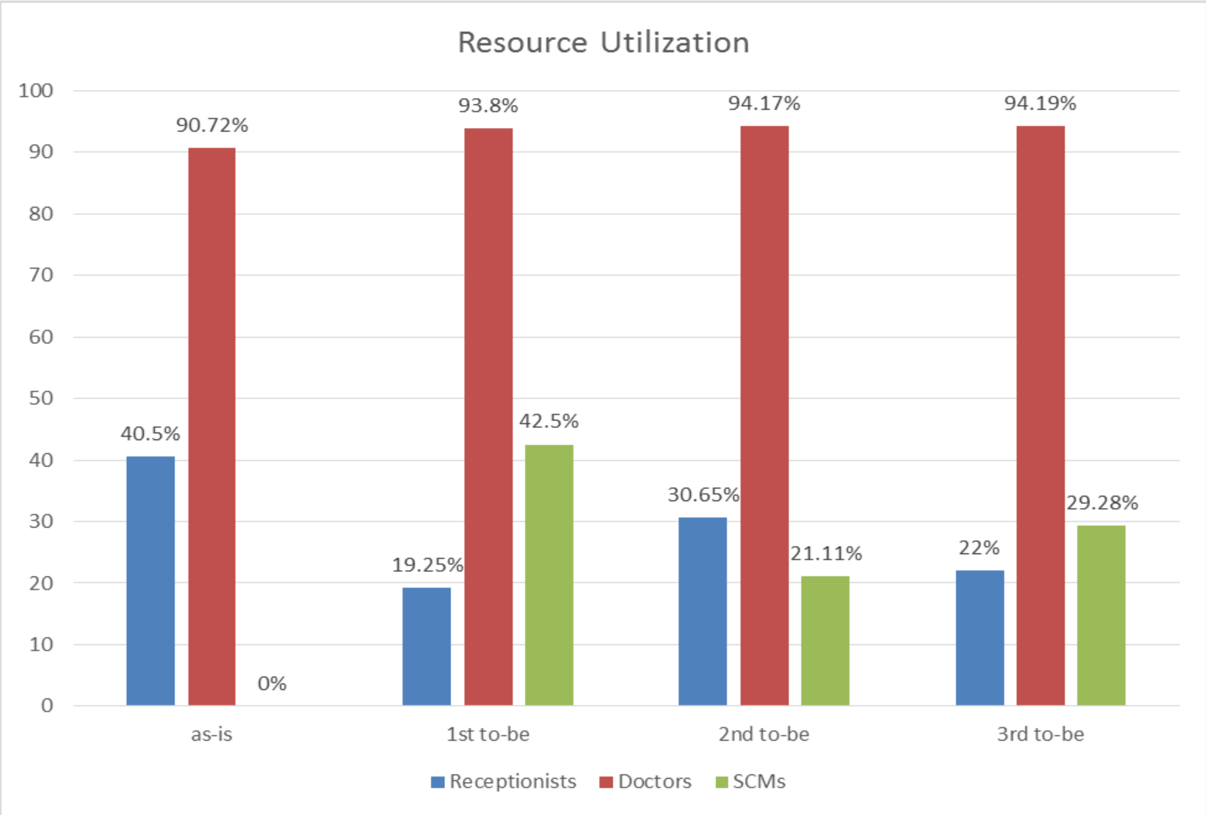

Figure 33: The comparison of the resource utilization for all the scenarios

6 Conclusion and future research

In this project, the patient's admission process at a hospital is studied with a focus on the patient waiting time at the hospital. The main objective of this study is to model and simulate the patient flow at the hospital to improve the operating performance and also improving the quality of the services provided to the patients.

Based on the real data collection and also on the developed simulation model, it is shown that there is a long waiting time for a patient with an appointment at the hospital which can decrease the patient's satisfaction.

Simulation models show that a long waiting time for the patients exists at the hospital. Therefore, three scenarios were considered to improve the patient's waiting time at the hospital, to reduce the required receptionists, and to increase the patient's satisfaction, at the same time.

In the first scenario, a self-check-in machine is added to the patient's check-in process. The results show that adding one self-check-in machine can reduce the total waiting time at the hospital. This reduction is around 18 minutes.

In the second proposed scenario, two self-check-in machines are added while the number of receptionists is also reduced to two receptionists. In addition, the patients are shared between the self-check-in machines and the two receptionists equally (50/50). The evaluations results show that this scenario maintains the same results as the first scenario while reducing the number of required receptionists for the patient's check-in process. This reduction can help the hospital to have more staffs for improvement of the current services and also to implement new services.

Finally, the third scenario is proposed which is increased the use of the self-check-in machines. The third scenario is similar to the second scenario while the patients use the self-check-in machines for 66% of the time. This will happen when patients get to use the self-check-in machines more frequently. The results of the evaluation show that this proposed solution can reduce the total waiting time of patients to 34 minutes, which is 6 minutes less than the other scenarios. Therefore, our final solution is the third solution because it reduces the total waiting time at the hospital while let the hospital uses two other receptionists for other tasks like the implementation of new services or improvement of the current services. This is to ensure the high quality of delivered services to the patients as well as to reach the high level of patient's satisfaction.

In conclusion, the new scenarios for the to-be, improve the resource utilization. The doctor's utilization is increased around 4%. In addition, the results show that the receptionists and self-check-in machines have a higher capacity to be used by more patients.

In response to our research questions, the as-is scenario cannot achieve a high patient satisfaction because they should wait at the hospital around one hour for a prescheduled consultation. By using the self-check-in machines, we improve this time to around half an hour which has a high influence on the patient satisfaction and improve it. Consequently, we suggest the third scenario as the best solution which can improve the total waiting time at the hospital and at the same time reduce the hospital cost by reducing the number of receptionists. Therefore, having two receptionists and two self-check-in machines is the best combination for the hospital to achieve both objectives: reducing costs and increasing the patient satisfaction.

6.1 Future work

The next step in this research project is to test the applicability of simulation model developed that can be used by other departments in the hospital as well as by either public or private healthcare. Furthermore, the use of the simulation model to study the resource allocation such as reducing doctor's idle time and staff allocation and scheduling at the hospital is another interesting line of research.

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APPENDIX A: The Simulation layout