SIMULATION OF THE AMBULATORY PROCESSES IN THE BIGGEST BRAZILIAN CARDIOLOGY HOSPITAL: A PETRI NET APPROACH

Fábio Lima
Centro Universitário FEI, Brazil
E-mail: flima@fei.edu.br

Matheus Felipe Cortez
Centro Universitário FEI, Brazil
E-mail: mfrcortez@hotmail.com

Patricia Pessoa Schmidt
Centro Universitário FEI, Brazil
E-mail: patri_schmidt@hotmail.com

Ana Karoline Silvério
Centro Universitário FEI, Brazil
E-mail: anakaroline.silverio@gmail.com

Alfredo Manoel da Silva Fernandes
Incor-Universidade de São Paulor-HC, Brazil
E-mail: alfredo.fernandes@incor.usp.br

João Chang Júnior
Centro Universitário FEI, Brazil
E-mail: chang.joao@gmail.com

ABSTRACT

This paper presents a simulation of an ambulatory processes using timed Petri net (TPN). The simulation considers the flow of patients in the biggest Brazilian cardiology hospital. The TPN is used as a decision support system (DSS) to improve the processes, to reduce the waiting time of the patients in the ambulatory and in this way to assure a high-quality service to the patients. Simulations were carried out using the software Visual Object Net++. This is a free software and therefore the presented solution is a low-cost solution. Providing a low-cost solution has a huge importance in this work since the hospital is kept from the government efforts and operates with limited financial resources.

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The patients' flow in the hospital can be faced as a service and the modelling and optimization of these services bring more efficiency to the system as well as improve the human factors involved. The results proved that some changes could be made in the processes to improve the performance of the system.

Keywords: Discrete Event Simulation; Applications in Healthcare Systems; Petri Nets; Modelling; Simulation Applications

1. INTRODUCTION

Hospital care and organization in ambulatory sectors of hospitals are the main critical points of the Brazilian public health system. According to the City Hall, the number of people who go to ambulatories in São Paulo, one of the largest conurbations of the world, is huge when compared to other hospital sectors. Thus, it is extremely important to improve the flow and optimize individuals' length of stay in the system.

Even though in Brazil the total per capita spending on healthcare grew 102.8 % between 1999 and 2009 (Araujo, Barros & Wanke, 2014) the public health system in Brazil still suffers from limited resources. For this reason, finding cost-effective solutions that improve the performance of public health systems is crucial.

A recent survey performed by one of the most important survey institute in Brazil showed that the public health care system is considered the most important problem in the year of 2019 (Datafolha, 2019). Figure 1 presents the graphical results of the that survey.

The main objective of this study is to analyze quantitatively the performance of the ambulatory sector of a public hospital specialized in cardiology, using the Petri Net tool as a Decision Support System (DSS). The patient's flow (Ling & Schmidt, 2000; Wang & Zeng, 2008; Wang, Li & Howard, 2013; Rohleder et al., 2011) of the ambulatory is modelled. The diagnosis obtained through this tool were interpreted to reach a qualitative solution.

Petri Nets (PN) (Murata, 1989) is used in this study, which is a tool to model and project systems, using a mathematical representation of the system. In the Petri Net model, two events that are enabled and do not interact may occur independently (parallelism or competition). It is not necessary to synchronize events, unless it is required by the system being modelled. This way, these events become ideal to model systems of distributed control, with multiple processes executing concurrently in time. From a logical perspective, the only important property of time is to define a partial order of events occurrence.

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Considering the theoretical context of Petri Nets, this study initially explores the techniques of modeling and analysis of health systems (HS) (Xiong, Zhou & Manikopoulos, 1994) based on techniques of discrete events simulation. It is sought to highlight the potential that the Petri Net has as a technique to characterize logical structure and systems' dynamic behavior, in an accessible language to different professionals, being efficient in its analysis.

The health system is classified as a system of discrete events defined by activities from doctors, nurses, technicians, and patients, among others. They are mapped through states of the health systems, whose evolution (change of states) may be defined by the occurrence of discrete events (Rau et al., 2013).

Thus, a simulation tool may raise its dynamic behavior through some explicit rules and an adequate model, allowing a safe and economic analysis of the decisions that affect it.

The Petri Net, among other tools, is one that presents several appropriate tools to model the health service. As previously mentioned, it has a relatively "simple" graphic representation, which allows a precise interpretation and makes dialogue among teams that participate in the system analysis easier. Another advantage is the ability to build the model in different hierarchical levels of abstraction (with higher or lower level of details). Finally, it specifies cases in which items (patients, doctors, medical charts, equipment, etc.) interact in situations of conflict (occurrence of competition among items for the same resource), parallelism (occurrence of events in parallel), and sequentialization (occurrence of events in sequence).
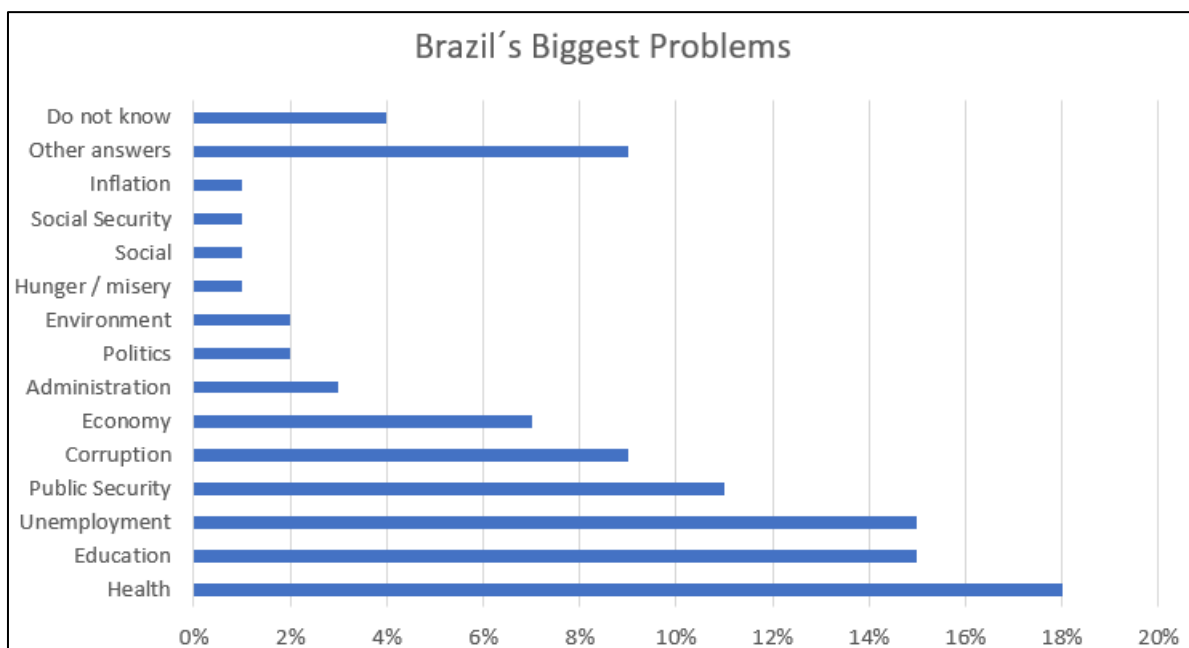

Figure 1: Brazil's problems according to citizens
Source: adapted from: Datafolha (2019)

The paper section structure is: related work; the basics of PN; the ambulatory flow description; the Petri net models; chosen simulation results and finally, the conclusion.

2. RELATED WORK

As mentioned before, the HS can be modelled and analyzed as a discrete event system. Several articles use this approach to propose improvements in such systems using different methods. Some of them uses the Petri net as the main tool of modelling. Following some related works are presented in chronological order considering several aspects in HS. The comments highlight the main features and findings in each article.

An analysis of the literature in health care is provided by (Brailsford et al., 2009). The authors separated the articles in several groups to discuss the consistence of the literature in that area. It is noticed that one of the most used methods to face health care problems is the discrete event simulation.

Another review of using Discrete Event Simulation (DES) in HS is presented in (Günal & Pidd, 2010). The authors discussed the increase number of papers in this subject from 2004 e also highlight that most of the papers addressed specific models. General models are still missing.

A TPN solution is proposed by (Dotoli et al., 2010) applied to a pulmonology department in a hospital, focusing on the department workflow and the drug distribution system.

A stochastic PN is proposed in (Leite et al., 2010) to model the medical care provided to patients in the intensive care unit.

In (Astilean et al., 2010) a flexible support system to offer warnings, therapies and recommendations for remote patient surveillance is presented. An inference mechanism based on Petri nets and Fuzzy theory was designed and experimentally implemented for diseases evolution supervising purposes.

Another work that used DES applied to hospital problems is found in (Rys, 2011). He used the Arena software (which is not a free software) to analyze the arrival pattern of patients in an ED.

An analysis of complex processes in nursing and caregiven services is presented in (Hiraishi et al., 2012). After that, the authors propose an implementation based on object-oriented Petri net.

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In (Mahulea, Garcia-Soriano & Colom, 2012) HS is modelled using modular Petri nets. The first module modelled the medical protocols as state-machine Petri nets and the second add the (shared) medical resources.

In (Fanti et al., 2013), a three-level strategy of solving HS problems is proposed. PN is used in the three levels, which are modeling, optimization and, simulation and decision.

Several works consider the use of Petri nets for solving problems related to the health systems (HS). In (Fanti & Ukovich, 2014) a review of techniques and models applied to HS are made. The use and importance of TPN is demonstrated.

An application of PN applied to health care at home is presented in (Fanti et al., 2014). The proposed model detects troubles as accidents and inform the doctor, the family or the emergency system.

Evolutionary PN was used by (Suzuki & Hamagami, 2014) applied to a team medical care support.

A PN model for primary HS systems is proposed by (Mahulea et al., 2014). In that work, the authors modelled the diseases and medical protocol using a state-machine Petri net.

A modeling methodology of the primary healthcare system based on Petri nets is presented in (Mahulea et al., 2014). A disease of a patient is diagnosed and cured by following a sequence of treatments and cares belonging to a medical protocol.

The researches (Emami & Doolen, 2015) conducted a work in a hospital concerning the development of a set of forward-looking metrics at the operational level that should drive all aspects of performance. They used Analytic Hierarchy Process (AHP) to determine the most important learning and growth categories and metrics within each category.

Differently of this proposed work, (Cho, Song & Yoo, 2015) proposed and outpatient process analysis based on process mining. The idea was to identify the patterns from the hospital data for future use in the hospital strategies.

A forecast model for Emergency Departments (ED) using regression and Neural Networks was carried out by (Gul & Guneri, 2016). The work used the data from a public hospital in Istambul and the results achieved aimed at providing the managers of the hospital an accurate forecast to take decisions on ED.

The objectives of the paper from (Hsieh, 2017) are to propose a viable and systematic approach to develop a scalable and sustainable scheduling system based on multi-agent system

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(MAS) to shorten patient stay in a hospital and plan schedules based on the medical workflows and available resources. To achieve interoperability and sustainability, Petri Net Markup Language (PNML) and XML are used to specify precedence constraints of operations in medical workflows and capabilities of resource agents, respectively.

The work of (Khayal & Farid, 2017) is focused on patients with chronic diseases rather than the traditional models based on patient throughput. paper develops a healthcare dynamic model for personalized healthcare delivery and managed individual health outcomes. It utilizes a heterofunctional graph theory rooted in Axiomatic Design for Large Flexible Engineering Systems and Petri nets.

The paper from (Mahulea et al., 2018) presents a modular approach for modeling healthcare systems using Petri nets. It is shown that a healthcare system can be constructed by different modules whose inputs and outputs are connected according to their geographical location. A public healthcare area in Zaragoza is considered as a use case.

The work of (Li et al., 2018) focuses on a cloud healthcare system, which is a novel integrated healthcare system by the technique of Internet in very recent years. A Petri net is presented to describe the relationship among medical process and resources in that integrated healthcare system.

The paper of (Bernardi, Mahulea & Albareda, 2019) presents a decision support system to be used in hospital management tasks which is based on the clinical pathways. They propose a very simple graphical modeling language based on a small number of primitive elements through which the medical doctors could introduce a clinical pathway for a specific disease.

The paper from (Zhou, Wang & Wang, 2019) presents a generic and resource oriented stochastic timed Petri Nets (STPN) simulation engine that provides all critical features necessary for the analysis of service delivery system quality vs. resource provisioning. The power of the simulation system is illustrated by an application to emergency health care systems.

3. METHODOLOGY

This methodological work is quantitative and exploratory. The methodological approach adopted is modeling and simulation, comparing quantitatively the results obtained from the computer simulation of two laboratories in the largest cardiology hospital in Brazil. The use of Petri nets and free software promoted low-cost analysis for the hospital as a support

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in its decision-making. The results show the impact of the proposed solutions on the performance of the outpatient clinics.

4. BASICS ON PETRI NETS

Petri nets are a graphical and mathematical modeling tool applicable to many systems (Murata, 1989). The conceptual paradigm of Petri nets deals inter alia with modeling, logical analysis, performance evaluation, parametric optimization, dynamic control, diagnosis and implementation issues (Silva, 2013). This work uses TPN for modeling the workflow in a Brazilian cardiology hospital. Following are presented the basis of TPN extracted exactly as appears in (Fanti et al., 2013; Peterson,1981).

Definition 1: A TPN (Peterson, 1981) is a bipartite digraph described by the five-tuple *TPN = (P, T,* Pre*,* Post*,* F), where *P*, *T*, Pre, Post, and F are defined as follows:

a) *P* is a set of places with $|P| = m$.

b) *T* is a set of exponential transitions with $|T| = n$.

c) Matrices **Pre** : $P \times T \rightarrow \mathbb{N}^{m \times n}$ and **Post** : $P \times T \rightarrow \mathbb{N}^{m \times n}$ are the *pre-* and *post-incidence matrices*, respectively, that specify the arcs connecting places and transitions. More precisely, for each $p \in P$ and $t \in T$ element, **Pre**(p,t) [**Post**(p,t)] is equal to a natural number indicating the arc multiplicity if an arc going from *p* to *t* (from *t* to *p*) exists, and it equals zero if otherwise.

d) Function **F**: $T \rightarrow \mathbb{R}_+$ specifies for each exponentially distributed timed transition $t_j \in T$ the average firing delay, i.e., **F**$(t_j) = 1/\lambda_j$, where λ_j is the parameter of the corresponding exponential distribution.

Note that $\mathbb{N}$ is the set of nonnegative integer numbers, and $\mathbb{R}_+$ is the set of nonnegative real numbers.

The m $\times$ n incidence matrix of the net is defined as C = **Post** - **Pre**. Moreover, for the pre- and postsets, it is used the dot notation, e.g., $^{\bullet}p = \{t \in T : \textbf{Post}(p, t) > 0\}$ is the transition preset of *p*.

The state of a TPN is given by its current marking, which is a mapping $\mathbf{M} \rightarrow \mathbb{N}^m$, assigning to each place of the net a non-negative number of tokens. **M** is described by a |P|vector, and the *i*th component of **M**, indicated with **M**i, represents the number of tokens in the *i*th place *p*i $\in P$. A TPN system <TPN,**M**0> is a TPN with initial marking **M**0. A transition

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tj $\in T$ is enabled at a marking **M** if and only if (iff), for each p_i $\in$ •tj , **M**$_i$ $\geq$ Pre(pi, tj) holds, and the symbol **M**[tj> denotes that tj $\in T$ is enabled at marking **M**. When fired, tj produces a new marking **M'**, denoted by **M**[tj>**M'** that is computed by the PN state equation **M'**=M+ C$\vec{t}_j$, where $\vec{t}_j$ is the *n*-dimensional firing vector corresponding to the *j*th canonical basis vector.

To solve the confliction transition problems, probability values are assigned to edges connecting places and the multiple transitions in their postset. Hence, function RS: P×T $\rightarrow$ $\mathbb{R}_+$ associates a probability value called random switch to conflicting transition edges.

A TPN system is denoted by the couple <TPN,**M**0>.

5. AMBULATORY FLOW DESCRIPTION

The ambulatory is divided into two parts: the General, which is the gateway of patients at the ambulatory, and whose focus is to provide an initial treatment; and the Specialties, which aims at continuing the treatment of those patients who did not receive discharge from the General ambulatory.

5.1. General Ambulatory

Patients may be received by the SUS (National Health System) of São Paulo and all queries have an appointment.

Initially, a new patient will enter the General ambulatory. On the appointed day, he must go to the entrance counter and fill your registration form to then wait for the query in the waiting room. After the consultation, the patient should return to counter and remove a chip on which the information will be the next steps of treatment. Generally, the doctor asks some exams, which can be done in the clinic and the patient bring them back in the query. There is a counter to input, two for requesting the return, registration or discharge and five offices that will serve patients waiting at the waiting room.

5.2. Specialties Ambulatory

Once registered, the patient will go to treatment in Specialties ambulatory that aims at serving patients in different offices depending on their specific problem. This ambulatory has 19 Specialties and follows the same dynamics of the General: the patient, with an appointment, arrives on the counter and waits at the waiting room; after being served, he goes to a counter in the ambulatory entrance and removes the sheet that contains the information of the next steps.

There is also the possibility of returning to the Specialties ambulatory. Depending on the severity of the patient's problem, the doctor may request that it conduct exams, or even forwards it to the surgery room. In this case, after surgery, the patient should mark a return for a follow-up. If the patient does not show more symptoms, he gets a medical discharge. Figure 2 presents a flowchart of the real condition of both General and Specialties ambulatory.

5.3.   Data Set

The data from the General Ambulatory are presented in tables 1 and 2. Table 1 presents the ambulatory patients entrance data and 2 presents the awaiting time of the patients (in hour:minute:second format). The data from the Specialties Ambulatory are presented in tables 3 and 4. Table 3 presents the ambulatory patients entrance data and 4 presents the awaiting time of the patients (in hour:minute:second format).

6.   PETRI NET MODEL

The Petri net model was developed to the ambulatories using the Visual ObjectNet ++ software. The transition times mean the time of each step, in minutes, from table 2 and 4. The values presented in the positions mean the flow of people during the month of April. This month was chosen because it represents the most critical situation in terms of number of patients.
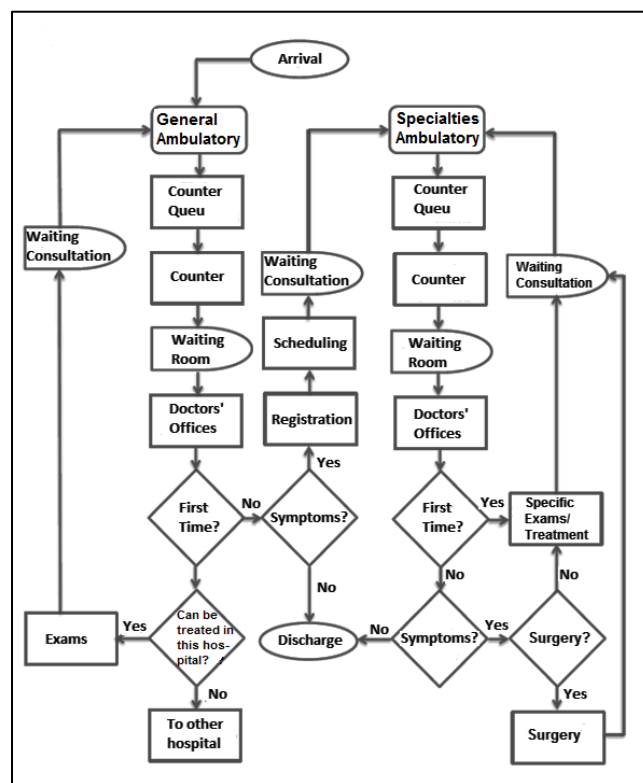

Figure 2: Ambulatories flowchart

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6.1.   General Ambulatory

The beginning of the General ambulatory process is presented in Figure 3.

New patients represented by New Arrivals position (NA) and patients with scheduled return, represented by Return Arrivals (RA), coming into the system and are leaded to the Entrance Counter (EC), when it is free (ECF). To define the service order in EC, synchronizers (S1 and S2) were used, allowing patients to return to EC along with others. If there is no return patient, Arrivals Free Return position (AFR) remains with the token and the simulation usually continues with new patients. The position Awaiting Consultation (AC) indicates that the patient is awaiting from the moment it takes the return guide to re-enter the system.

After entering the EC, the patient goes to the Waiting Room (WR). To facilitate the construction of the model, the position Distribution (DIST) was created and the Waiting Room (WR) was divided into five units. However, this adjustment does not change the result of the simulation. Again, it was used synchronizers (S3, S4, S5, S6 and S7) to direct patients to doctor's offices.

After waiting the average waiting time, the patient enters in one of the Doctors' Offices (O1, O2, O3, O4 or O5), and after the end of the consultation, is aimed at Counter Queue (CQ) to wait for service. Patients are only released to enter the office when the Free Office position (FO1, FO2, FO3, FO4 or FO5) is with one token. This model is shown in Figure 4.
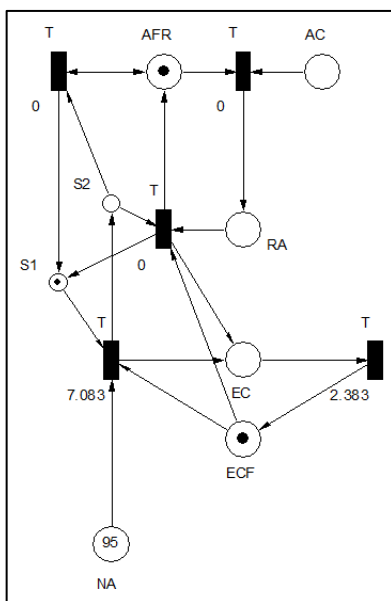

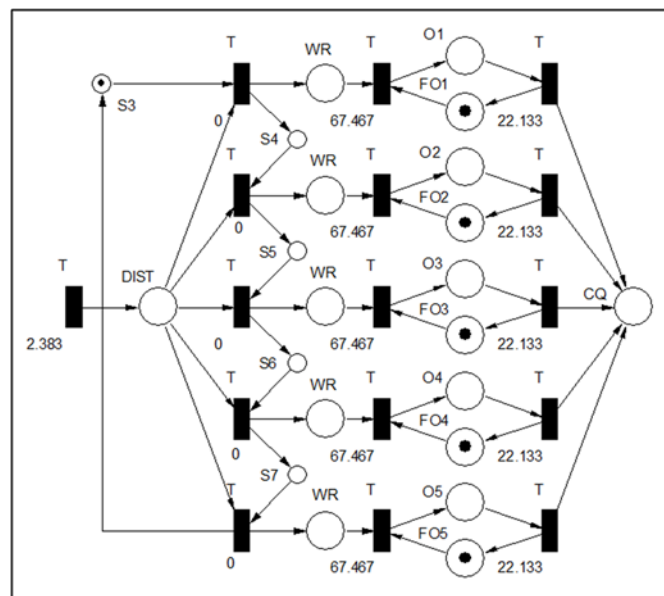Figure 3: General ambulatory entrance   Figure 4: Doctor's offices – General ambulatory

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According to Figure 5, when leaving the queue, the patient will be treated in one of the return counters, registration or discharge (REG and DISC). At this stage, the patient may receive the guide for exams at the ambulatory itself, which will be presented at follow-up visit, discharge from the doctor, or lead to the Specialties ambulatory, which will hold its registration.

Synchronizers of capacity (SC1, SC2, SC3, SC4, SC5 and SC6) are used to direct the correct number of patients that receive a demand for exams, discharge or are leaded to registration.

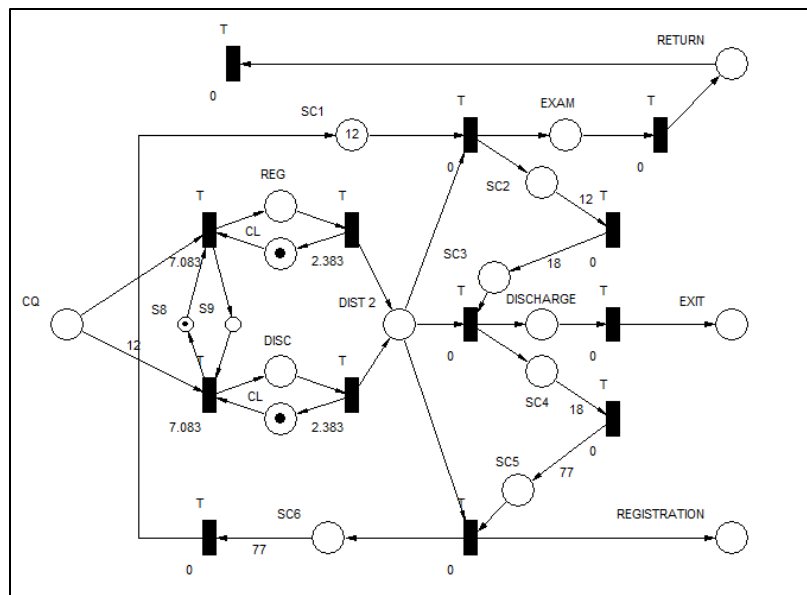Figure 6 presents the entire Petri net model for the General ambulatory.
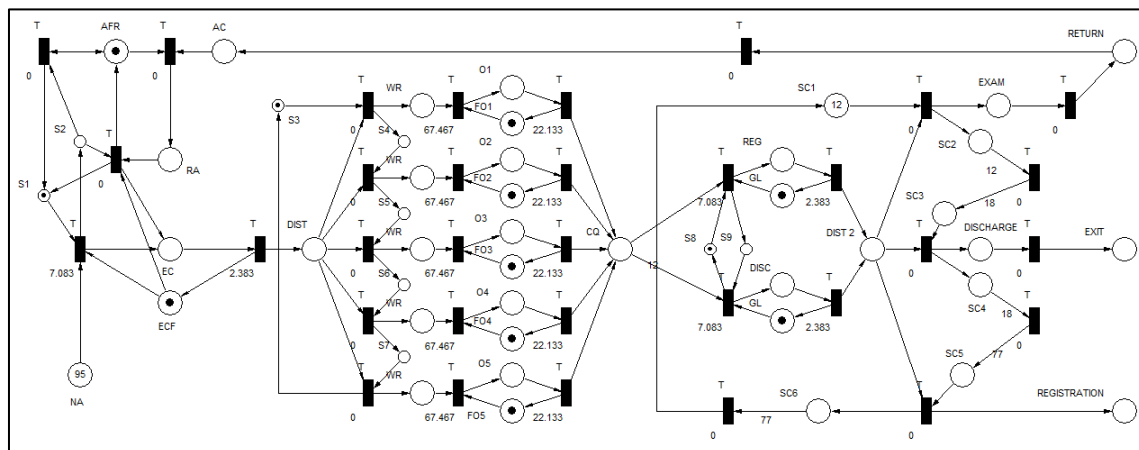

Figure 5: Patient flow - General ambulatory

Figure 6: General ambulatory: complete model

6.2.   Specialties Ambulatory

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The first step at Specialties ambulatory is the admission of the patients from registration, represented in the Petri net of the Figure 7 by the position New Arrivals (NA). The patients from return, represented by the position Return Arrival (RA), go to the Entrance Counter (EC). Again, as in the General ambulatory, synchronizers (S1 and S2) were used allowing that patients from return could be admitted in the EC position as well as the patients from registration. In case there is no return patient the position Entrance Counter Free (ECF) remains with the token allowing the continuity of the simulation with the patients from New Arrivals. Position FAR (Free Arrival Return) allows the admittance of a patient from return.

Leaving the Entrance Counter, the patients are redirected to the waiting room for after being attended in one of the nineteen doctors' offices of the Specialties ambulatory. A position called DIST was inserted in the model (Figure 8) to allow the entrance of the patients into the doctors' offices. Again, synchronizers were inserted to lead the patients from the waiting room to the doctors' offices. After consultation, the patients go to the counter queue (CQ).

After being attended in the Specialties Ambulatories Counter (SAC), the patients are leading to exams (EXAM), to the surgery room (SR) or directly to return. Some patients after consultation go to discharge and leave the system. Figure 9 presents the flow of patients in the described system.
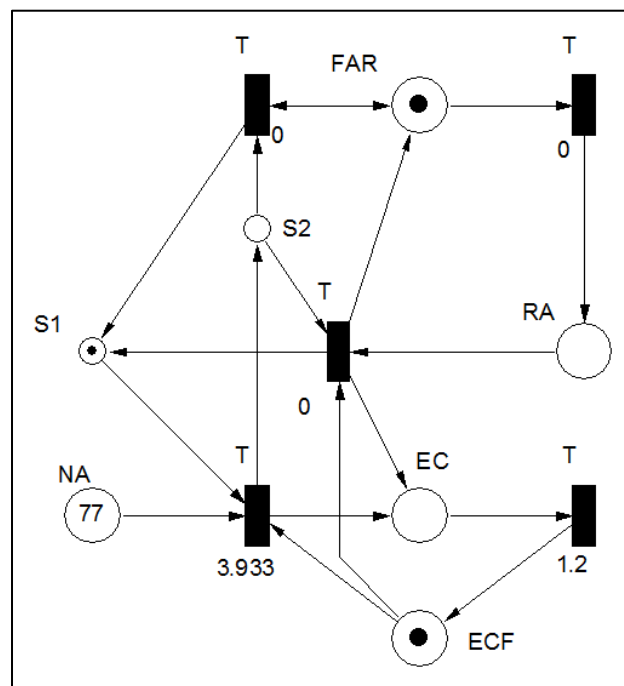

Figure 7: Specialties ambulatory entrance

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Table 1: General Ambulatory Entrance Data

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
working days	22	19	20	22	21	20	22	22	21
Patients - Total	2102	1772	2005	2356	2296	2075	2177	2254	2245
New Patients	1872	1578	1785	2098	2045	1848	1939	2007	1999
New Patients/day	85	83	89	95	97	92	88	91	95
Return	230	194	220	258	251	227	238	247	246
Return/day	10	10	11	12	12	11	11	11	12

Table 2: Waiting Time

		Queue	Counter	Waiting Room	Consultation
General Ambulatory	Average	00:07:05	00:02:23	01:07:28	00:22:08
	Deviation	0.00187	0.00073	0.02034	0.00746
	Minimum	00:00:00	00:01:13	00:29:42	00:09:12
	Maximum	00:11:28	00:05:50	01:59:25	00:45:13

Table 3: Specialties Ambulatory Entrance Data

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
working days	22	19	20	22	21	20	22	22	21
Patients - Total	11460	9708	10528	11960	10977	10781	10504	12079	10515
New Patients	1627	1378	1495	1698	1558	1531	1491	1715	1493
New Patients/day	74	73	75	77	74	77	68	78	71
Return	9242	7829	8491	9646	8853	8695	8471	9742	8480
Return/day	420	412	425	438	422	435	385	443	404
Discharge	591	500	543	616	566	556	541	623	542
Discharge/day	27	26	27	28	27	28	25	28	26
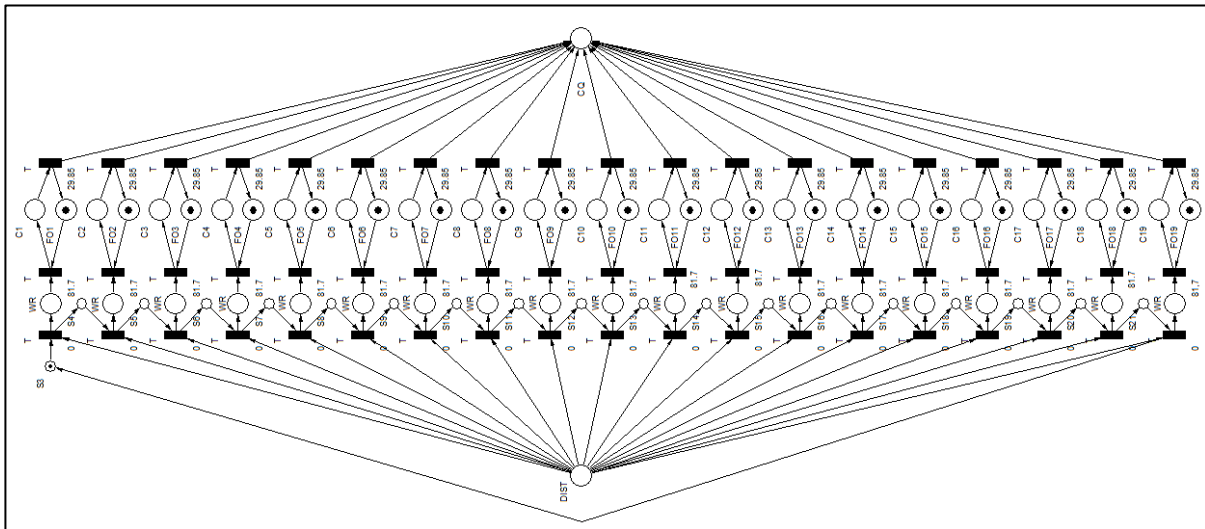
Figure 8: Doctor's offices: Specialties ambulatory

Table 4: Waiting Time

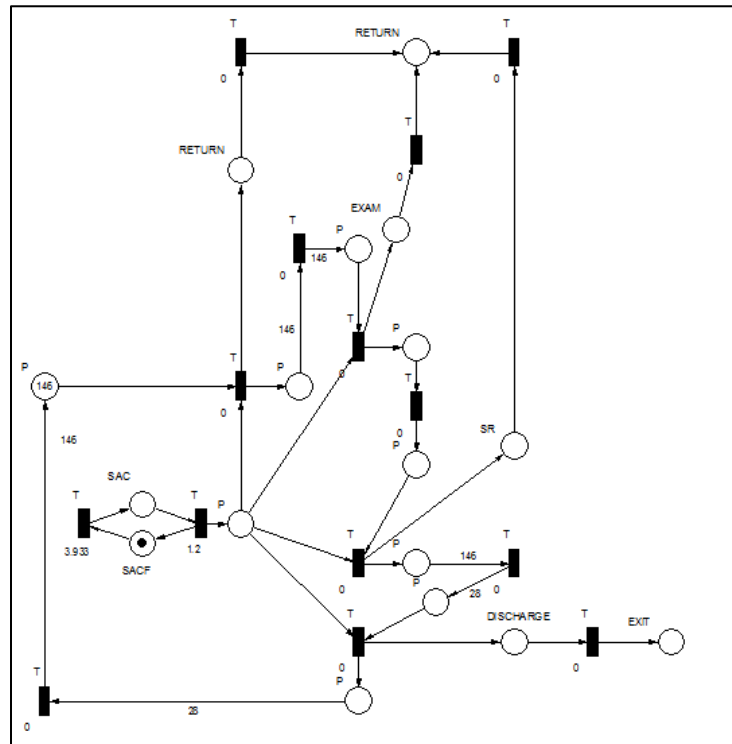|		Queue	Counter	Waiting Room	Consultation
Specialties Ambulatory	Average	00:03:56	00:01:12	01:21:42	00:29:51
	Deviation	0.00310	0.00039	0.02745	0.01220
	Minimum	00:00:00	00:00:35	00:24:03	00:06:30
	Maximum	00:11:25	00:02:02	02:40:01	01:09:40

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Figure 9: Patients' flow: Specialties ambulatory

7. CHOSEN RESULTS

After constructing the models, several scenarios were simulated with the intention of optimize the system. This means to reduce the length of stay of the patient in the hospital increasing the quality of the service provided.

7.1. General Ambulatory

The simulations focused on the most important positions (WR, CQ, Registration). The current situation of the system was considered.

Figure 10 presents the number of patients in the waiting room before entering the doctor's office. From the Figure 10 it is possible to notice that the maximum number of patients waiting is 12.

Position CQ allows to understand the attendance distribution of the doctors' offices in the General ambulatory. The Figure 11 presents the uniform characteristic of the distribution due to the fact of using an average time for all offices. It is possible to notice some idle time since preceding positions (doctors' offices, C1 to C5) be the bottleneck of the system. The idle time of the Counter Queue is 38.8 minutes.

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Figure 12 presents the result from the registration position. It is important to notice here that in the simulation the synchronizers direct the first patients to make exams, the following to exit and the last ones to the registration. This guarantee that each position receives the correct number of patients per day. The last patient for registration reaches this position in 2010.8 minutes.

After the initial simulations, the model was modified with the intention of reducing the idle time of the CQ position. The number of doctor's offices was increased from six to nine. It was observed that the best results were obtained with eight offices, reducing the idle time of CQ from the original 38.8 minutes to 18.5 minutes. It means a reduction of 52.3% of the idle time. Increasing the number of offices beyond nine did not affect the system. Figures 13 and 14 present the new graphics for the waiting room and the registration. The maximum number of patients in the waiting room was decreased as well as the time for registration of the last patient. The maximum number of patients at Waiting Room is now four (reduction of 33%) and the total time for registration was decreased to 1294.7 minutes (reduction of 36%).

The second strategy was to change the number of counters after the consultation (positions REG and DISC). Before changing the number of counters an analysis was made to analyze the occupation of the counter REG. The result is presented in Figure 15. It was observed a large idle time.

Considering the result presented in Figure 15 it was proposed a new simulation reducing the number of counters. A new simulation was carried out with a single counter. The result is presented in Figure 16.

It was observed that one counter is sufficient to attend the demand of patients that come from the offices. This implies in a reduction of cost to the hospital.
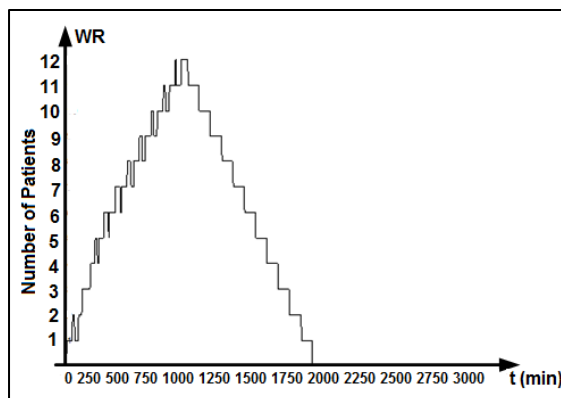

Figure 10: Waiting room: Current situation

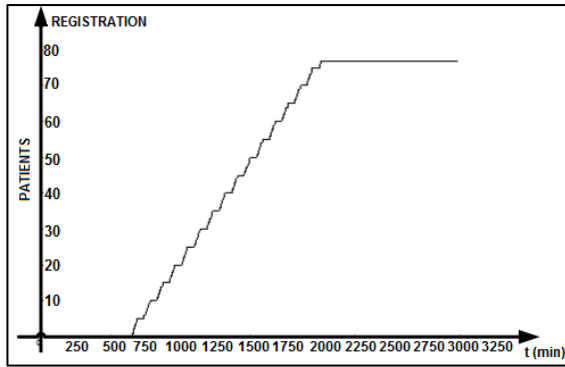Figure 11: Counter queue: Current situation

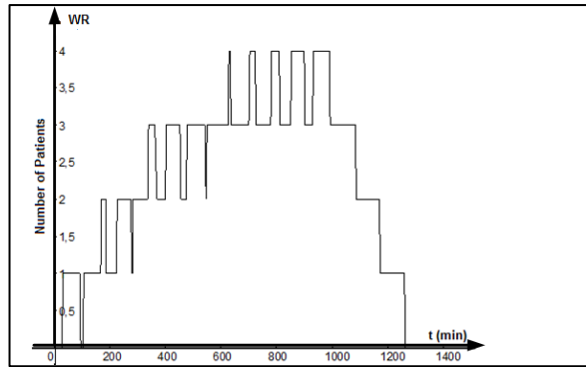233

Figure 12: Registration: Current situation

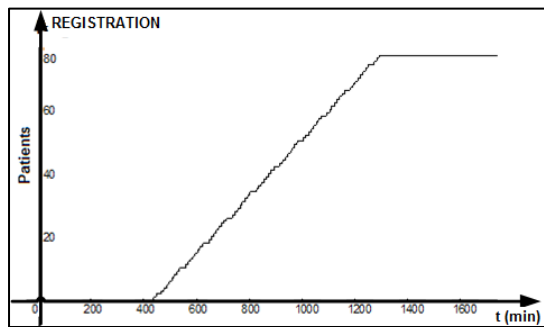Figure 13: Waiting room: Proposed situation (8 offices)

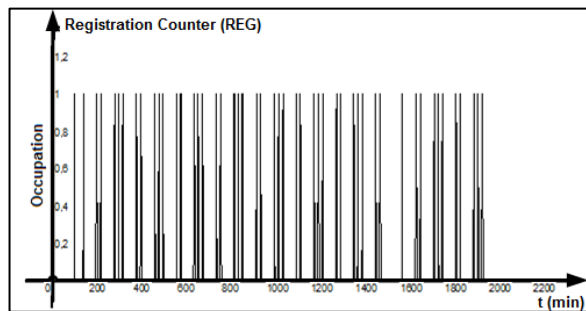Figure 14: Registration: Proposed situation (8 offices)

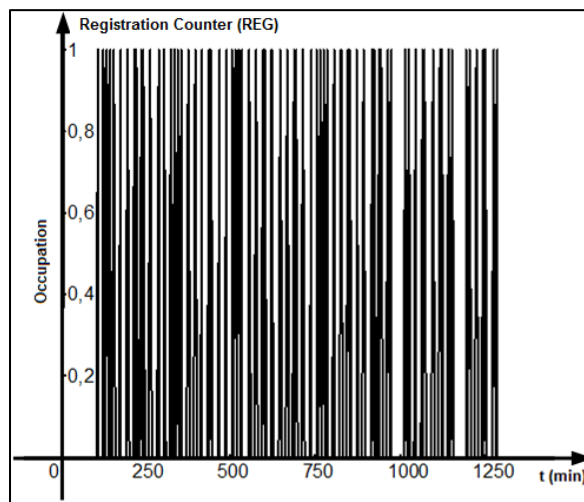Figure 15: Registration Counter occupation

Figure 16: New Registration Counter occupation

7.2.   Specialties Ambulatory

The system starts with patients from the General Ambulatory and patients who were already in the system, for example, a person hospitalized after surgery, performed previously, awaiting a return visit.

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The first study was carried out on the Discharge position, which is the total time system simulation for a day, or as soon as the position reaches the number of 28 patients. In Figure 17, it is possible to identify this time as 2845.9 minutes.

After, the occupation at the waiting room was verified. Figure 18 presents this occupation. A maximum number of 23 patients was observed.
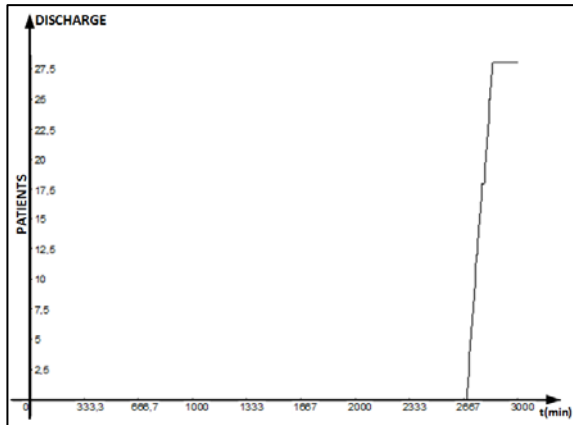

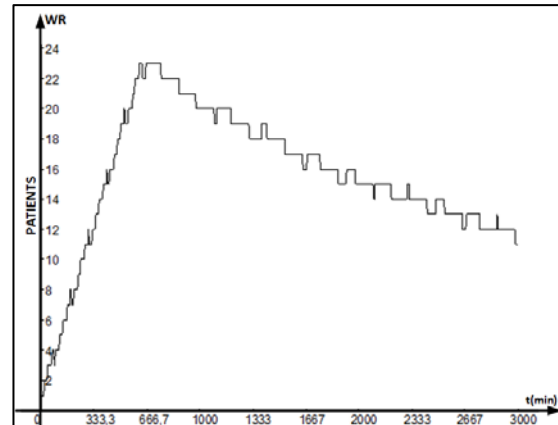Figure 17: Discharge   Figure 18: Waiting room

The last analysis is related to the counter queue. Unlike the counter queue of the General Ambulatory, there is no idle time to the counter queue of the Specialties Ambulatory due the high number of doctors' offices. There is a cyclic behavior of the queue, summing 15 patients at the peak. Figure 19 presents this situation.

After the simulation of the current situation of the Specialties Ambulatory some proposals were applied in the simulation aiming at improving the performance of the system. At first, a new counter was inserted in the system since as presented before the counter queue has a peak of 15 patients. The results did not bring any significance impact in the current situation. The number of patients in the waiting room were not modified. The peak of patients in the counter queue was reduced from 15 to 14 patients.

As carried out to the General Ambulatory, the number of doctors' offices was increased. Increasing one office implied to a reduction of 1 patient in the waiting room (from 23 to 22) and the peak of the counter queue was increased in one patient (from 15 to 16).

In a simulation considering 22 offices, the total time until the last patient out the system (Discharge) was reduced in 10.8%. In the waiting room, the peak of the patients achieved a maximum of 19. This condition is presented in Figure 20.

On the other hand, the counter queue presented a crescent number of patients over time as presented in Figure 21.
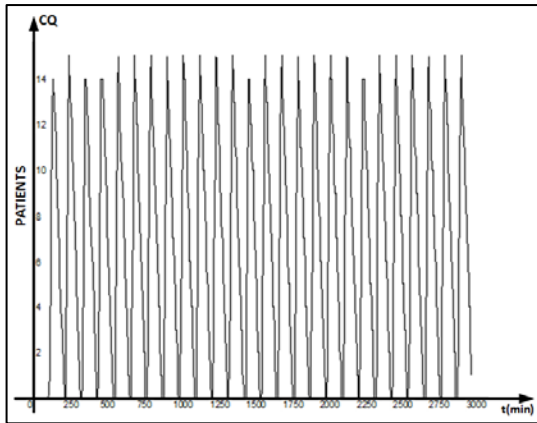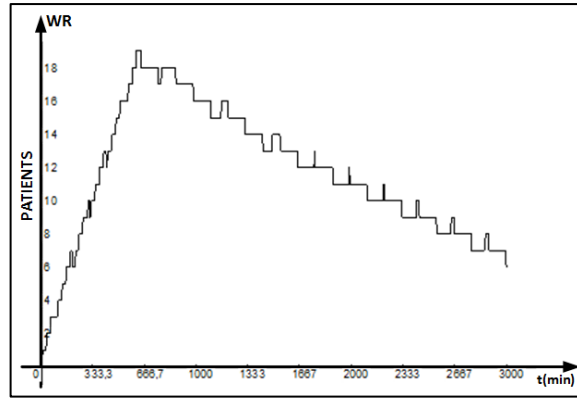
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Figure 19: Counter queue
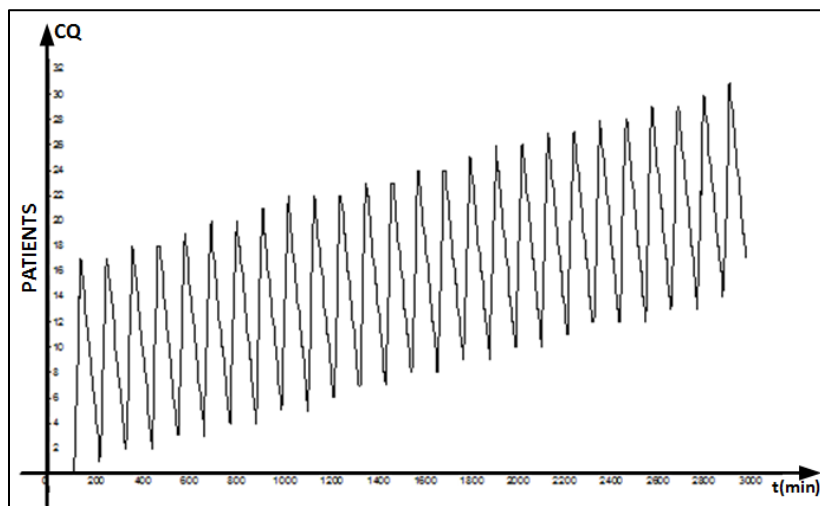

Figure 20: Waiting room: 22 offices

Figure 21: Counter queue: 22 offices

This study showed that the addition of medical offices while benefiting the distribution of patients in the waiting room and reduce the total simulation time, overloads the service in the post-consultation counter. Therefore, it is not justified the increase in the number of medical offices without making any other changes related to the optimization of the service counters.

Considering the number of patients in the post-consultation counter new simulations were carried out considering the insertion of a new post-consultation counter.

The best situation occurred with 21 doctors' offices.

Table 5 summarizes the best results from the simulations of the General Ambulatory. It compares the current real data of the General ambulatory to the best scenario proposed from the simulations. Table 6 summarizes the best results from the simulations of the Specialties Ambulatory.

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Table 5: General Ambulatory: Simulation Results

	Current Situation	Best Proposal (5 Offices)
Waiting Room	12 Patients	4 Patients
Counter Queue (Patients)	1 Patient	1 Patient
Registration	2010.8 min	1294.7 min
Counter Queue (Idle time)	38.8 min	18.5 min

Table 6: Specialties Ambulatory: Simulation Results

	Current Situation (19 offices – 1 counter)	Best Proposal (21 Offices – 2 counters)
Waiting Room	23 Patients	21 Patients
Counter Queue (Patients)	15 Patients	15 Patients
Registration	2845.9 min	2586.1 min

8. CONCLUSIONS

This paper presented a modelling and simulation of a cardiology hospital ambulatories. The simulation using timed Petri nets showed itself a powerful tool to analyze the flow of patients into the ambulatories. The simulation used a free software providing a low-cost solution to the hospital. Two ambulatories were modelled and simulated: General and Specialties.

The models are connected since some patients from the General ambulatory can enter the Specialties ambulatory. After modelling the current situation in both ambulatories some proposals were made aiming at improving the performance of the system. It was observed that some simple modifications have a huge impact on the performance.

The most impressive results were achieved in the General ambulatory. Increasing the number of offices from five to eight implied in reduction of the total patients' time in the system as well as allowed the reduction of the number of patients in the waiting room and the idle time of the counters.

Although the models were constructed considering a specific situation of a Brazilian hospital the paper contributes with the subject when presenting the possibility of modelling these kinds of systems with a free software tool. The situations modelled are typical of these systems so the models proposed could be easily adapted for other hospitals.

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