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Modélisation et optimisation des systèmes de gestion de flux de personnes : Application aux domaines socio-économiques

Présentée par: **DERNI Oussama**

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Devant le jury :

Présidente	DEBBAT Fatima	Pr	Université M. S. de Mascara
Examinateur	AHMED-FOITIH Zoubir	Pr	U.S.T.O. Mohamed Boudiaf
Examinateur	SALEM Mohammed	MCA	Université de M. S. de Mascara
Directeur	KHELFI Mohamed Fayçal	Pr	Université Oran 1 Ahmed Ben-Bella
Co-directrice	BOUFERA Fatma	MCA	Université M. S. de Mascara

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Modeling and Optimization of People Flow Management Systems: Application to Socio-Economic Areas

Presented by: DERNI Oussama

In 06/01/2020

In front of the jury:

President	DEBBAT Fatima	Prof	University M. S. of Mascara
Examiner	AHMED-FOITIH Zoubir	Prof	U.S.T.O. Mohamed Boudiaf
Examiner	SALEM Mohammed	MCA	University M. S. of Mascara
Director	KHELFI Mohamed Fayçal	Prof	University Oran1 Ahmed Ben-Bella
Co-director	BOUFERA Fatma	MCA	University M. S. of Mascara

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Abstract

People's flow management is one of the interesting areas of research due to its effect on the productivity and performance of organizations in numerous areas. Care quality is a key factor in the quality of human living in any nation. This aspect is one of the main parameters for measuring the socio-economics' status. In this context, we mainly focused on studying the flow of patients in a specific department: the hospital Emergency Department (ED). The selection of this service is based on the huge daily volume of patients it receives. Our objective is to improve the care quality compared to a managerial component and the performance of the system using methodologies that allow scientific management. In this thesis, we initiate by highlighting the context and the problematic of the socio-economic systems, then we focus on the chosen study field by presenting a survey on the realized studies. We have taken two cases of emergency departments belonging to different kinds of Algerian hospitals. Next, we have proposed two different approaches with shared aims represented in the modeling and improvement of EDs. In the first approach, we take a medium size ED and we model the system using colored Petri nets to identify the problems and failures in the system. After identifying different problems, we propose a set of solutions and we study the impact of each one. As a result of our research work, a set of feasible solutions with their implementation costs have been proposed to the managers of the service. This momentum will contribute to improving the quality of care and it can be applied at the level of any service. It only requires a slight adjustment of some parameters. The second approach exploits the use of Fuzzy Logic in determining the number of resources needed to achieve a target improvement; it has been applied in one of the biggest hospital emergency structures in the Algerian west. The obtained results have proved the effectiveness of the approach. Finally, a qualitative comparison between the two studies is presented in the last chapter to provide a clear and complete vision of the accomplished works.

Keywords: Hospital emergency department, patient flow, processes, system modelling, optimization, simulation, patient waiting times.

ملخص

تعد إدارة تدفق الأفراد أحد مجالات البحث المهمة نظرًا لتأثيرها على إنتاجية المؤسسات وأدائها في العديد من المجالات. إن جودة الرعاية الصحية هي عامل رئيسي في جودة الحياة البشرية في أي دولة. هذا الحد هو أحد المعايير الرئيسية لقياس حالة الاقتصاد الاجتماعي. في هذا السياق، ركزنا بشكل أساسي على دراسة تدفق المرضى في قسم معين: قسم الطوارئ الاستعجالية بالمستشفى. يعتمد اختيار هذا القسم على الحجم اليومي الضخم للمرضى الذي يستقبلهم. هدفنا هو تحسين جودة الرعاية بالنسبة للمكون الإداري وأداء النظام باستخدام منهجيات تسمح بإدارة علمية. في هذه الأطروحة، نبدأ بتسليط الضوء على السياق وإشكالية النظم الاجتماعية والاقتصادية، ثم نركز على مجال الدراسة المختار من خلال تقديم دراسة استقصائية عن الدراسات التي تم انجازها. لقد قمنا بأخذ حالتين لقسمين للطوارئ الاستعجالية تابعة لفئتين مختلفتين من المستشفيات في الجزائر. بعد ذلك، اقترحنا نهجين مختلفين مع أهداف مشتركة متمثلة في نمذجة وتحسين أقسام الطوارئ. في النهج الأول نأخذ قسم طوارئ متوسط الحجم ونقوم بنمذجة النظام باستخدام شبكة بيتري الملونة لتحديد مشاكل وقصور النظام. بعد تحديد المشاكل المختلفة، نقترح مجموعة من الحلول ونقوم بدراسة وقع التأثير لكل منها. كنتيجة لعملنا البحثي، تم اقتراح مجموعة من الحلول الممكنة على مسؤولي الخدمة مع تكاليف التنفيذ لكل حل. سيساهم هذا الزخم في تحسين جودة الرعاية ويمكن تطبيق النهج المقترح على مستوى أي خدمة إذ يتطلب فقط تعديل طفيف لبعض الإعدادات. يستغل النهج الثاني استخدام المنطق الضبابي في تحديد عدد الموارد اللازمة لبلوغ نسبة تحسين مستهدفة؛ تم تطبيق هذا النهج على واحد من أكبر أقسام طوارئ المستشفيات في غرب الجزائر. وقد أثبتت النتائج التي تم الحصول عليها على فعالية النهج المتبع. في الأخير يتم تقديم مقارنة نوعية بين الدراستين في الفصل الختامي من أجل عرض رؤية واضحة وكاملة للأعمال المنجزة.

الكلمات المفتاحية :قسم طوارئ المستشفى، تدفق المرضى، العمليات، نمذجة النظام، التحسين، المحاكاة، مدة انتظار المرضى.

Résumé

La gestion des flux de personnes est l'un des domaines de recherche intéressants en raison de son effet sur la productivité et les performances des organisations dans de nombreux domaines. La qualité des soins est un facteur clé dans la qualité de vie humaine de n'importe quel pays. Cet aspect, constitue l'un des principaux paramètres de mesure du statut socio-économique. Dans ce contexte, nous nous sommes principalement focalisés à étudier le flux de patients dans un service spécifique : à savoir le Service des Urgences (SU) hospitalier. Le choix de ce service est basé sur le volume quotidien énorme de patients qu'il reçoit. Notre objectif est d'améliorer la qualité des soins par rapport à un volet managérial et la performance du système en s'appuyant sur des méthodologies qui permettent une gestion scientifique. Dans cette thèse, nous commençons par mettre en évidence le contexte et la problématique des systèmes socio-économiques, puis nous nous concentrons sur le domaine d'étude choisi en présentant un état de l'art sur les études réalisées. Nous avons pris deux cas des services d'urgences d'hôpitaux appartenant à différentes structures hospitalières en Algérie. Ensuite, nous avons proposé deux approches différentes avec des objectifs partagés représentés dans la modélisation et l'amélioration des SUs. Dans la première approche, nous prenons un SU de taille moyenne et nous modélisons le système en utilisant les réseaux de Pétri colorés pour identifier les problèmes et les défaillances dans le système. Après l'identification des différents problèmes, nous proposons un ensemble de solutions et nous étudions l'impact de chacune d'elles. Comme aboutissement de notre travail de recherche, un ensemble des solutions réalisables avec leurs coûts de mise en œuvre ont été proposées aux gestionnaires du service. Cet élan contribuera à l'amélioration de la qualité des soins et peut être appliquée au niveau de n'importe quel service. Il ne nécessite qu'un léger ajustement de certains paramètres. La seconde approche exploite l'aide de la Logique Floue dans la détermination du nombre des ressources nécessaires pour atteindre un objectif d'amélioration ; il a été appliqué dans l'une des plus grandes structures d'urgence hospitalière de l'ouest algérien. Les résultats obtenus ont prouvé l'efficacité de l'approche. Enfin, une comparaison qualitative entre les deux études est présentée dans le dernier chapitre afin de fournir une vision claire et complète des travaux accomplis.

Mots clés: Service d'urgence hospitalier, flux de patients, processus, modélisation de système, optimisation, simulation, temps d'attente des patients.

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List of abbreviations

- ED Emergency Department
- KPIs Key Performance Indicators
- CPNs Colored Petri Nets
- LOS Length Of Stay
- LWBS Left Without Being Seen
- DTDT Door To Doctor Time
- MAS Multi-Agent System
- DAI Distributed Artificial Intelligence
- AI Artificial Intelligent
- DSS Decision Support System
- UML Unified Modeling Language
- BaB Branch-and-Bound
- DP Dynamic Programming
- LS Local Search
- TS Tabu Search
- EN Elementary Net
- P/T Place/Transition
- HL+ADT High-Level Petri Nets with Abstract Data Types
- GUI Graphical user interface
- ESI Emergency Severity Index
- VE Vital Emergency
- SSHU Short-Stay Hospitalization Unit
- GP General Practitioner
- MC Medical Consultation
- SP Specialist Practitioner
- FL Fuzzy Logic
- FLC Fuzzy Logic Control
- FIS Fuzzy Intelligent System
- SES Surgical Emergency Service
- MES Medical Emergency Service
- VER Vital Emergency Room
- OTR Orthopedics and TRaumatology
- HCPN Hierarchical Colored Petri Net

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Chapter I

General introduction

I.1 Introduction

The mobility of entities, people or data has become a central and controversial concept. In public places such as hospitals, transport, concert halls, etc. the management of people flows must be considered very early in the design phase. While we optimize the operations, we need to manage most efficiently and comfortably the influence points. To address this issue, a contrasting view of emerging mobility security seeks to optimize risk management and surveillance through security measures that seek to better track the flow of data and people across the physical and virtual worlds. In this thesis, we will study this problem by modeling tools (Petri nets, Markov chains, etc.) and optimization technics that control and organize the different mobile data flows and people, precisely in healthcare systems.

Health systems and hospitals are particularly complex socio-economics organizations. Nowadays, interest in the improvement of healthcare quality through an evaluation of hospital performances is becoming increasingly necessary. Hospitals are the central core of the public health care system, and they play a vital role in the process of patient care.

Hospital emergency departments represent a principal component of the healthcare system, as well as the main entrance to the hospital. The complexity of hospitals and emergency departments systems are explained not only by the unpredictability and variability of the needs, but also by the very specificities of the medical activity, and the caregiver-patient relationship.

Moreover, for nearly twenty years, these systems have been subject to unprecedented change. Regardless of their size or mission, ED systems have had to confront with the growth in the demand for care, the change in user behavior and a series of reforms. In a healthcare organization, precisely emergency departments, the challenges are growing up significantly due to the increased amount of healthcare load, the appearance of infectious diseases and the omission of studying ED needs, specifically in the Algerian hospitals.

In this thesis, we will focus our study on a particular service represented in the hospital emergency department, which is the main gateway for all emergency states. The emergency service is not only involved in patient evaluation. Further, it is concerned also by the quality of care that faces many organization difficulties, taking into account many complicated measurements. The first step in studying such a convoluted system is presented in the modeling process. Which is an important phase in improving system understanding through graphics examinations, providing a detailed view of systems from multiple angles, facilitating the discovering process of causes and effects of different issues, besides it delivers a valuable comprehension of the interactions between system elements.

Numerous Key Performance Indicators (KPIs) will be used to evaluate the studied EDs performances, including the patient length of stay, waiting times, door to doctor time, and the rate of patient left without been seen. These KPIs are essential not only in performance measurements but also in the identification of lacks at the different stages of the patient care process. Following the identification of the studied system lacks, we move on to the optimization phase, which consists of the exploitation of operational research methods, and simulation techniques to limit the deficiencies and improve the quality of the target systems.

I.2 Context and problematic

Indeed, the number of people who are coming to the ED in most Algeria hospitals is steadily increasing, for a variety of reasons, including pauperization, aging of the population, increasing in pediatric consultations, and an increase in the number of chronic diseases. Furthermore, free and direct access to this facility, and specifically consultation at any time of the day or night, without any appointment and whatever the reason for consultation, these rise ED controlling challenges. The non-predictable amount of patient flow arrived at the ED with a limited resource to handle this flow rise the difficulties for ED managers. As a human being, patients at the ED expect to be treated in a minimal and fast way as soon as possible, which lead to pressure on medical staffs and ED supervisors. The main issue in these facilities is the long waiting times of patients at different stages of the admission process, which affect the care quality and patients satisfaction.

I.3 Objectives and contributions

The inefficiency of time management has a big impact on the treatment quality and the satisfaction of patients, especially in overcrowding situations, which lead to a longer waiting time and raise the rate of death. The necessity of a scientific study is crucial for solving these issues. To restrict these issues, many techniques of the industrial domain have applied in healthcare optimization. In the literature, many researchers have modeled different EDs, which is an essential step before the optimization process for such systems, due to their complexities. Several key performance indicators of the ED have used to measure the performance of the studied systems, as well, the rate of the achieved improvements. In this thesis, we have reached a significant improvement in the studied systems by applying two different approaches.

I.3.1 Approach 1: Colored Petri net for modeling and improving hospital emergency department based on the simulation model

In this approach, we chose the colored Petri nets (CPNs) as a performance mathematical model in concurrent systems modeling. In our case, we used CPNs for modeling hospital emergency department systems; CPNs have several interesting features such as modeling and visualization of parallel behavior, modeling, and resource sharing. Furthermore, it simplifies the modeling process by representation system state with colored tokens; in which every color represents the data value, which is more efficient than other Petri net types. Initially, we start with the phase of data collection from a selected ED, and then we build the simulation model of our case study system, using Colored Petri Net Tools components. Next, we move forward to the simulation phase; we propose numerous improvement scenarios, and we measure the impact of each scenario. Following, we compare these scenarios' results, to select the efficient scenario, based on several ED' KPIs. The final step is the measurement of the implementation cost for each scenario, which will provide to ED managers a clear view of the needed budget. This study has been formulated in a scientific paper, and it has been published in an international journal (Derni et al, 2019a).

I.3.2 Approach 2: A new approach for the optimization of patient flow in hospital emergency department

In the second approach, we mainly focus on the improvement of patient care quality. We based on the patient total length of stay and the rate of treated patients, as the main key performance indicators to measure the provided care' quality. We use Fuzzy Logic to demonstrate the link between the amounts of available resources, the number of incoming patients, the patient total length of stay in the ED and the rate of treated patients. Moreover, the fuzzy control system helps in the calculation of the target output values based on a set of inputs parameters. After we designed the Fuzzy Logic system, we choose a set of input values appropriated with our objective improvement target. Then, a colored Petri net simulation model is built to measure the improvement rate of the proposed solution, by adding a minimal amount of resources. This study has been the subject of a scientific paper in an international journal (Derni et al., 2019b).

I.4 Thesis structure

This thesis is structured into six chapters. In the first chapter, we present a general introduction and we clarify our research area. In chapter two, we are going to present the socio-economic problematic, we start by defining some terms and presenting the key characteristics of socio-economic systems. We mainly focus on healthcare organizations, specifically the Algerian hospitals, their duties, challenges, and limits. We end the chapter by introducing a crucial section of the hospital, which is the emergency department by presenting its main functionalities, missions, and the key indicators used in the measurement of its performance.

Chapter three provides a literature review of the modeling and optimization techniques used in the health field, it highlights the limits and advantages of each method. In chapter four, we are going to present our research contribution, the chapter will present our first approach, which is based on a colored Petri nets framework. The approach is applied in the case study ED of Chalabi Abdelkader Hospital.

In chapter five, we present a new approach for the optimization of patient flow inside the ED. The approach will be applied in a second case study emergency department of Benaouda Benzerdjeb Hospital located in Oran, Algeria.

Chapter six will provides a qualitative comparison between the effected studies in the chapters (Chapters 4 and 5). Finally, the thesis will be accomplished by a general conclusion, resumes the realized works and provides certain future perspectives of this modern research.

Our research contributions are illustrated in Figure I.1 in order to provide a clear vision of the key phases of the proposed approaches.

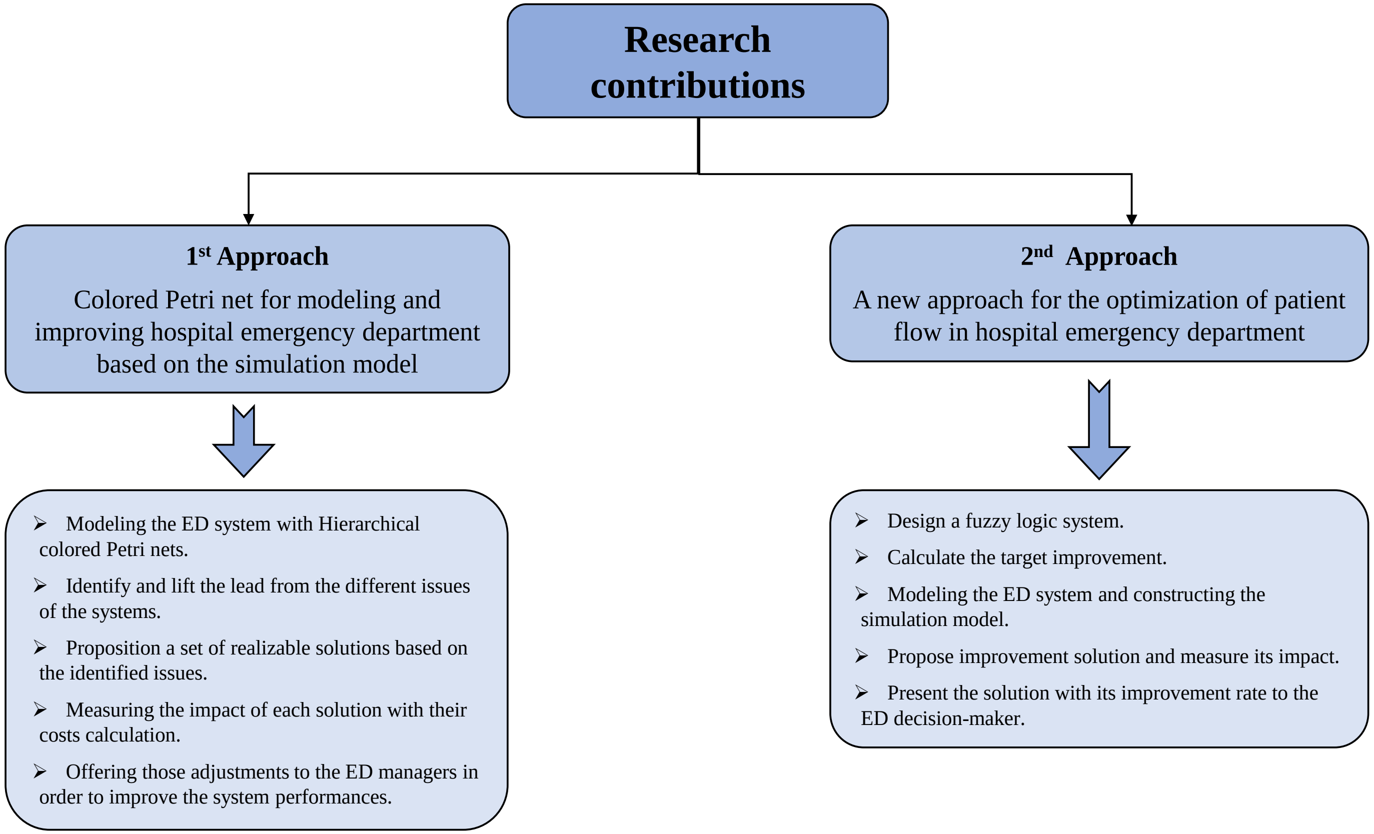


Figure I.1 – Summary of the different phases of the proposed approaches

Chapter II

The Socio-economic problematic context: the case of the healthcare system

II.1 Introduction

Before the studying of any system such as hospitals or more specifically emergency departments, we should focus on its relationship with a specified discipline or an accurate category. At the end of the 20th century, there has been a considerable increase in the number of studies about the interactions between socioeconomic factors and health. In fact, several social and economic factors are related to health. Besides, there is an augmented effect between socioeconomic status and health presented in the improvement of health with the increase in socioeconomic status (Shavers, 2007). According to (Adler and Ostrove, 1999; Bradley and Corwyn, 2002), socioeconomic status is a combined economic and sociological measurement of a person's effort, economic and social position in the society, based on numerous factors as education, occupation, and income. Indeed, socioeconomic status is further used to illustrate an economic difference in society as a whole.

In this chapter, we initially present some definitions of socio-economic systems, and then we present the socio-economic problematic context by mentioning certain of the main issues encountered in socio-economic organizations. Next, we focus on the health system, specifically in Algeria. Public hospitals play a key role in the Algerian health system. Hospitals are comprised of numerous services; each service is distinguished from the others by their duties and responsibilities. Studying the whole system, with all its services is such a hard and time-consuming task. Moreover, the sensibility and the influence of each service vary from one to another. We choose the emergency department, for a variety of reasons, the most significant one is its principal role as the main gateway of the hospital, which accepts all patients regardless of their states, urgent or not. In the following section, we are going to deliver different definitions of the ED, mentioning its characteristics, functionalities, and discussing the various key performance indicators used to measure its performances and routines. We complete this chapter with a conclusion, resuming all the delivered ideas and notions.

II.2 Socio-economic problematic

A swift examination of the literature immediately affirms the non-existence of any exact and commonly suitable definition of socio-economic. There is, however, a wide agreement that social-economic is concerned with social relations and these are their fundamental. Several definitions of socio-economics have been proposed:

(Davison, 1974) has defined socio-economic such as "*The study of a human population in the process of adaptation to its material environment*". According to (Bendavid-Val, 1975), social economics is concerned with developing a body of understanding, tools, and experience for application, along with the products of other specialized areas of knowledge, to assist in the process of social development. It conceives of social development as comprising two pursuits, complementary, inseparable, and of equal weight:

1. Maximizing human satisfaction, while;
2. Minimizing the disturbance to the earth and humanity.

From the perspective of (Hellmich, 2015) the term “socioeconomics” is theoretically of significant value, as it is in widespread use, conclusively highly visible, and attracting attention. He sees that socioeconomics could be an active mechanism in scientific dialogue.

In the following we are going to list, some of the main issues and challenges, which affect socio-economic organizations:

- **Income disparity:** It refers to the extent to which income is distributed in an uneven manner among a population. In the United States, income inequality, or the gap between the rich and everyone else, has been growing markedly, by every major statistical measure. According to the statistic realized by the Statistics of Income Division Organization, the incomes for the top 400 U.S earners have been jumped from an average of $50 million in 1992 to more than $300 million in 2014. It reflects the increase in the gap between the different classes of the populations.
- **Homelessness:** Homeless are people who live and sleep in places not intended for housing such as a cellar, parking, car, warehouse, and technical building, building sites, subway, station, street, etc. Working with the homeless or supporting families struggling with a shortage of food or poor housing presents a variety of challenges for social workers.

- **Access to health care:** Access to health care is becoming an extremely complicated issue, and it is further muddled by the underlying income disparity and race relation issues across the world. In the U.S, the income disparity is reflected in a health care industry in which access to care is split along economic lines.

In health area Baumann and Gao specify the definition of public health problem as follows: “*The Gap between a state of physical, mental, observed social health, expressed and a state of health deemed desirable, expected, defined by medical references developed by experts, the legislator, etc. or social norms elaborated by teams, society, etc*”.

A public health problem is thus to be distinguished from a health determinant that is a factor that influences the health status of a population either alone or in combination with other factors.

II.2.1 Characteristics

Numerous Socio-economic characteristics have been explored in the literature. We are going to highlight the most common, as follow:

1. **Education:** It is the most frequently used to measure the socio-economic status. In Algeria, according to the statistics of the “Office National des Statistiques”, in 2017 about 7 million students are in the primary and middle schools, which represents 16.74% of the population, without counting secondary and high education, which include 3.11% and 3.96% of the population, respectively.
2. **Employment:** The improvement of the rate of employment in a society will have a vast impact on socio-economic status. Which is in a gradual growth in Algeria.
3. **Income:** It is considered to have the highest effect on health variations. According to (Mikkonen and Raphael, 2010) “*Income is perhaps the most important social determinant of health. Level of income shapes overall living conditions affects psychological functioning and influences health-related behaviors such as quality of diet, the extent of physical activity, tobacco use, and excessive alcohol use.*”
4. **Housing:** It reflects the stability of the society; Algeria has recently seen great support for housing projects across the country.

II.3 Healthcare system

Algeria pays particular attention to health in the overall conduct of public policies. Many observed efforts in the field of health are made annually by the realization of key healthcare infrastructures, training health staff, and the acquisition of heavy equipment. Indeed, the system is based on several components with taking into consideration the interrelationships. It is designed and evaluated according to two main objectives, which are presented in the improving of the quality of healthcare, and its ability to meet the legitimate expectations of the citizens.

II.3.1 Definition

According to the compendium of U.S. Health Systems, the health system is defined as an organization that includes a minimum of one hospital and at least one group of a general practitioner that delivers a primary and specialty care, who are connected with each other and with the hospital through shared ownership. (Agency for Healthcare Research and Quality, 2017)

We could define it as a collection of activities, and means dedicated to protect and promote the health of the population. Its organization is designed to take care of the health needs of the population in a comprehensive, coherent, and unified way as part of the health plan. This system is managed by the state and it is based on the strengthening of the public sector in order to ensure a real development of free healthcare.

II.3.2 Structure

The health system is based on its units and the interconnection between them. It is constructed and analyzed according to several objectives. It is also defined based on the functions that it must assume, which are summarized in the delivery of personal care services (medical care, nursing, assistance to persons, etc.) in the field of public health. In addition to the other main functions which include administration, human resources, and funding.

The distribution of care includes activities providing preventive and curative care directed to all social structures: family, educational environment, work environment, living environment.

II.3.3 Main objectives

We can summarize healthcare ambitions and objectives in the following main points:

- Integration of the private sector into the national health system.
- Taking into consideration the development of the health information system.
- Adaptation of the organizational system to the adjustment and development of the socio-economic system.
- Prioritization of the distribution of care in the context of the health map.
- Preservation of the public sector and improvement of its performance.
- Institutionalization of the evaluation and control of health activities tasks according to the assigned objectives.
- Improvement of working conditions of the socio-professional situation of all health personnel.
- Encouraging the development of the national equipment and pharmaceutical industry and ensuring swift access to essential products.
- Focusing on the technical platform by setting up a quality assurance system.

II.3.4 Public hospitals

Hospital systems are particularly complex socioeconomic organizations. In Algeria, the hospital and health systems are facing several difficulties related to significant changes in their social and economic status, organizations, as well as an increase in their missions, without taking into consideration the amount of the needed resources, whether it was human or material. Permanently, the main objective of this facility is to provide and enhance the quality of the delivered healthcare. The optimization of hospital performance requires sustained effort to preserve care quality and the imposed cost with suitable time management.

Several definitions have been found in the literature, with almost the same meaning, according to the World Health Organization, hospitals are health care institutions that have an organized medical and other professional staff, and inpatient facilities, and deliver services 24 hours per day, 7 days per week. They offer a varying range of acute, convalescent and terminal care using diagnostic and curative services. (World Health Organization, 2019)

Hospitals are organized from different departments, the number and kind of departments differ from hospital to another relative to the size and type of the hospital. In the following, we are going to mention some of those departments:

- General surgery
- Anaesthetics
- Breast screening
- Critical care
- Occupational therapy
- Orthopaedics
- Emergency department

II.3.4.1 Algerian hospitals financing

Back from independence until 1974, the payment terms were made based on a daily price and acts pricing. A second period during which free treatment was instituted from 1974 to the present day, which is characterized by the implementation of a new financing procedure called "Budgeting", which replaced the former financing mechanism based on daily pricing. In the financing by the global budget, we distinguish two modes of payment either by the average price of the day of hospitalization or by the package per pathology.

II.3.4.2 Main challenges

Faced with the growing demand for healthcare under numerous constraints, the hospital confronts many issues. One of its duties is to find the appropriate balance between the cost, quality, and delay. Among the challenges, we mention the following:

- Health expenses control.
- Resources enhancement.
- Improving the quality of care.
- Response to future needs.
- Effective exploitation of recent technologies.

- Keeping pace with global developments (orient towards smart hospitals).

II.4 Hospital emergency department

The hospital emergency department is a crucial part of the health system and serves as the main portal for patients to the hospital. People may present for care only when symptomatic with acute illness or injury, expressly when there are logistical or financial barriers to healthcare access. Generally, the ill and injured present to frontline providers responsible for the care of both children and adults with medical, surgical and obstetric emergencies, including injuries, communicable and non-communicable diseases, and complications of pregnancy.

II.4.1 Definition

The word “emergency” refers to the crucial need to react to a situation in immediacy without delaying it. The most explicit illustration is that of the medical emergency, where the intervention cannot suffer any delay. (Daknou, 2011)

II.4.2 Characteristics

The emergency department is the main destination for patients whose states need immediate treatments. Considering its main characteristics will provide a clear vision of the kind of system, which we are dealing with. In the next, we are going to summarize the common characteristics of the hospital emergency departments in the following points:

- ED represents the main gateway to the hospital, which makes it suffering from an increased number of patients.
- Limited number of resources (human or material).
- Dedicated to swift treatments of urgent and critical cases.
- Its duty is to accept the patient at any time of the day or night.
- Contains numerous sections for different pathologies.
- Hospitalization does not exceed one week in most EDs.
- Lack of the number of beds and medicals staffs.
- The scheduling operation of medicals staff is crucial and needs precision.

- Most EDs are suffering from organizational and structural difficulties.
- It has a restricted budget in developing countries.

II.4.3 Functionalities

Due to the vital mission of hospital emergency departments, the necessity for EDs to meet citizen requirements, specifically when it is related to healthcare. Plays an important role in the success of these facilities. The following points are the main functionalities expected by every patient who resorts to this facility:

- Providing fast treatments, as soon as possible, with high quality.
- Preserving lives, stabilizing patients' state through care.
- Short-term hospitalization, availability of beds.
- An orientation of the patient at the right time, in the correct path, to the precise service.
- Deliver a continued service, 24 hours per day, 7 days per week.
- Improving care quality, by applying new and recent strategies based on scientific background.
- Acquisition of harmonious medicals teams, to reach a high treatment quality.
- Patients' satisfaction must be the slogan.

II.4.4 Key performance indicators

In this sub-section, we are going to mention briefly the commonly used emergency department key performance indicators (shown in Figure II.1). The role of the KPIs is to measure the performance of the ED, to identify the lacks of the system, which helps in targeting precise sites to reach a significant improvement in the study system. The following KPIs are the most used in the literature (Komashie and Mousavi, 2005):

- The patient total Length Of Stay (LOS): it provides a global idea about the system, it represents the duration of the patient inside the ED, from its entrance until its discharge or reorientation. The limit of this indicator is that it does not provide a precise view of system performance at different stages of the patient admission process.

- Left Without Being Seen (LWBS): it represents the rate of patients, which they enter the ED, but left without been seen by a doctor, due to the long waiting time.
- The Door To Doctor Time (DTDT): it is the amount of time between the arrival of the patient and the first medical examination. This indicator clarifies the system performance in the early stage of the patient admission process.
- Waiting times: taking into account the waiting times of patients at different stages of its treatments, will provide a precise view about the care quality and it will help in targeting the right place to be optimized.

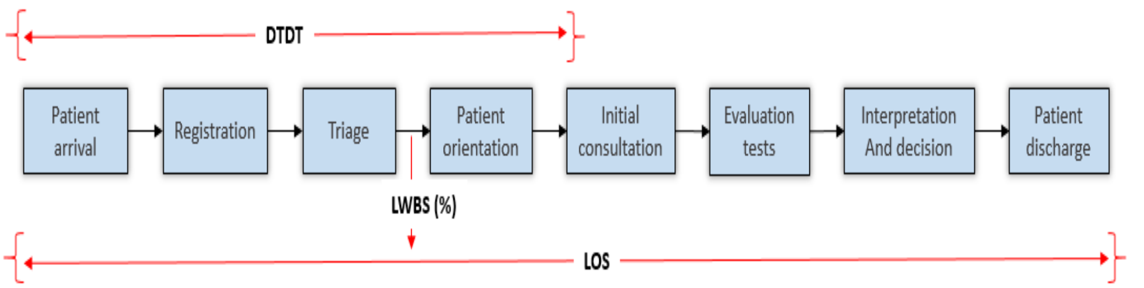


Figure II.1 - Key performance indicators of the hospital emergency departments

II.4.5 Overcrowding: A phenomenon at the emergency department

Beyond the common difficulties of the hospital system in general. Emergency departments are suffering from an undesirable phenomenon, presented in overcrowding situation. Overcrowding is a major issue for EDs managers, and which is the main reason for the long waiting time of patients inside the ED. Overcrowding in EDs is a concerning global problem and has been identified as a national crisis in some countries. (Evans et al., 2008; Fraikin, 2005) defines it as "*the situation in which ED function is impeded primarily because of the excessive number of patients waiting to be seen, undergoing assessment and treatment, or waiting for departure comparing to the physical or staffing capacity of the ED.*"

Some of the main consequences of this phenomenon are longer waiting times, extended patient length of stay, decrease in the rate of treated patients, reducing the care quality, and a drop in the performance of medicals staff, etc.

II.4.6 Challenges

Despite the efforts made by the Algerian government, emergency departments problems are in grow, for several reasons, including pauperization, which is increased by 10 million in the last twenty years, aging of the population, increasing in pediatric consultations, and growth in the number of chronic diseases, such as diabetes. Moreover, many reports highlight the seriousness of the situation in emergency departments. Some of the challenges are listed in the following points:

- Improving the quality of care.
- Facing the increase in chronic diseases in an effective way.
- Limiting overcrowding situations by applying adequate strategies.
- Optimization of resources utilization.
- Integrating recent technologies.
- Improving the level of medicals staff via training courses.
- Effective management of the budget by following the basic requirements.

II.5 The global scheme of the context

In this section, we are going to clarify our research position. To facilitate the underlined objectives and to specify precisely the area of this modest research. Socio-economic areas are numerous and enormous, Figure II.2 illustrates the chosen socio-economic field among various fields, and points our research context.

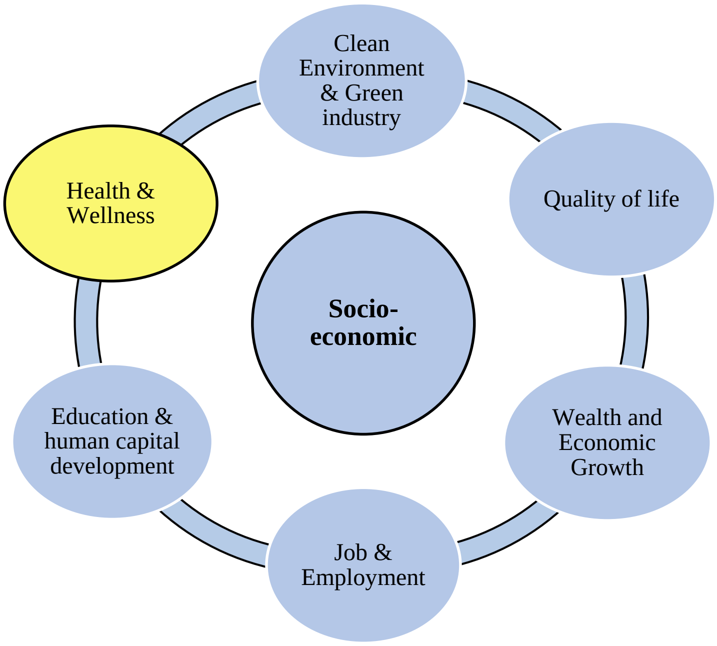


Figure II.2 - Concerned socio-economic area of this research (highlighted in yellow)

Among the different areas of the socio-economic system, we chose the field of health, due to its crucial effect on the level of evaluation of any country. Furthermore, the necessity of high-quality treatment services has a major priority for every human. The influence of health care systems on social inequalities in health remains controversial.

In Algeria, the Ministry of Health and Hospital Reform is the government department responsible for public health. Several institutions are under his supervision. Due to the enormous size of the healthcare system, we focus mainly on hospital emergency department, the positioning of the chosen system is showed in Figure II.3.

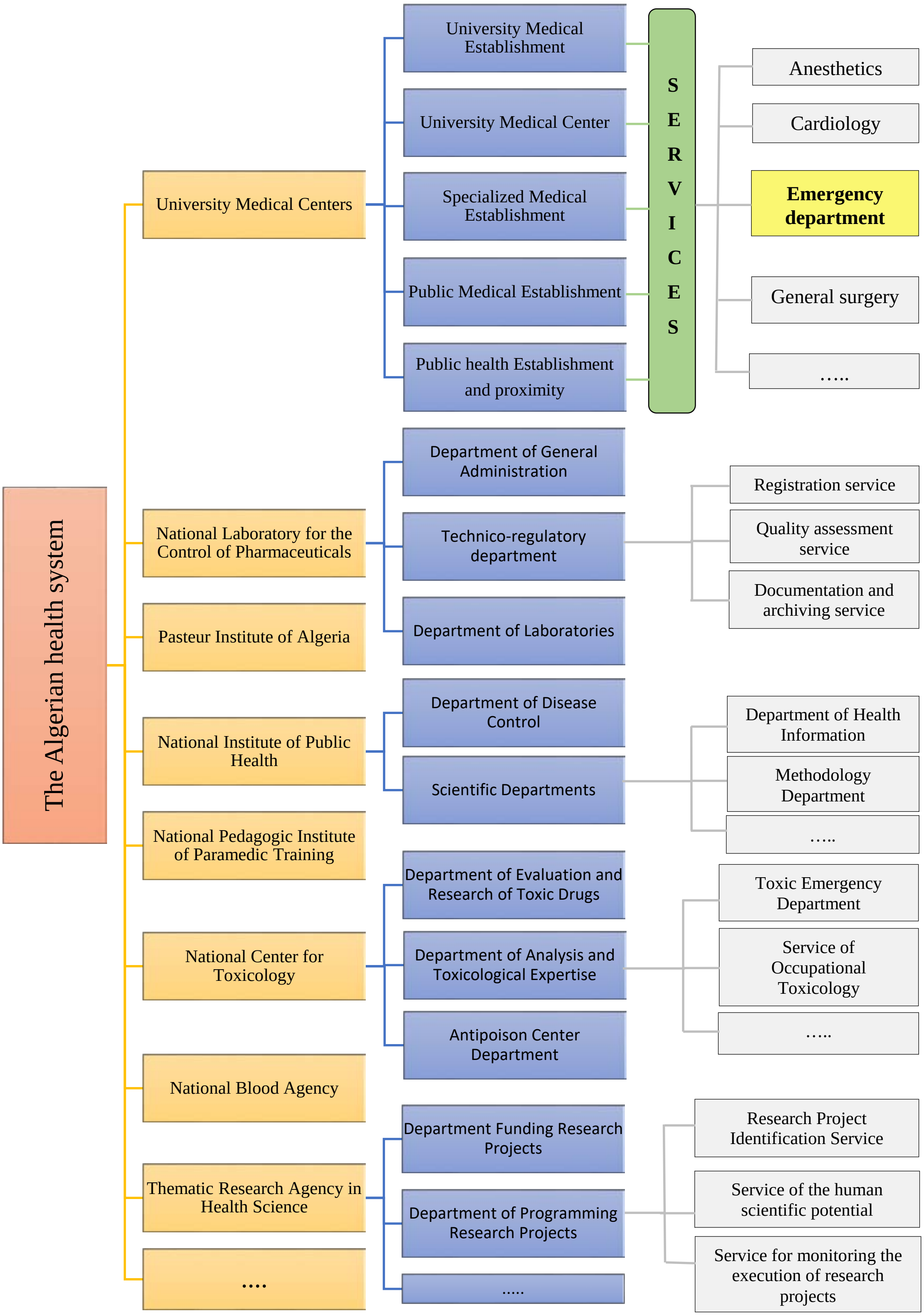


Figure II.3 - Organization of the Algerian health system (the concerned service is highlighted in yellow)

II.6 Conclusion

In this chapter, we have introduced the context of socio-economic problematic; we saw their vital issues and characteristics. We have also presented the organization of the Algerian health system, its structure, and the main objectives. We mainly focus on emergency departments, which represent the main entrance to the hospital. We provided their characteristics, as well as the different functionalities. Hospital emergency departments are complex organizations. Their complexities are associated with the complex nature of the care activity. The specificity of the hospital activity is, therefore, itself difficult and can only reinforce the complex nature of the organizations. Thus, we have discussed the main key performance indicators of the emergency department, which are useful to measure the performance of such a system. A set of EDs challenges are highlighted, to clarify the needed improvements. The encounter issues and the characteristics of this facility have allowed us to set the purpose of this thesis dedicated to developing new approaches for the improvement of hospital emergency departments, whose interest is the minimization of the total length of stay of the patient, as well as the waiting times. In order to reach our objective in improving the quality of the care process. A state of art on the different existing tools and approaches in the literature will be presented in the next chapter, to help us position our research.

Chapter III

Survey of the modeling and optimization technics applied in the healthcare field

III.1 Introduction

The purpose of this chapter is to present a survey of approaches and methods used in the design and piloting of complex care systems and more specifically in the hospital emergency departments. The importance of research work on hospital management and improvement issues has taken a large interest over the last twenty years, due to the growing concerns in those systems. In fact, faced with a difficult socio-economic context, the majority of hospitals around the world must comply with new management rules in order to minimize costs and maximize comfort and patient care quality. Many researchers thus looked at this problem, trying to bring new strategies of organization and planning for hospitals.

The advantage of the modeling of such a system is mainly presented in the identifying of the flaws and problems encountered. The modeling is a considerable help in the analysis phase of the existing state. Diverse optimization methods have been applied in performance improvement of healthcare systems, performance evaluation of a real system is broken down into a step of modeling to move from the system to the model and a step of analysis of model performance. This chapter presents different methodologies used for modeling and optimizing hospital emergency departments.

III.2 Modeling approaches

There are several methods and tools for modeling, optimizing and simulating a hospital system (Xie et al., 2016; Casucci et al., 2018; Wimmer et al., 2016; Helm, et al., 2015), as well for emergency services (Kadri et al., 2016; Chen and Wang, 2015; Ahalt et al., 2016). The choice of suitable methods and tools is made about the characteristics of the hospital system itself as well as the intended purpose of the modeling. In the following subsections, we will present several modeling methods, and valuable tools used in the modeling phase of such a system.

III.2.1 Multi-Agent Systems (MAS) approach

A Multi-Agent System (MAS) is a computerized system composed of multiple interacting intelligent agents. Multi-agent systems can solve problems that are difficult or impossible for an individual agent or a monolithic system to solve. Autonomous Agents and MAS represent a new approach or method for analyzing, designing and implementing complex computer systems. Agents are used in a variety of ever-increasing applications. The class of applications concerned by MASs is expanding more and more.

Multi-Agents Systems are distributed computer systems. Like most distributed systems, they are composed of computer entities that have interactions between them. Unlike conventional distributed systems, the entities that constitute them are "smart". Indeed, the field of multi-agent systems is derived from the field of Distributed Artificial Intelligence (DAI). When addressing this area, it is probably necessary to start by defining the terms "agents", "agent-based systems" and "multi-agent systems", which will be presented in the following subsections.

III.2.1.1 Agent definition

There is no exact definition of what an agent is. Among many definitions of the term "agent", we present the definition of (Ferber, 1995); he defines an agent as a physical or virtual entity who is:

- Able to act in an environment,
- Can communicate directly with other agents,
- Who is driven by a set of trends,
- Has its resources,
- Able to perceive (but in a limited way) its environment,
- Has only a partial representation of this environment,
- Has skills and offers services,
- Which can eventually be reproduced.

Moreover, it is also an entity whose behavior tends to meet its goals, taking into account the resources and skills at his disposal, and in according to its perception, representations and communications that she receives. Another definition of (Russell and Norvig, 2009), defined an agent as anything that can be viewed as perceiving its environment through sensors and acting upon that environment through actuators. The term “agent” for some Artificial Intelligent (AI) researchers has a meaning of a computer system that has a property which is either conceptualized or implemented using concepts that are more usually applied to human (Wooldridge and Jennings, 1995).

III.2.1.2 Agent classification

There is three main architectures are commonly used in MAS as following:

- **Reactive agents**: These kinds of agents are characteristics by their high speed, their actions are assimilated to reflexes. They operate according to a stimulus model. Indeed, as soon as they see a change in their environment they react by a programmed action. These agents are constantly in a standby state waiting for a likely change in the environment. Contrary to cognitive agents, the reactive agents do not have a clear picture of their environment.
- **Cognitive agents:** Is the most represented in the field of DAI, because it originates in the desire to communicate and cooperate with conventional expert systems (Ferber, 1995). These kinds of agents can work relatively independently, due to their sophistication and ability to reasoning about the world. Which they have an explicit representation of their environment, other agents and themselves. They have cognitive abilities: to anticipate, reasoning, memorizing, planning, and communicating.
- **Hybrid agents:** Is an agent architecture that combines a reactive system with a cognitive system. These agents combine the speed of response of the reactive agents with the reasoning capabilities of cognitive agents. The hybrid design approach attempts to respond by integrating to the diversification of the activities that are carried out by an agent.

A second dimension classification by (Nwana, 1996), defines seven categories of agents according to their architecture and function: (1) collaborative agents; (2) interface agents; (3) mobile agents, (4) information agents, (5) reactive agents, (6) hybrid agents, and (7) intelligent agents (illustrated in Figure III.1).

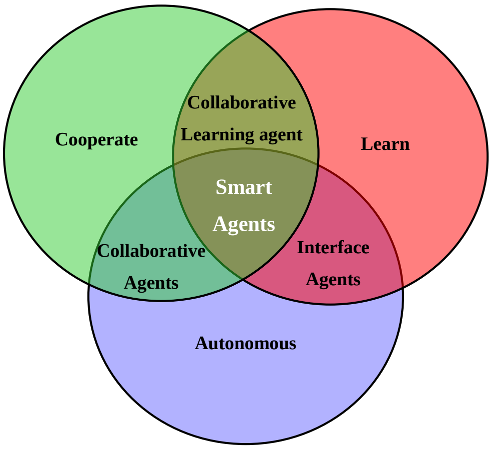


Figure III.1 - Agents categories defined by (Nwana, 1996)

III.2.1.3 Literature review of MAS applications in the health field

Hospital organizations nowadays operate in an uncertain environment and face many glitches emphasized by the growth in health, aging of the population, and an increasingly expensive shortage of medicals staff. In this perception, the characteristics of MASs seem to be particularly adapted for the representation and simulation of dynamic hospital systems. In the literature, many researchers have exploited the advantages of MASs, in the modeling and optimization of healthcare organizations.

In the thesis of (Daknou, 2011), the author implements a Decision Support System (DSS) to organize patients flow, schedule the activity of care process, and build schedules for the medical staff of the ED. Therefore, she proposed an open and dynamic system based on software agents to manage the patient management issues in the ED, whose objective is to minimize the patient's waiting time and the costs of care, with the preservation of care quality. The author has combined between optimization and MAS; she proposed a scheduling algorithm named OR-3P. It provides the scheduling of multi-skilled care operations and calculates the start dates of operation, taking into account the availability of the medical staff of the ED. A scheduler reactive MAS agent executes the proposed algorithm; the proposed approach provided acceptable results.

In the paper of (Pickering et al., 2012), the authors analyze the employment of smart strategies in daily care to expand the care given to patients. One of the features of agents is the natural incorporation of different entities with different roles. Daily care consists of a distributed attempt carried out by multidisciplinary staff teams that plan, schedule and execute difficult functions.

In recent research of (Liu et al., 2017), authors developed a systematic method to automatically examine a general emergency department model with incomplete data. They built a simulation model to search for the best value of model parameters. Then, they presented a case study to demonstrate the technique to test an agent-based model of an emergency department with real data lack. In fact, the flexibility of MAS is due to the composition of systems by several agents that can solve different problems; it makes it a decent choice for researchers in the modeling phase of healthcare systems.

A new Medical Multi-agent system has been proposed by (Jemal et al., 2015) to solve numerous complications in the hospital organization. Authors exploit the characteristics of the intelligent agent (proactivity, sociability, autonomy), to deal with the collaboration between hospital departments, planning of medical diagnostics, coordination among medical staff and the assortment patients' information. In order to improve care quality.

III.2.2 Unified Modeling Language

Unified Modeling Language (UML) is a language for modeling and non-proprietary specification. It is a symbolic graphic modeling language designed to provide a standard method for visualizing the design of a system. UML is an object-oriented language that is mainly used in the field of software engineering.

The UML offers a set of standardized graphical notation grouped into fourteen types of diagrams (see Table III.1), as it is specified in the modeling language specification version 2.5.1 published in December 2017 (OMG Unified Modeling Language, 2017). A common mistake for beginners is to consider UML as a method; in fact, it is a modeling language. In the following, we present more specifically the different kind of UML2 subsets: (1) views, their goal is to describe the system from a given point of view whether organizational, dynamic, temporal, architectural, etc.; (2) diagrams, they describe the content of the views; (3) Model elements, it is a basic UML bricks used in several types of diagram.

As with any other modeling tools, UML has advantages, as well as limitations. Some of the benefits of using UML is the gain of precision and it guarantees stability. UML is a powerful communication support; it facilitates the understanding of complex abstract representations. Moreover, it a universal language due to its versatility. On the other hand, the implementation of UML is dangerous because the modeling is totally free, and it requires learning and goes through a period of adaptation. Thus, the integration of UML in a process is not trivial and the improvement of a process is a complex and time-consuming task.

Table III.1 - A brief description of the different types of UML diagrams (OMG Unified Modeling Language, 2017)

UML Diagrams	***Description***
Structure Diagrams	
Class Diagram - Structured Classifiers	This diagram defines the structure of a system by showing the system's classes, their attributes, operations, and the relationships among objects. This type of diagram is mainly used for general conceptual modeling of the systematics of the application, and it is translated into a programming code.
Object Diagram – Classification	An object diagram focuses on some specific set of objects and attributes, and the links between these instances, it represents an instance of the class.
Component Diagram - Structured Classifiers	It describes how components are linked together to form larger components or software systems. Their usage is to illustrate the structure of arbitrarily complex systems.
Composite Structure Diagram - Structured Classifiers	The purpose of this diagram is to show the core structure of a class and the collaborations that this structure makes likely.
Deployment diagram – Deployments	Deployment diagram models the physical deployment of artifacts on nodes. It captures the association between an exact conceptual or physical element of a modeled system and the information assets given to it.
Package Diagram – Packages	Characterize the dependencies between the packages that compound a model.

Profile Diagram – Packages	Act at the meta-model level to show stereotypes as classes with the stereotype (“A stereotype defines how an existing meta-class may be extended,”), and profiles as packages with the «profile» stereotype, it uses XML Metadata Interchange (XMI) for the exchange of metadata information.
Behavior Diagrams	
Activity Diagram - Activities	Are graphical representations of activities workflows, with support choice, iteration, and concurrency. Activity diagrams are intended to model both computational and structural processes, as well as the data flow intersecting with the related activities.
Use Case Diagram - Use Cases	This diagram provides a representation of the interaction between the user and the system that illustrates the involvement of the user in different use cases.
State Machine Diagram - State Machines	The objective of this diagram is to overcome the main limitations of traditional finite-state machines while retaining their main benefits. A state machine diagram is a directed graph in which nodes denote states, and connectors denote state transitions.
Sequence Diagram – Interactions	It shows the different processes or objects that live concurrently, and as horizontal arrows, the messages interchanged between them, in the order in which they arise.
Communication Diagram – Interactions	This diagram models the interactions between objects in terms of sequenced messages. It represents a combination of information taken from different diagrams (classes, sequences, and use case diagrams), to illustrate the static structure and dynamic behavior of a system.
Interaction Overview Diagram - Interactions	This diagram is useful to in the deconstruction of complex scenarios; In the interaction overview diagram, each activity is depicted as a frame that can contain a nested interaction diagram.

Timing Diagram – Interactions	This diagram is a special case of sequence diagram; it adds the time notion, which is used to explore the behaviors of objects throughout a given period.

III.2.2.1 UML in the health field

In the health field, several kinds of researches have relied on UML as a modeling tool, due to the simplification of the comprehension of complex systems representations. In the paper of (Luzi et al., 2017), authors had developed a methodology based on UML to capture and single out meaningful parts of the child healthcare pathways to facilitate comparison among thirteen European Union countries within the Models of Child Health Appraised project. They use the "use case" diagrams to identify the activities, the actors involved and their relationships to a malady.

In the research of (Mans et al., 2015), a healthcare reference model was developed. This study aims to trace event data easily and to support data extraction. The development of the proposed healthcare reference model is based on an analysis of the available data in several hospitals in Germany. The model consists of 122 UML class diagrams that provide a good overview of the key data relevant for process mining. At present, UML is the industry standard in terms of diagrammatic modeling for software systems and parts of it, have also been used in other fields including healthcare (Komashie and Clarkson, 2016). In recent research of (Ma et al., 2018), authors focused on utilizing UML models to establish the use case diagram, class diagram, sequence chart and collaboration diagram. In order to fulfill the demands of the regular patient visit, inpatient, drug management and other related tasks.

In the paper of (Antonelli et al., 2018), researchers present a discrete event simulation of patient flows in elective surgery exploiting the recovery logs of a hospital department. They used a UML activity diagram to model the surgery process, and then they built a stochastic model of queuing network, identify its parameters and conduct different simulated experiments, in order to select the solution that best optimizes the performances of the system. As a result of their study, they found a large variation in waiting times in correspondence to small variations of the average value of the inter-arrival times.

III.2.3 Workflow approach

One of the initial usages of the term "workflow" was in a railway-engineering journal from 1921. Nowadays, Workflow becomes one of the common modeling approaches; it allows you to create a model that represents the behavior of a system, which is the first step before its implementation by an integrated motor. Throughout the implementation, the Workflow allows human actors to interact (reading and writing) at the right time, with the system through graphical interfaces. By reading, to profit from the right information at the right time, to perform the tasks in progress, and in writing to feed punctually the system of information necessary for its good progression.

III.2.3.1 Workflow definition

Workflow is a process that automates the flow of information flow within a company. The process affects various actors, including employees but also people in charge of tasks outside the company but concerned by them. The term "Workflow" is more commonly used in particular industries. It is used as a software engineering technique for the management of organizational processes. In the same context, we find the term Workflow management that refers to the domain, which focuses on the logistics of the business process (Van Der Aalst, 1998; Van der Aalst et al., 2004).

III.2.3.2 Objectives

The Workflow tool improves the validation circuit. It shares with each contributor the information needed to carry out its tasks. It indicates the delivery times or deadlines for completion of the task and recalls the validation methods. Its various functions enable it to organize the various tasks that employees must perform and to make sure that each task is carried out correctly. Moreover, it provides to manager a full control of the running, the performance and determines the points of blocking. Furthermore, it provides a precious distribution of the work between humans and computers.

III.2.3.3 Concepts

There are four principal concepts used in the Workflow approach presented in the following points:

1. **Process:** A process is a more general notion than Workflow; it consists of several tasks that need to be carried out and a set of conditions that control the order of the tasks. A process can also be called a procedure. A task is a logical unit of work that is carried out as a single whole by one resource (Papazoglou et al., 2002).
2. **Planning and scheduling:** A plan is a description of the logically necessary, partially ordered set of activities required to accomplish a specific goal given certain starting conditions. The scheduling problem consists of mapping tasks to nodes optimally. Often used approach to represent workflow is a directed acyclic graph. A significant part of the scheduling problem is the estimation of workflow execution time (Chirkina and Kovalchuk, 2014).
3. **Flow control:** In Workflow, it represents a dynamic control of the flow speed and flow volumes in motion and process. Such orientation to dynamic aspects is the basic foundation to prepare for more advanced job shop controls, such as just-in-sequence. It could perform the control flow of a large information system, with the application programs carrying out its data transformations (Papazoglou et al., 2002).
4. **In-transit visibility:** This monitoring concept applies to both transported objects and works in progress.

III.2.3.4 Workflow approach in the health field

Over the past years, healthcare facilities have entered the era of collaboration computerized, and to remain competitive, they must continuously increase the quality of healthcare. The Workflow approach is used for modeling and managing the activities of health facilities. It consists of working models for the coordination of medical staff activities. As well, to ensure a perfect interconnection by relying on the existing information systems. Many researchers have used Workflow model to test, and improve ED activities.

The authors have presented a workflow approach for modeling and optimization of the hospital emergency department based on a simulation model. In our study (Derni et al, 2018), we found that Workflow facilitates the design of patient flow inside the ED, and provides different levels of perspective on the studied flow. Furthermore, it offers an easy transition for the construction of the simulation model.

In the work of (Ajmi et al., 2014), the authors tried to determine the indicators and barriers that contribute to overcrowding situations. A Workflow model of patient flow has been built based on real data, which is effective for the detection of delay origins, and to avoid the indicators of congestion situations. While, in the paper of (Gatewood et al., 2015), researchers developed a protocol for early detection of patients with uncomplicated sepsis, in addition to severe sepsis and septic shock. They built a Workflow model to understand the current state of sepsis care in the studied ED. As a result of their study, they concluded that early screening interventions can lead to expedited delivery of care to patients, with sepsis in the ED and could serve as a model for other facilities.

In the research of (Weigl et al., 2017), authors have defined Workflow interruptions in the ED as an intrusion of an unexpected task or communication event, causing discontinuation of the current task and an observable task switch behavior. They found that the mere count of interruption sources was not associated with ED professionals' stress at work. Another interesting research paper (Tekin and Erol, 2016) have proposed a Workflow model to represent the sequence of operations at a dental hospital; the system is modeled with the software Rockwell Arena 13.5 simulator to configure the necessary improvements. This study aims is to solve the following issues: the calculation of appointment capacities and the assignment of an adequate number of staff to the appropriate services with improved scheduling.

In our paper (Derni et al, 2019c), we presented a description of patient flow inside a hospital ED. The study aims to prevent the care complication scheme by adopting a workflow approach to design the patient flow in a chosen ED. The objective is to enhance patients' flows, to improve the quality of patient supervision by targeting the minimization of the total and waiting times. A simulation model of the study system has been built and validated for a maximal rapprochement to reality.

Then, we evaluated many solutions using the Rockwell ARENA simulator to measure the impact of each solution. As a result of the study, we provided to ED supervisors many improvement solutions and recommendations to the issues identified in the modeling phase.

III.3 Optimization techniques

An optimization problem is defined as the search for the minimum or maximum optimum solution of a given function, called the objective function or cost function. The need for optimization is to provide the user of a system the best solution or nearest to the optimal, which meets his or her requirements. Optimization has introduced in order to improve the services, regardless of the field in which it is applied. An optimization problem concerns the execution of methods specific in search of an optimum solution. The optimum solution can be a value that maximizes or minimizes an objective function. There are numerous optimization methods; the choice of the method depends on the case study, whether it is a single variable or multi-variable problem, continuous or discrete. One of the crucial phases is the choice of an appropriate optimization method, which fits the context to solve the problem efficiently. Otherwise, the expected optimization will be ineffectiveness. Following the complexity of the problem, it may be solved by an exact method or an approximate method (Talbi, 2009) (see Figure III.2). Optimization methods are categorized into different classes (exact methods, approximate algorithms, Metaheuristics, and greedy algorithms); each class comprises a set of methods, each of those methods has its strengths and limits based on the kind of the faced problem.

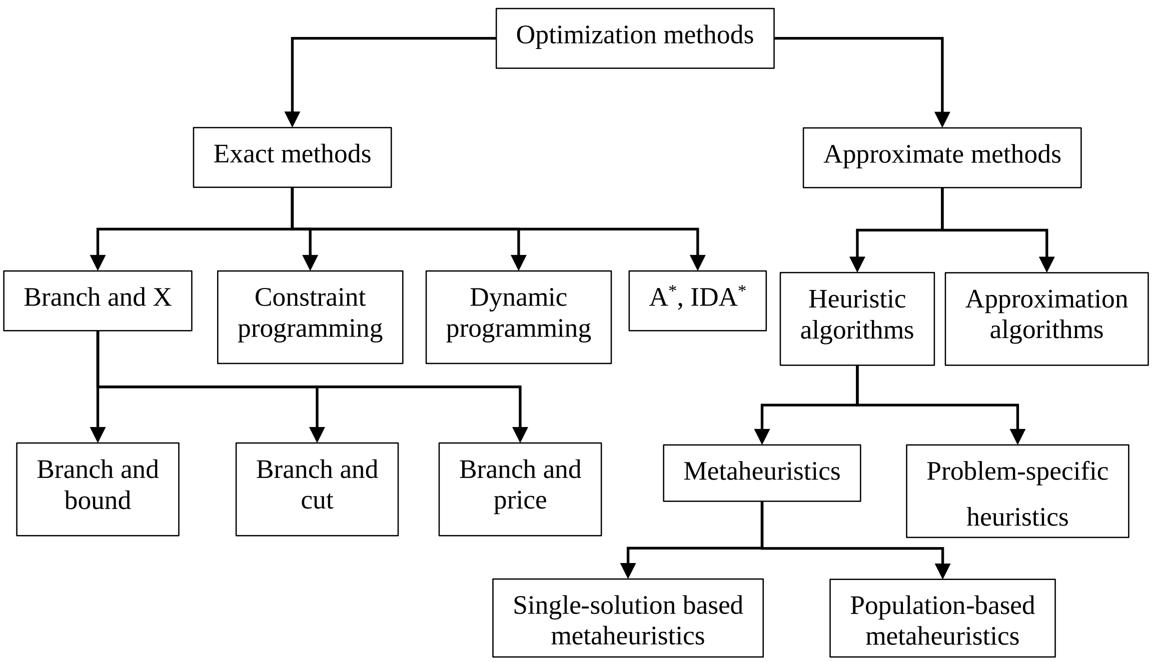


Figure III.2 - Classical optimization methods (Talbi, 2009).

III.3.1 The Branch-and-Bound (BnB) algorithm

This algorithm is based on an implicit enumeration of all solutions to the concerned optimization problem. It is classified in the category of the enumerative algorithm of mathematical programming approaches. BnB algorithm is dedicated to solving discrete and combinatorial optimization problems. The search space is explored by dynamically building a tree whose root node represents the problem being solved and its whole associated search space. The leaf nodes are the potential solutions and the internal nodes are sub-problems of the total solution space. The pruning of the search tree is based on a bounding function that prunes sub-trees that do not contain any optimal solution (Talbi, 2009).

This algorithm operates according to the following principles: (1) It recursively splits the search space into smaller spaces, then minimizing or maximizing the value of the objective function on these smaller spaces. (2) It starts a brute force search by enumerating and testing all search space solutions. For performance reason, it keeps track of bounds on the minimum/maximum that it is trying to find, and uses these bounds to restrict the search space.

III.3.1.1 Branch-and-bound algorithm in the health field

Back in 2000, in the paper of (Beaulieu et al., 2000), a new approach was proposed for the scheduling task of the physicians in the emergency room. Researchers had used the branch-and-bound algorithm for swift identification of effective feasible solutions. Then, they found that the schedule identified by the BnB algorithm is inefficient. An iterative approach was provided to improve the obtained poor quality, the approach proceeds as follows:

- Identify the rules that are violated in the current schedule.
- Add the corresponding constraints to the model.
- Use the BnB method to identify a new schedule.

In the work of (Defraeye and Nieuwenhuyse, 2016), authors have presented a BnB approach for the estimation of optimal shift schedules in systems with non-stationary stochastic demand and service level constraints. The algorithm is intended for personnel planning in-service systems with limited opening hours. As result, after many computational experiments, they conclude that the algorithm is efficient in avoiding regions of the solution space that cannot contain the optimum; moreover, it requires only a limited number of evaluations to encounter the estimated optimum. The proposed approach could be applied in the scheduling process of ED medical staff.

One of the robust points of the BnB algorithm is its rapid way to find good solutions while eliminating the sub-optimal branches. In recent research (Van Bockstal and Maenhout, 2018), the authors tried to solve the stochastic emergency department planning problem, while considering the planning of nurses and physicians simultaneously. The branch-and-bound method was used to solve a specified problem, for each sample scenario generated by a sampling method.

(Choi and Banerjee, 2015) have realized a comparison between two heuristics, the first heuristic adopts a branch-and-bound approach, while the second heuristic uses a sequential-inverse newsvendor approach using a starting solution. The objective of this study is to compare the mentioned heuristics to search for an optimal solution for outpatient appointment scheduling systems. As a result, the authors found that the heuristic that uses a sequential-inverse newsvendor approach provides near-optimal solutions far faster than the BnB based heuristic.

III.3.2 Dynamic programming

One of the common exact methods is Dynamic Programming (DP); it is an efficient method for obtaining an exact solution to an algorithmic problem. The effectiveness of this method is based on the principle of optimality stated by the mathematician Richard Bellman: "*An optimal policy has the property that whatever the initial state and initial decision are, the remaining decisions must constitute an optimal policy with regard to the state resulting from the first decision.", Another way is to say: "every optimal policy consists only of optimal sub policies*" (Bellman, 1957). Dynamic programming is based on the recursive division of a problem into simpler sub-problems. The procedure avoids a total enumeration of the search space by pruning partial decision sequences that cannot lead to the optimal solution (Talbi, 2009).

Designing a dynamic programming procedure for a particular problem requires the definition of the following components (Talbi, 2009; Bertsekas, 1998): (1) Define the stages and the states. A problem can be divided into a number of stages N. A number of states are associated with each stage. (2) Define the cost of the initial stage and states. There is an initial state of the system x_0. (3) Define the recursive relation for a state at stage k in terms of states of previous stages. The system takes the state x_k at stage k. At the k stage, the state of the system changes from x_k to x_{k+1} using the following equation $x_{k+1} = f_k(x_k, u_k)$.

III.3.2.1 Dynamic programming in the health area

The main idea behind dynamic programming is to start by solving the smaller sub-problems along keeping the values of these sub-problems in a dynamic programming table. These values are then used to calculate the value of large and larger sub-problems until we get the solution to our global problem. DP has been used in different research areas, as well as in the health field. Recent research of (Elalouf and Wachtel, 2016), suggest a DP algorithm and corresponding fully polynomial-time approximation scheme to help the ED physician in the triage phase to schedule patients' examinations and treatment while considering uncertainty regarding patients' actual medical requirements during their stay in the ED. In the paper of (Chan, 2018), the author chose a dynamic programming model. In the chosen model, physicians care about how they discharge individual patients and the number of patients they are left at the near end of shift time. As physicians proceed through their shifts, their choices to discharge patients are affected by expectations of future patient assignments. The model allows the simulation of the costs of physician time, patient time, and hospital resources under counterfactual assignment policies.

Interesting research of (Dai and Shi, 2018) focused on the assigning of inpatient beds; they model hospital inpatient flow as a multi-class, parallel-server queuing system and formulate the overflow decision problem as a discrete-time, infinite-horizon average cost Markov decision process. They used approximate dynamic programming to overcome the curse-of-dimensionality of the formulated Markov decision process. As a result, they demonstrate, via numerical experiments in realistic hospital settings, that the proposed algorithm is significantly effective in finding good overflow policies.

In modern work (Liu and Xie, 2018), the authors proposed discrete-time models for approximating the patient waiting times for any given ED staffing. The waiting time approximation is based on three things: (1) the separation of patients served in a period and patients overflowed; (2) the combination of M/M/c (multi-server queuing model) approximation for patients served and waiting time analysis of overflow patients; (3) the transformation of the performance evaluation into an optimization problem with the number of overflow patients as decision variables. Then, they used a DP method to decompose the staffing evaluation into a set of stage-dependent and state-dependent problems. Each stage is related to a period t, and the state is defined as the number q_{t-1} of overflow patients from previous periods.

III.3.3 Heuristics and metaheuristics

The first question that comes to the novice's mind is the difference between the two-optimization approaches. The word "heuristic" comes from the ancient Greek, which has the meaning of "discover". A heuristic is an algorithm designed to solve a given optimization problem. In fact, a heuristic is just a method of resolution, often informal and individual. It is an approach for problem-solving that employs a practical method, not guaranteed to be optimal, perfect, logical, or rational, but instead, it discovers reasonably good solutions in a practical time. A metaheuristic is just a generic heuristic, that is, a heuristic that can be used to solve unrelated problems. Unlike exact methods, metaheuristics allow tackling large-size problem instances by delivering satisfactory solutions in a reasonable time. There is no assurance to find the global optimal solutions or even bounded solutions (Talbi, 2009).

When we talk about metaheuristics, we have to refer to the number of methods divided into two categories; single-solution based metaheuristics such as local search, simulated annealing, the Tabu search, and iterated local search, etc. In addition to the first category, there are population-based metaheuristics, which comprises the following methods: genetic algorithms, evolution strategies, evolutionary programming, and ant colony algorithms, etc. We can classify the algorithms based on another criterion such as mono or multi-objective metaheuristics and so on. In the following sub-sections, we are going to introduce some related concepts, thus common used metaheuristics.

III.3.3.1 Common metaheuristics concepts

In order to design any metaheuristic, it is necessary to choose a representation (encoding) of the solutions and to define the objective function that will guide the search.

III.3.3.1.1 Encoding

The choice of representation of the manipulated solutions is crucial. Most metaheuristics have parameters whose adjustment is not necessarily trivial. The encoding must be suitable and relevant to the tackled optimization problem. Moreover, the efficiency of representation is also related to the search operators applied to this representation (neighborhood, recombination, etc.) (Talbi, 2009). Among the most common encoding, we have binary encoding, a vector of binary values, a vector of discrete values, a vector of real values, and permutation.

III.3.3.1.2 Objective Function

Called also fitness function, it serves as a criterion for determining the best solution to an optimization problem. In concrete terms, it associates a value with each instance of an optimization problem. In another term, it associates with each solution of the search space a real value that describes the fitness of the solution. The goal of the optimization problem is then to minimize or maximize this function forward to the optimum.

III.3.3.2 Local search

Most metaheuristics methods are based on the principle of Local Search (LS) metaheuristic, due to its simplest and efficiency. A local search starts at a given initial solution. Then, at each iteration, the heuristic replaces the current solution by a neighbor (obtained for example by a flip operation) that improves the fitness function. The search stops when all candidate neighbors are worse than the current solution, in other word when we reach a local optimum solution. (See Figure III.3).

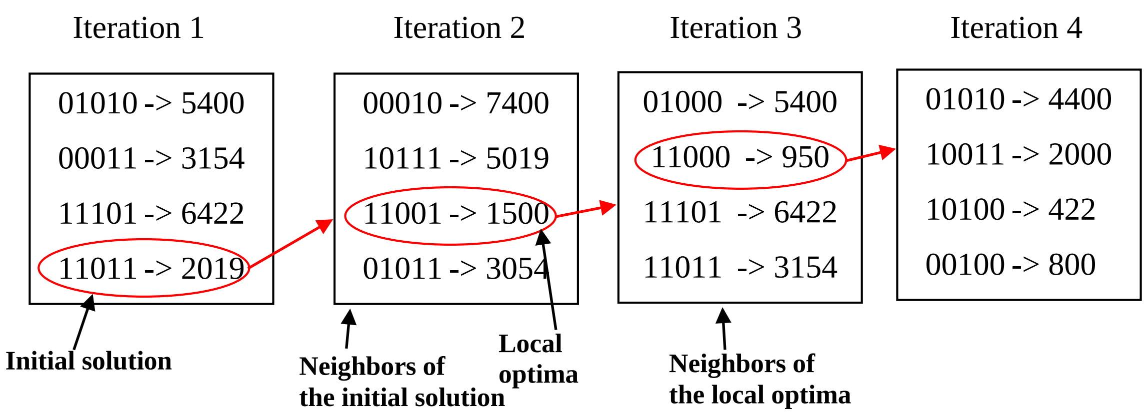


Figure III.3 - Local search process using a binary representation of solutions, a minimization objective function.

III.3.3.3 Simulated Annealing

Simulated Annealing or SA it is a metaheuristic inspired from the thermodynamic process, it is often presented as the oldest metaheuristic. The method comes from the observation that the natural cooling of certain metals does not allow the atoms to be placed in a solid-state. The most stable state is achieved by controlling cooling and slowing it down by external heat input, or by insulation. This method was developed by (Kirkpatrick et al., 1983). A template of the algorithm can be presented as follow:

Simulated annealing algorithm

Input: Cooling schedule.
$t = t_{max}$; // t is the initialized temperature at a high value
$s = s_0$; // s_0 is the initial solution
best_s = s;
Repeat
r = s';
p = random(0,1);
If ($f(r) < f(s)$) **OR** ($p < e^{\frac{f(r)-f(s)}{t}}$) **Then**
s= r;
If ($f(s) < f(best\_s)$) **Then**
best_s = s;
decrease t;
Until (best_s is the best solution **AND** nb_iterations = max **AND** t <=0)
Output: Best solution found (best_s).

III.3.3.4 Tabu search

The Tabu Search (TS) algorithm is a technique of research whose principals have proposed for the first time by (Glover and Laguna, 1998) it differs from other research methods by using a history of the visited solutions, to reduce the randomness of the search process. It becomes possible to get out of the local minimum. However, to avoid falling back periodically, some solutions are considered taboo. Indeed, the originality of the method is the introduction of memory through the use of taboos. This consists of recording what happened in the past stages in a list called "tabu", in order to keep track of the latest solutions visited to prevent this from happening again. The goal is obviously to encourage a broad exploration of the space of solutions and to avoid looping in a local optimum or to return too quickly. A template of the algorithm is presented as follow (Talbi, 2009):

Tabu search algorithm

$s = s_0$; // s_0 is the initial solution
Initialize the tabu list, medium and long term memories;
Repeat
Find best admissible neighbor s'; // non tabu or aspiration criterion holds
s = s';
Update tabu list, aspiration conditions, medium and long term memories;
If (intensification_criterion holds) **Then** intensification;
If (diversification_criterion holds) **Then** diversification;

Until (Stopping criteria satisfied)
Output: Best solution found

III.3.3.5 Genetic algorithms

Genetic Algorithms or GAs are inspired by molecular biology. They have proposed by (Holland, 1975) in Michigan, USA. GAs consider a solution as a structure of chromosomes containing good and bad phenotypes. Assuming the good one's phenotypes are part of the optimal solutions, the GA uses the mechanism of reproduction, natural selection and the principle of mutation to produce new solutions in which chromosome contains better phenotypes. In practice, at each iteration, a set of chromosomes is selected for the reproduction process. The selected chromosomes are then crossed to produce new chromosomes called children chromosomes. The first step is the representation or coding of the solutions. Then, we create an initial chromosome population with a fixed-size, either randomly or by a heuristic. Subsequently, GAs generate new individuals to perform better than their predecessors. The improvement process is carried out by the use of genetic operators (selection, crossover, and mutation).

III.3.3.6 Metaheuristics in the health field

Metaheuristics proved to be a class of approximate methods highly adaptable to a large number of combinatorial problems and constraint assignment problems. These methods are very effective in providing good, approximate solutions for multi-objective optimization problems. In the health field, many researchers have benefited from the strengths characteristics of metaheuristics in the improvement of the systems' performances.

In the paper of (Zheng, et al., 2015), authors have studied the risk prediction of hospital readmissions, they mix between meta-heuristic and data mining approaches. Their study aims to demonstrate the risk of the increased number of readmission. They proposed various data mining approaches to identify the risk group of a particular patient, including the neural network model, the random forest algorithm, and the hybrid model of swarm intelligence.

Another interesting research of (Wachtel, and Elalouf, 2017), which proposed a scheduling algorithmic approach to reduce the crowding phenomena in an emergency department. Their approach is based on the "floating patients" method, in which the ED triage can send some patients directly to hospitalization departments instead of providing them with full examinations in the ED. The authors designed an integer linear algorithm model and metaheuristic model to deal with all the problem's factors. The main goal of their study is to enable to ED' decision-maker to control and balance the crowding in the ED with the crowding in other hospital sections.

In recent work (Sajadi et al, 2016), researchers use a simulation-optimization approach for nurse scheduling in an Iranian hospital emergency department. In their research, they proposed a mathematical method for nurse scheduling that fulfills the hospital limitations and nurse preferences, to minimize the patients' waiting times. Annealing algorithm is applied to find the appropriate schedule. As a result, they reached an improvement of 18% in the waiting time compared to the existing schedule.

In the research of (Bastos et al., 2019), a mixed-integer programming approach was proposed for the patient admission scheduling problem. In their paper, they consider a static offline operational level variant for which they proposed a comprehensive mixed-integer programming formulation and advance an exact solution method. As a result, they generated the new best solution for nine out of thirteen benchmark instances from a publicly available repository.

III.4 Recap of the modeling and optimization approaches used in the health area

In this section, we are going to present all the cited methods and technics used in the modeling and optimization of healthcare systems. Table III.2 presents the modeling and optimization technics with their advantages and limits.

Table III.2 - Advantages and limits of the modeling and optimization approaches used in the health area

Approach	***Authors***	***Pros***	***Cons***
Multi-Agent Systems	(Wang et al., 2010), (Garcia-Vázquez et al., 2010), (Daknou, 2011), (De Meo et al., 2011), (Isern et al., 2011), (Pickering et al., 2012), (Su and Chu, 2014), (Jemal et al., 2015), (Liu et al., 2017).	✓ Proper for the modeling of the healthcare system, such as ED, by modeling each medical staff by an agent. ✓ Provides an easy way to test new configurations of medical teams by adding/removing staffs, which are represented by agents.	✗ Multi-agent systems are complex, difficult to apprehend and conceive. ✗ Sometimes the design of MAS is difficult, due to the complexity and the lack of certainties in most healthcare services.
Unified Modeling Language	(Ji et al., 2014), (Mans et al., 2015), (Komashie and Clarkson, 2016), (Boussadi and Zapletal, 2017), (Luzi et al., 2017), (Ma et al., 2018), (Antonelli et al., 2018).	✓ UML is a formal and standardized language; it offers a gain of precision and stability when we deal with healthcare systems. ✓ The numerous UML diagrams simplify the system modeling	✗ Applying UML requires learning and goes through a period of adaptation, which is not an easy task specifically in the healthcare field. ✗ UML does not solve all communications problems, which is

		process and issue identification.	fundamental between the medical entities in the health area.
Workflow approach	(Ajmi et al., 2014), (Gatewood et al., 2015), (Boelstler et al., 2015), (Lee et al., 2015), (Tekin and Erol, 2016), (Weigl et al., 2017).	✓ Modeling patient movements inside medical services (e.g. emergency department), it speeds up the modeling and provides a clear view of the system flow. ✓ A Workflow model offers great help in the building of the simulation model.	✗ High cost of software and training. ✗ The graphical models become more complex and difficult to understand when dealing with huge systems. Such as big emergency departments, when the systems compromised numerous sections.
Branch-and-bound	(Beaulieu et al., 2000), (Defraeye and Nieuwenhuyse, 2016), (Van Bockstal and Maenhout, 2018), (Choi and Banerjee, 2015).	✓ It swiftly provides good solutions and eliminates sub-optimal branches. ✓ Provides acceptable solutions in the planning problem (medical staff).	✗ The prohibitive number of solutions makes the enumeration ambiguous. ✗ The solutions are not guaranteed to be optimal, which may impose more cost on the managers of the concerned service.
Dynamic programming	(Elalouf and Wachtel, 2016), (Dai and Shi, 2018), (Liu and Xie, 2018),	✓ Offers an implementation relatively straightforward and obtaining an exact solution, which represents an improvement decision of the studies health service.	✗ Conducts to a combinatorial explosion of the set of states when one tries to take into account less restricted constraints. ✗ The definition of constraints is not obvious, specifically when dealing with complex systems, such as health services.

Metaheuristics approaches	(Zheng, et al., 2015), (Wachtel, and Elalouf, 2017), (Sajadi et al, 2016), (Bastos et al., 2019).	✓ Ease adaptation to any type of optimization problem, which gives the possibility of its success in the health area.	× Non-guarantee that the discovery solution is the global optimum. × The final solution may result in a low-quality decision.

III.5 Conclusion

In this chapter, we highlighted the common modeling and optimization approaches used in the health field. We presented numerous modeling approaches (Multi-Agent Systems, Unified Modeling Language, and Workflow); which help in the identification of system dysfunctions and glitches, each of those methods has its pros and cons. Furthermore, a literature review was presented to indicate the utilization of industrial and operational research approaches in the healthcare domain, which is in continued growth, especially in the last two decades. Likewise, we detailed different optimization technics (Branch-and-Bound algorithm, Dynamic programming, and Heuristics and Metaheuristics), which are applied in many kinds of researches. Especially, in healthcare optimization problems (scheduling, resource management, decision making, etc.). The following next two chapters will present the author contributions, we will study and propose two optimization approaches, applied on different case study Algerian emergency departments. In the next chapter, we are going to start by presenting an introduction to the colored Petri net framework, and then we explain in detail our optimization approach, with its application in an existing hospital emergency department.

Chapter IV

Modeling and optimization of the ED system: a case study in Chalabi Abdelkader Hospital

IV.1 Introduction

Patient flow management has significantly grown during the previous period, as it straight affects the patients' health and their satisfaction level. Mismanagement of patients' flows in EDs is one of the common reasons, which leads to overcrowding, long waiting times, high mortality rates, and a low number of treated patients. Most of the recent researches realized in the ED such as (Carvalho-Silva et al., 2018; Konrad et al., 2013; Azari-Rad et al., 2014), has significantly focused on optimization of patient flows.

Emergency department overcrowding is a widespread circumstance in the world (Chan et al., 2011), as in Algerian hospitals. Indeed, the number of people who came to the EDs in most Algerian hospitals is steadily increasing, for a variety of reasons, including pauperization, aging of the population, increasing in pediatric consultations, and growth in the number of chronic diseases. Moreover, free and direct access to this facility and specifically consultation at any time of the day or night without an appointment, and whatever the reason for consultation, rise ED management challenges. Studying such a system requires a modeling phase due to the complexity of the system.

In this chapter, we start by introducing a Colored Petri Net Framework, which is a widely used formalism for describing concurrent systems (Westergaard and Kristensen, 2009). Then, we present our approach for modeling and optimization of ED systems. Afterward, Colored Petri Net tools (Westergaard and Kristensen, 2009; Ratzer et al., 2003) is employed to simulate patient flow in a case study system, besides the validation and its aid in the process of selecting the effective improvement scenario, which can be applied in a real environment. This study aims to provide to the ED managers numerous improvements solutions to enhance the care quality, by minimizing the total patient's length of stay. This is an important key performance indicator for EDs, and it has been used in many previous works (Carter and Potts, 2014; Armony et al., 2015), for the purpose to evaluate the level of health care quality and patients' satisfaction.

IV.2 Petri nets

Petri nets is an excellent mathematical modeling language for the description of dynamic execution, and modeling of distributed systems. They were been created by Carl

Adam Petri in the 1960s, and the initial use of Petri nets' concepts was for describing chemical processes.

Petri nets have rarely been used in the field of modeling and simulation in the health field, but some of the few studies (Wang et al., 2018; Gaudel et al., 2015; Chiang et al., 2018) that have done in recent years, had provided good results. Petri nets are an excellent tool, for their swift orientation to the simulation. A Petri net is also a modeling language represented in the form of a directed bipartite graph composed of nodes called places and transitions, connected by weighted arcs. Yet the Petri nets are the only set of tools that allows both the specification functional, modeling and evaluation of production systems. Besides, it offers simple natural graphics support to designers.

IV.2.1 Formal definition

A Petri net donated by PN is a four-tuple $PN =< P, T, A, W >$, where:

- P is a finite, non-empty, set of places,
- T is a finite, non-empty, set of transitions, with $P \cup T \neq \emptyset$ and $P \cap T = \emptyset$
- A is a finite set of arcs; $A \subseteq (P \times T) \cup (T \times P)$
- $W: (P \times T) \cup (T \times P) \rightarrow \mathbb{N}$ is a mapping that assigns a weight to an arc: $W(x, y) > 0$ iff $(x, y) \in A$, and $W(x, y) = 0$ otherwise, where $x, y \in P \cup T$.

IV.2.2 Places, Transitions, and Arcs

A Petri net has three main components, named places, transitions, and arcs. Graphically, a place is represented by a circle and a transition by a box or a bar. Places and transitions are connected by arcs (a line-linking place and transition). The number of places and transitions are finite and not zero. An arc is directed and connects either a place to a transition or a transition to a place. In another word, a Petri net is a bipartite graph (see Figure IV.1).

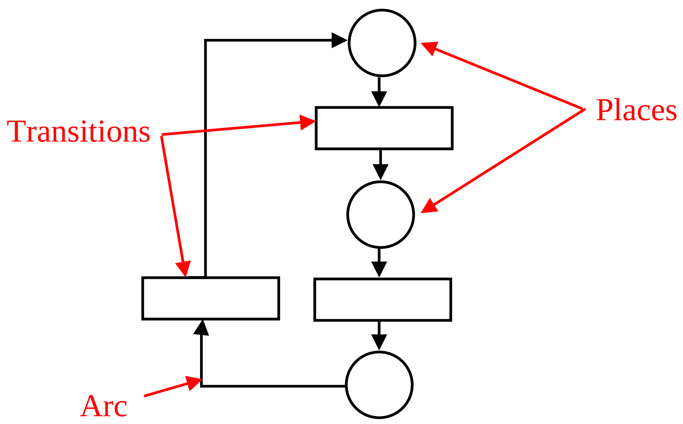


Figure IV.1 - A graphical representation of a non-marked Petri net

IV.2.3 Marking

In a marked Petri net (see Figure IV.2), each place contains a natural number, which represents the number of tokens or marks on that place. The marking defines the state of the Petri net, or more precisely the state of the modeled system. The complete configuration of the net, with all positioned marks, forms the marking and defines the state of the system. The evolution of the state thus corresponds to an evolution of the marking, an evolution that is caused by the firing of the transitions. In the following, we will explain the transitions firing concept.

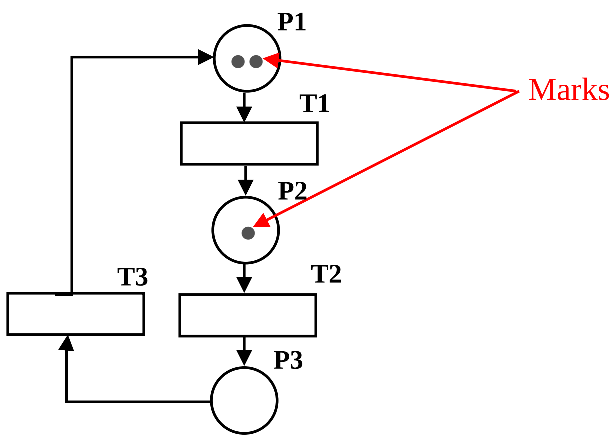


Figure IV.2 - A graphical representation of a marked Petri net

IV.2.4 Transitions firing

Petri nets integrate a formalism to go from one mark to another, by crossing transitions. A transition is traversable if each of its entry places contains at least one mark. For traversable transitions, we define the effective crossing according to the following rules:

- the crossing is an atomic operation, not devisable neither interruptible,
- a mark is consumed (removed) from each entry (input place) of the fired transition,
- a mark is produced in each output place of the crossed transition.

Figure IV.3 shows a system state before and after firing a transition (T1), as it is illustrated in the figure, a token has been moved from an input place (P1) to an output place (P2). The example shows an ordinary Petri net (arcs weight equal to 1).

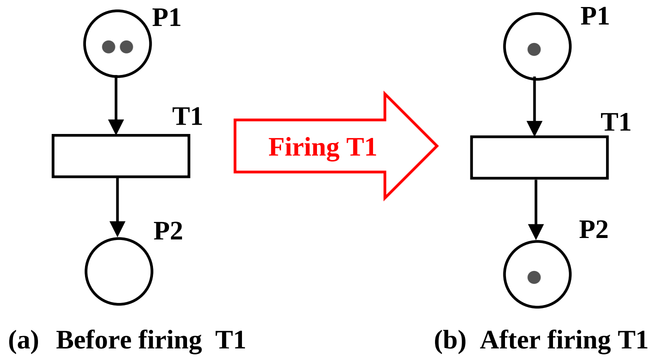


Figure IV.3 - Marking (system state) before and after firing the transition T1

IV.2.5 Classification of Petri Nets

Back in 1995, Monika Trompedeller has proposed a Petri nets classification based on a survey made by (Bernardinello and De Cindio, 1992). The classification is, however, valuable for getting a quick summary of the key differences between the various types of Petri nets. She classified Petri nets into three different levels, presented in the following:

- **Level 1:** in this class, Petri nets are identified by places, which can define Boolean value, for example, a place is marked by at most one unstructured token. Some of the common Petri nets of this level with their specific tools are listed as follow:
    - Condition/Event Systems: POSES, HyperNet, and WinPetri.

  - Elementary Net (EN) Systems (Brauer et al., 1987).
  - 1-safe systems: Environment for Action and State-based Equivalences (EASE), which is an environment for net transformations and reductions based on State-based Equivalences.
- **Level 2:** Petri nets of this level are characteristic by places, which can represent integer values, for example, a place is marked by a number of unstructured tokens. There are several examples of the second level Petri nets. We mention, Place/Transition (P/T) Nets, which are supported by numerous simulation tools (CPN/AMI, PENECA, PNS, CAPSNET, etc.), as well as performance analysis tools (PESIM, TORAS, INA, and WINPETRI).
- **Level 3:** Petri Nets characterized by places, which can represent high-level values, i.e., a place is marked by a multi-set of structured tokens. Many Petri nets belong to this class, we mention the following:
  - High-Level Petri Nets with Abstract Data Types (HL+ADT), which includes:
    - Algebraic High-Level Nets
    - OBJSA Net Systems
  - Environment/Relationship (ER) nets are high-level Petri nets where tokens are environments.
  - Product Nets.
  - Well-Formed (Colored) Nets (WN), which are an extension of Regular Nets.
  - Traditional High-Level Petri Nets includes:
    - Predicate/Transition Nets.
    - Colored Petri Nets, this type will be discussed in detail in the next sections.

Numerous tools are available for the simulation and process analyzing, which provide excellent support for the mentioned Petri nets. Among them, we cite the following tools: SANDS-COOPN, CABERNET, Product Net Machine, PSITool, VOLTAIRE, etc. Each of those tools has its strengths and limits, which principally depends on the kind of the used Petri net and the concerned case study system.

IV.2.6 Advantages

Some of the main benefits of Petri nets are resumed in the following points:

- Petri nets are particularly suitable for planning and scheduling in production systems.
- It can be transparently transposed to the health field.
- The formalism of Petri nets allows a description of the dynamic behavior of a system in a precise way by evolving the marking of the net.
- Petri nets can be interfaced with a control system.
- Their simplest concepts accelerate the modeling process.

IV.3 Petri nets in the health field

Petri nets are a rich modeling tool for the modeling and simulation process of complex systems. In the health field, several kinds of research have relied on Petri nets as a modeling tool. In recent research (Mahulea et al., 2018), authors have presented a modular approach for modeling healthcare systems using Petri nets. They constructed a model of the healthcare system using separated modules. Each module has been modeled in two phases: obtain the sequences of treatments and cares received by a patient in the case of a particular disease/condition, and add the resources necessary to perform the previous sequences. The final model (global model) is the fusion of inputs and outputs of each sub-module. Which presents a new subclass of Petri nets named healthcare Petri nets. Their approach is applied in a Spanish public healthcare area, the obtained model simplifies the study and the structural analysis of healthcare systems' problems.

In the paper of (Oueida et al., 2018), researchers have proposed a Resource Preservation Net (RPN) framework using Petri net, the proposed framework is integrated with a custom cloud and an edge computing suitable for ED systems. As a result, after the simulation of the system, they reached a significant improvement in terms of the patient's total length of stay at the ED, as well as a reduction in patient waiting times.

Patients scheduling in a hospital is a complex task for the medical supervisor, due to the distributed nature of the system, unpredictability of patient flow and the lack of resources. A systematic approach has been developed by (Hsieh, 2017), for system scheduling; the approach is based on MAS, to reduce patient stay duration in the hospital and plan schedules based on the medical workflows and the available resources. The approach is a combination between MAS architecture, contract net protocol, workflow specification models based on Petri nets and the cooperative distributed problem-solving concept.

Many researchers have targeted the overcrowding phenomena in the EDs, in the study of (Duma and Aringhieri, 2017); authors have applied Process Mining techniques to a real case study: from the ED database, discovery techniques identify the possible paths of a patient based on the information available at the triage. Their study aims to obtain a detailed process model for the predicting of patient flows inside the ED. They mined a Petri nets' process model, using an inductive miner. This study is viewed as an initial stage of implementing online algorithms for patient flow optimization, with objective presented in minimizing ED overcrowding.

The study of healthcare protocols is a crucial portion of the optimization process of healthcare organizations, due to the benefices obtained by analyzing and identifying different issues that affect care quality. (Whittaker et al., 2015) have introduced an augmented form of Petri nets called "Choice-point nets" that can capture timing and probability. The goal of the developed form is to model health-care protocols, in which the events or actions taken by health-care professionals, institutions and patients occur either at prespecified times or after a prespecified lapse of time.

Simulation technics have been applied in different areas of research, as well as in the health field. The paper of (Zehrouni et al., 2017) presents a simulation model, for the evaluation of health care emergency plans and assesses the resilience, in case of a major flood. A timed Petri net is used to model patient flow. As a result, the proposed model can be used to elaborate on an optimized strategy for evacuation and transfer operations. In the paper of (Durojaiye et al., 2018), authors have described a process mining approach for mapping the in-hospital flow of pediatric trauma patients, to identify and characterize the major patient pathways and care transitions and to identify opportunities for patient flow and triage improvement in the emergency department. Other researchers have focalized in enhancing outpatient clinics.

In the research of (Alfonso et al., 2012), modeling and simulation of blood collection systems in France were done. Petri net was used to model and describe the different blood collection processes, donor behaviors, resource requirements, and relevant regulations. Petri net models are then enriched with quantitative modeling of donor arrivals, donor behaviors, activity times and resource capacity. Their study aims to provide simulation models, which can serve as a decision aid tool for identifying adequate strategies of capacity planning of medical staff (physicians and nurses) and donor appointment scheduling strategy in clinics. Scheduling patients in a hospital is a challenging issue as it calls for sustainable architecture and an effective scheduling scheme that can dynamically schedule the available resources.

The objective of the research accomplished by (Hsieh and Lin, 2014) is to propose a viable and systematic approach to develop a distributed cooperative problem solver for scheduling patients based on MAS to minimize the patient stay in a hospital. They used the Petri net as the workflow specification language, and then the scheduling problem is divided into several scheduling subproblems that are solved by several cooperative scheduling agents.

IV.4 Colored Petri nets

Colored Petri Nets shorted CPN, are a backward-compatible extension of the concept of Petri nets. They are classified in the third level, according to the classification made by Monika Trompedeller, which is based on the survey of (Bemardinello and De Cindio, 1992). Indeed, more precisely, these kind of Petri nets are part of the Traditional High-Level Petri Nets (see sub-section IV.2.5). As in all other kinds of Petri nets, a CPN model is constructed by a set of places and a set of transitions, linked by arcs. The places and their tokens represent states, while the transitions represent state changes. However, each place may contain several tokens and each of these has a color, which represents a data value. We can classify CPNs into two main classes, Hierarchical and Non-Hierarchical Colored Petri nets, in the following we are going to present both classes.

IV.4.1 Non-Hierarchical Colored Petri nets

According to (Jensen, 1991), the formal definition of Non-Hierarchical Colored Petri nets is defined as a tuple $NHCPN = (\Sigma, P, T, A, N, C, G, E, IN)$ satisfying the following requirements (see Table for an explication of each of those points):

(a) **Σ** is a finite set of types, called **color sets**. Each color set is finite and non-empty.

(b) ***P*** is a finite set of **places**.

(c) ***T*** is a finite set of **transitions**.

(d) ***A*** is a finite set of **arcs** such that: $P \cap T = P \cap A = T \cap A = \emptyset$.

(e) ***N*** is a **node** function. It is defined from A into $P \times T \cup T \times P$.

(f) ***C*** is a **color** function. It is defined from P into Σ.

(g) ***G*** is a **guard** function. It is defined from T into expressions such that:

- $\forall t \in T: [Type(G(t)) = Bool \wedge Type(Var(G(t))) \subseteq \Sigma]$.

(h) ***E*** is an **arc expression** function. It is defined from A into expressions such that:

- $\forall a \in A: [Type(E(a)) = C(p(a))ms \wedge Type(Var(E(a))) \subseteq \Sigma]$.Where $p(a)$ is the place of $N(a)$.

(i) ***IN*** is an **initialization** function. It is defined from P into expressions such that:

- $\forall p \in P: [Type(IN(p)) = C(p)ms \wedge Var(IN(p)) = \emptyset]$.

The following table presents a brief explanation for each of the mentioned requirements.

Table IV.1 - Explanation of the main requirements of Non-Hierarchical Colored Petri Nets

Requirements (components)	***Explanations***
(a) The color sets	It determines the types, operations, and functions that can be used in the net inscriptions for arc expressions, guards, initialization expressions, color sets, etc.
(b) The places, (c) transitions and (d) arcs	Are described by three sets P, T and A which are demanded to be finite and pairwise disjoint.
(e) The node function	It maps each arc into a pair where the first element is the source node and the second the destination node.
(f) The color function	It maps each place P into a set of possible token color $C(p)$. Each token on p must have a color that belongs to the type $C(p)$.

(g) The guard function	This function maps each transition t into an expression of type Boolean.
(h) The arc expression	It maps each arc a into an expression, which must be of type $C(p(a))ms$ This means that each evaluation of the arc expression must yield a multi-set over the color set that is attached to the corresponding place.
(i) The initialization function	This function maps each place p into an expression which must be of type $C(p)ms$.

IV.4.2 Hierarchical Colored Petri nets

The absence of compositionality in Petri nets models has been one of the main critiques. To meet this critique, hierarchical Colored Petri nets have been developed. In this class of CPN model, it is possible to create a number of individual CPNs, which then can be related to each other in a formal way - i.e. in a way, which has a well-defined behavior and thus allows formal analysis. A hierarchical CPN is a tuple $HCPN = (S, SN, SA, PN, PA, FS, PT, PP)$ satisfying the following requirements (Jensen, 1991):

(a) $S = \{S_i \mid i \in I\}$ is a finite set of **pages** such that:

- Each page is a non-hierarchical CPN: $Si = (\Sigma_i, P_i, T_i, A_i, N_i, C_i, G_i, E_i, IN_i)$.
- The sets of net elements are pairwise disjoint:
  $\forall(i,k) \in I: [i \neq k \Rightarrow (P_i \cup T_i \cup A_i) \cap (P_k \cup T_k \cup A_k) = \emptyset]$

(b) $SN \subseteq T$ is a set of **substitution nodes**.

(c) SA is a **page assignment** function. It is defined from SN into S such that:

- No page is a subpage of itself:
  $\{i_0\, i_1 \dots i_n \in I^* \mid n \in \mathbb{N}_+ \wedge i_0 = i_n \wedge \forall k \in 1..n: S_{i_k} \in SA(SN_{i_{k-1}})\} = \emptyset.$

(d) $PN \subseteq P$ is a set of **port nodes.**

(e) PA is a **port assignment** function. It is defined from SN into binary relations such that:

- Socket nodes are related to port nodes: $PA(x) \subseteq X(x) \times PN_{SA(x)}$
- Related nodes have identical color sets and equivalent initialization expressions:
  $\forall x \in SN\ \forall(x_1, x_2) \in PA(x): [C(x_1) = C(x_2) \wedge IN(x_1) \Leftrightarrow IN(x_2)].$

(f) $FS = \{FS_r\}_{r \in \mathbb{R}}$ is a finite set of **fusion sets** such that:

- FS is a partition of P.
- Members of a fusion set have identical color sets and equivalent initialization expressions: $\forall r \in R\ \forall x_1, x_2 \in FS_r: [C(x_1) = C(x_2) \land IN(x_1) \Leftrightarrow IN(x_2)]$

(g) FT is a **fusion type** function. It is defined from fusion sets such that:

- Each fusion set is of type: global, page or instance.
- Page and instance fusion sets belong to a single page: $\forall r \in R: [FT(FS_r) \neq global \Longrightarrow \exists i \in I: FS_r \subseteq P_i]$.

(h) $PP \in S_{ms}$ is a multi-set of **prime pages**.

The below table presents a brief explanation for each of the mentioned requirements.

Table IV.2 - Explanation of the main requirements of Hierarchical Colored Petri Nets

Requirements (components)	***Explanations***
(a) The set of pages	Each page is a non-hierarchical CP-net. We use Σ to denote the union of all the color sets Σ_i of the individual pages. The pages have pairwise disjoint sets of nodes, and arcs, and this means that for functions and relations, defined on places, transitions and arcs, we can omit the page index without any ambiguity.
(b) The set of substitution nodes	Each substitution node is a transition.
(c) The page assignment function	The page assignment relates substitution transitions to pages. When a transition $t \in SN_i$ is related to a page S_k, we say that S_k is a direct subpage of the page S_i which is a direct super-page of S_k.
(d) The set of port nodes	Each port node is a place. We notice that even a non-subpage have port nodes. Such port nodes have no semantic meaning (and thus they can be turned into non-ports without changing the behavior of the CPN).
(e) The port assignment function	The port assignment relates socket nodes (the places surrounding a substitution transition) with port nodes (on the corresponding direct subpage). Each related pair of socket/port nodes must have identical color sets and equivalent initialization expressions.
(f) The set of fusion sets	The fusion sets are the components in a partition of P and this means that a place can belong to at most one fusion set.

	All members of a fusion set must have identical color sets and equivalent initialization expressions. Usually, it is only a few places that belong to fusion sets and thus the partition is partial
(g) The fusion type function	The fusion type divides the set of fusion sets into global, page and instance fusion sets. For the last two kinds of fusion sets, all members must belong to the same page.
(h) A multi-set of prime pages	The prime page is a multi-set over the set of all pages and they determine, together with the page assignment, how many instances the individual pages have. Often the multi-set contains only a single page (with coefficient one).

IV.4.2.1 Hierarchical colored Petri nets advantages

Some of the main benefits of using hierarchical colored Petri nets are listed as follow:

- Allows the modeler to make much more concise and adaptable, without losing the possibility of formal analysis.
- Complex models can be divided between the net structure, the net inscriptions and the declarations, which help when we deal with complex systems.
- Provides an easy way to describe data manipulation using expressions, rather than a complex set of places, transitions, and arcs.
- Each token can carry complex information, which gives more scalability of presenting more complex natural entities.
- CPN gives a possibility to describe relatively complex objects with a minor number of places and transitions.

IV.5 An overview of Petri nets tools

Petri nets are supported by numerous tools, commercial and non-commercial software after we realized deep research we found different tools each of them has its pros and cons. In the following sections, we are going to present the most common PN' tools:

IV.5.1 CPN-AMI

CPN-AMI is a collection of tools federated in FrameKit. It is a Petri net-based case environment. It offers functions such as modeling facilities, simulation, model checking and computation of structural properties. This software provides numerous services, such as (Kordon and Paviot-Adet, 1999):

- **Syntactic verifier:** It checks the AMI-Net syntax and transforms the Petri net into an internal representation.
- **Modular Petri net assembling:** It gives support to the designers to assemble modules communicating either by means of places or by means of transitions.
- **Pretty Petri Nets:** This service aims to rearrange intersected Petri nets to facilitate its readability.
- **Colored Petri net simulator:** The developers of this tool tried to keep the analogy with programming language debuggers, by providing many options such as the choice of execution modes, breakpoint possibilities, data extractions during the execution and so on.
- **Colored place invariants:** this tool computes invariants using an adapted version of the general algorithm.

Each one of them is delivered by an integrated tool, some of the benefits of this tool are summarized in the following points:

- It provides an ease use graphical editor
- A fast simulation
- Simple management of places and transitions
- It offers a flexible structural analysis
- Support different interchange file format
- Offers various services for modular modeling.

Some of the boundaries of this tool are the halt of its maintenance since 2010, and its incompatibility with the new version of recent operating systems.

IV.5.2 GreatSPN

GreatSPN is an open-source software package for the modeling, validation, and performance evaluation of distributed systems using Generalized Stochastic Petri Nets and their colored extension (Stochastic Well-formed Nets). The tool provides a friendly framework to experiment with timed Petri net-based modeling techniques. It implements efficient analysis algorithms to allow its use on rather complex applications. It supports three types of Petri nets (High-level Petri Nets, Stochastic Petri Nets, and Petri Nets with Time). The main functionalities of this tool are outlined as follows:

- **Graphical interface:** It provides an interactive token game for PNs with priorities and inhibitor arcs, access to the model database, with cut and pastes options for sub-models. It offers a graphical representation of performance results, with a graphical interactive simulation of timed and stochastic models.
- **Structural properties:** It includes the principal components (Place- and Transition- invariants) for nets with priorities and inhibitor arcs. Additionally, it contains structural boundedness and unbounded transition sequences.
- **Linear programming:** performance bounds for timed P/T nets: upper and lower bounds for transition throughputs and average place markings.
- **Simulation:** It comprises different modules for interactive event-driven simulation. In cooperation with the graphical interface, they provide both, interactive simulation and batch simulation.

Moreover, GreatSPN offers the possibility of nets composition through algebra, which is a missed option in many other tools. One of the limits of GreatSPN is the absence of support to CPNs.

IV.5.3 GPenSIM

GPenSIM is the acronym of General-purpose Petri Net Simulator developed by Reggie Davidrajuh in 2008. It defines a Petri net language for modeling and simulation of discrete-event systems on the MATLAB platform. GPenSIM is also a simulator with which Petri net models can be developed and simulated (Davidrajuh, 2008; Davidrajuh, 2018).

The GPenSIM modeling tool is ideal, primarily due to its flexibility in being able to control the system via the model to incorporate embedded computational components that can vary the token holding times. Many researchers in different areas of research also use it. The advantage of using GPenSIM is its simplicity integrity with MATLAB, so it does not require any long and complicated installation process. The absent of interactive graphical support, make the modeling process difficult and take a long duration.

IV.5.4 Colored Petri net Tools

Abbreviated CPN Tools is one of the wells knows Petri nets tools; it is a tool for editing, simulating, and analyzing high-level Petri nets. It supports basic Petri nets plus timed Petri nets and Colored Petri nets. It comprises a simulator and a state-space analysis tool. CPN Tools is developed by CPN Group at Aarhus University, as part of the CPN2000 project. The functionality of the simulation engine and state-space facilities are similar to the corresponding components in Design/CPN, which is a widespread tool for Colored Petri Nets (Ratzer et al., 2003). The main components of CPN Tools are presented in the following sub-sections.

IV.5.4.1 Graphical user interface (GUI)

CPN Tools provides an excellent interactive interface to facilitate and speed up the modeling and simulation processes. The main components of CPN Tools' GUI, are presented as follow:

1. **Toolbox:** It contains a list of palettes, which are used in the design process of the Petri net model. It contains ten items, each of them provides a set of graphical components:
   - **Auxiliary:** provides a set of helpful shapes and labels.
   - **Create:** Used to create the main components (places, transitions, arcs) of a Petri Net.
   - **Declare:** it delivers an easy way to declare constraints related to the constructed model.
   - **Hierarchy:** a set of components for the construction of hierarchical Petri net (check section IV.4.2)
   - **Monitoring:** a set of components that take the role of data collectors and can save the collected data in a file.
   - **Net:** Provides different options for the management of the current Petri Net.

- **Simulation:** it offers a straightforward interface to set and runs the simulation.
- **State Space:** it contains a useful set of tools for the analyze and report of the state space.
- **Style:** add a good appearance to the model to facilitate its readability.
- **View:** provides a set of options (zooming, grouping, etc.) to organize the model.

2. **Help:** offers aids and support to the designers.
3. **Options:** set up the simulation settings, and configure the remote host options if needed.
4. **Current model:** it provides useful information about the current model, such as:
   - **Model name:** "Simple net.cpn".
   - **Step and time:** presents the current time and step of the simulation's progress.
   - **Options:** for setting the performance report statistics, and extensions.
   - **History:** Under each open net is there a History entry, which contains a list of the last 10 commands that were performed on the net and that can be undone.
   - **Declarations:** This is an important section, which includes all the declaration of different elements such as color sets, variables, functions and so on.
   - **Monitors:** their purpose is to collect statistical data about the model, at different phases of the simulation and in a precise manner.
   - **List of pages:** It offers an easy way to move on from page to another, in the presented figure we have only one page named "Net Page".
5. **Page:** This is the place where we build the model; by dragging/dropping the different components to construct the model.

IV.5.4.2 Simulation

CPN Tools developers have done a great job in the construction of the simulation module. During the simulation, the provided tools, allow us to accomplish numerous tasks to facilitate the simulation process, the main profits are mentioned as follow:

- An easy interactive way in the editing of places' tokens.
- A simple way of error displays using speech bubbles.
- The possibility of selecting the used binding when firing a transition.
- During the simulation, several feedbacks (markings, tokens number, steps, time, and transition states, etc.) are displayed, to reflect an immediate picture of the system state.

For solid and trustful simulation results, many replications must be executed. CPN Tools provides the function “CPN'Replications.nreplications” in order to set the number of replications needed. Then, a reporting system will collect the simulation results of each replication to merge them, to deliver the final results. The collected data, which appear in the report, depends on the user choices and it has numerous forms (average, maximum, minimum, sum, variance, and time interval, etc.)

Additionally, to the mentioned points, the simulation module offers different kinds of functions used in ML scripts. Table IV.3 shows the common ones, with their explanation.

Table IV.3 - Common functions in timed simulations

Function	***Explanation***
time()	Returns the current time of the simulation model
ModelTime.toString t	Converts simulation model time “t” to a string
ModelTime.fromInt i	Converts an integer “i” into a time value
ModelTime.add(t1,t2)	Adds the two time values t1 and t2
ModelTime.sub(t1,t2)	Subtracts the two time values t1 and t2
ModelTime.mult(t1,t2)	Multiplies the two time values t1 and t2
CPN'Replications.nreplications n	Runs n simulation replications

IV.5.5 Why CPN Tools?

The choice of CPN Tools rather than any other tool is connected to several facts, stated as follows:

- Not distributed for profit or commercial benefit means that it is free of use for everyone.
- It provides a powerful interactive graphical user interface, which speeds up the modeling process.
- The designers made it a tool for editing, simulating and analyzing untimed and timed Petri nets, which attracts numerous users with different aims.
- It offers extensibility possibilities via extensions.
- The official site provides rich documentation, with examples and answers to the common questions.
- Availability of a support team provides great help in the solving of the encountered issues.

In the following section, we are going to present our proposed methodology for hospital emergency department optimization, and then we apply it in a case study system.

IV.6 Methodology

In our proposed approach, we chose the CPN as a performance mathematical model in concurrent systems modeling. Petri nets are graphical and mathematical tools for modeling, and verifying the dynamic behavior of discrete event systems such as manufacturing systems and transportation networks. In our case, we use CPN for modeling hospital emergency department systems; CPNs have several interesting features such as modeling and visualization of parallel behavior, modeling, and resource sharing. Furthermore, it simplifies the modeling process by representation system state with colored tokens; In which every color represents the data value, which is more efficient than other Petri net types.

Numerous Petri net tools are available, in this study, we selected CPN tools (Ratzer et al., 2003; Westergaard and Kristensen, 2009), which provides a mature environment for constructing, simulating, and performing analysis of CPN models (check sub-section IV.5.5 for more motives). After the selection of the simulation tool, we move on to the phase of data collection from a selected ED, and then we build the simulation model of our case study system, using CPN Tools components. Next, we move forward to the simulation phase; we propose numerous improvement scenarios, and we measure the impact of each scenario. Finally, we compare these scenarios' results, to select the efficient scenario, based on several ED KPIs. An important stage is the measurement of the implementation cost of each scenario, which will provide to ED managers a clear view of the needed costs. The next section introduces the case study ED, which is an interesting phase before applying our approach.

IV.6.1 Description of the case study hospital emergency department

The Emergency Department of Chalabi Abdelkader Hospital (non-university public hospital establishment) has 16 patients' rooms, including one critical room for trauma patients or patients with deadly injuries. The emergency department has two waiting rooms, one for adults and another for minors, which are used simultaneously for the triage operation by a triage nurse. Besides, there are five rooms for stays containing 11 beds, one orthopedic room, and two other rooms for sewing and care treatment. Patients with critical conditions may bypass triage, and be treated directly by the physician in the surgical unit. Low-acuity patients are sent to the waiting room. Patients are categorized into those with and without a painful state; patients with a painful state need immediate treatment. After the triage operation, five acuity Emergency Severity Index (ESI) levels are assigned to patients: critical, emergent, urgent, non-urgent, and minor. Acuity level 1 is the most critical, patients need a treatment instantly, whereas level 5 is least urgent and often represents clinic type patients. Critical state patients have the highest priority in the entire emergency department, and the emergency department should always be ready to accept new critical patients. Emergent and urgent patients (acuity level 2, 3) must be treated in average time less than 15 minutes after their arrival, as for those who have low-acuity they can wait up to 2.5 hours. Figure IV.4 shows the physical structure of the case studied ED.

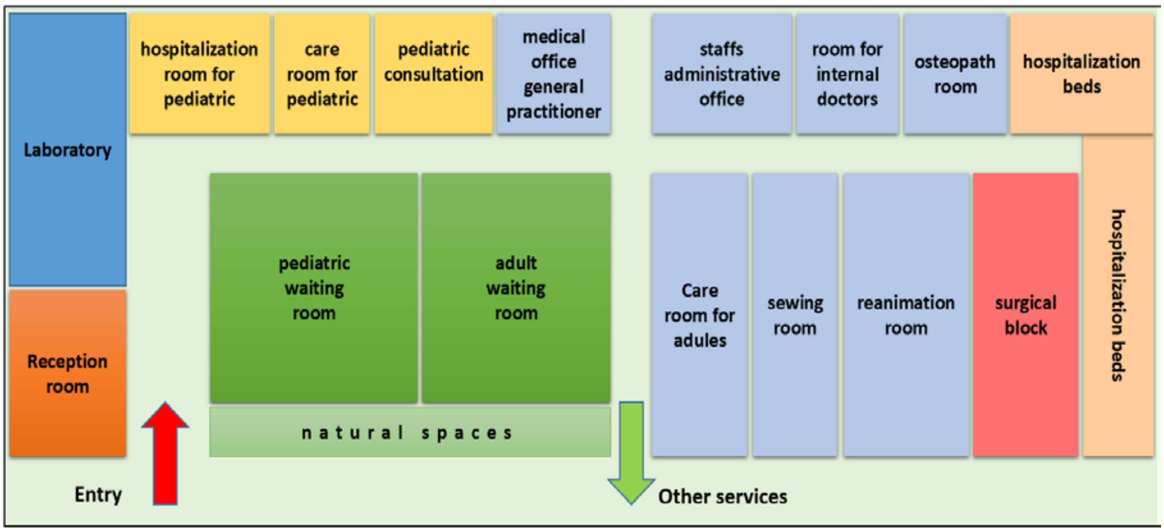


Figure IV.4 - Physical structure of the Chalabi Abdelkader Emergency Department

IV.6.1.1 Flowchart of the patient admission process

Figure IV.5 illustrates the possible patient paths inside the considered emergency department. The flowchart provides a basis for the discrete event simulation model. This flowchart is depicted, based on the existent patient flow of the study system. Patient arrival is either walking or by ambulance, then patients are triaged on arrival at the emergency department. The triage nurse makes an initial evaluation of the patient state, based or signs and symptoms. Next, according to the ESI, she classifies the patient in one of the five severity levels. A patient in level 1 has a critical state and should be treated immediately while a patient in level 5 is, in fact, an outpatient with a more stable state. After this stage, we figure four typical patient trajectories as follows:

- Patients with severity level 1, carry to Vital Emergency (VE) to be treated by a surgeon, whenever the surgery success, the patient will be moved to the short-stay hospital unit (SSHU), for a duration does not exceed 24 hours, then the patient will be discharged from the ED to another service.
- Patients with the emergency state (ESI 2), are directly consulted by a nurse and then by a General Practitioner (GP), before being referred to the short-stay hospital unit of the emergency department, to monitor their states.

- Patients with an urgent state (ESI 3), follow the same trajectory as ESI 2 patients. The difference is that the state of those patients requires one or more additional tests before they will be discharged by a GP after checking the additional test results.
- Patients non-urgent (ESI 4, 5) are guided directly to the waiting room to wait for nursing consultation. After the nursing consultation, the patient returns to the waiting room, to wait for the medical consultation. As soon as a doctor is free, he examines the patient before the patient leaves.

The frequency at which these different trajectories occur in the model is decided probabilistically, based on historical data of two years retrieved from the ED archives.

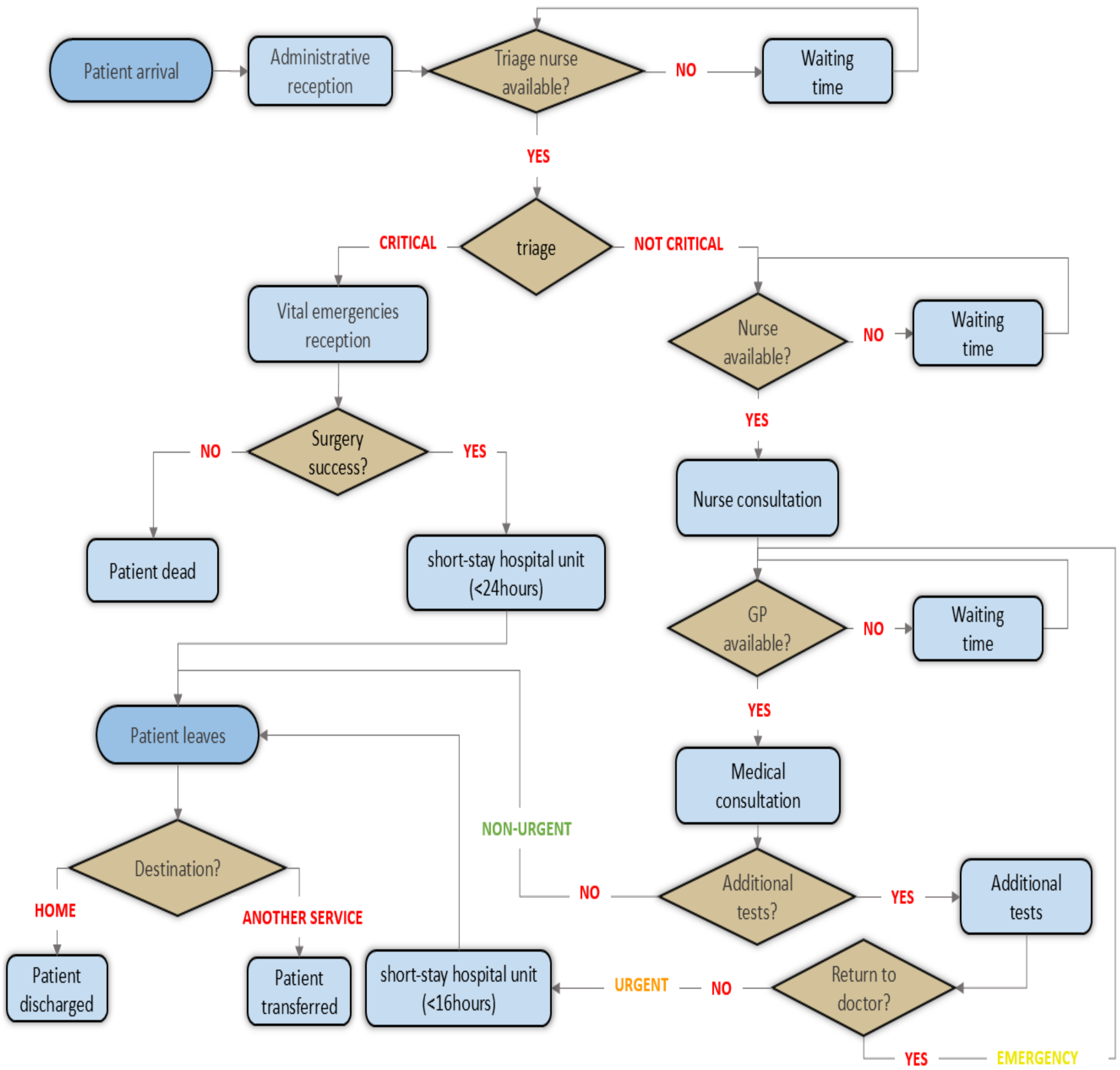


Figure IV.5 - Flowchart of patient admission process (Derni et al., 2019a)

IV.6.1.2 Data collection phase

Collecting the necessary data is one of the critical phases before moving on to any forthcoming stage. It is one of the vital and harder phases due to the omission, and the absence of well-organized data in most Algerian hospitals. In this phase, authors have based on ED' archives of two years, besides interviews with staff to gather the required data.

The collected data is presented in the form of graphical charts to facilitate its readability. We tried to separate adult and pediatric statistics for more visibility. Figure IV.6 shows curves of adults' consultation number per month for the two years (2015, 2016), where Figure IV.**7** is for pediatric. We can observe that the average consultation number for pediatric is less compared with the adults, which they have averages of 2300 and 5000 patients per month, respectively.

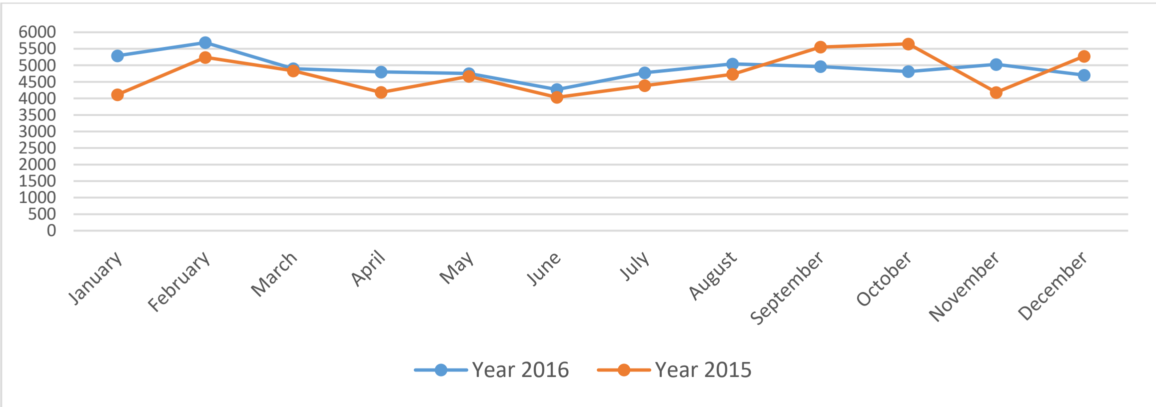


Figure IV.6 - The number of adult consultation per month during the two years (2015, 2016)

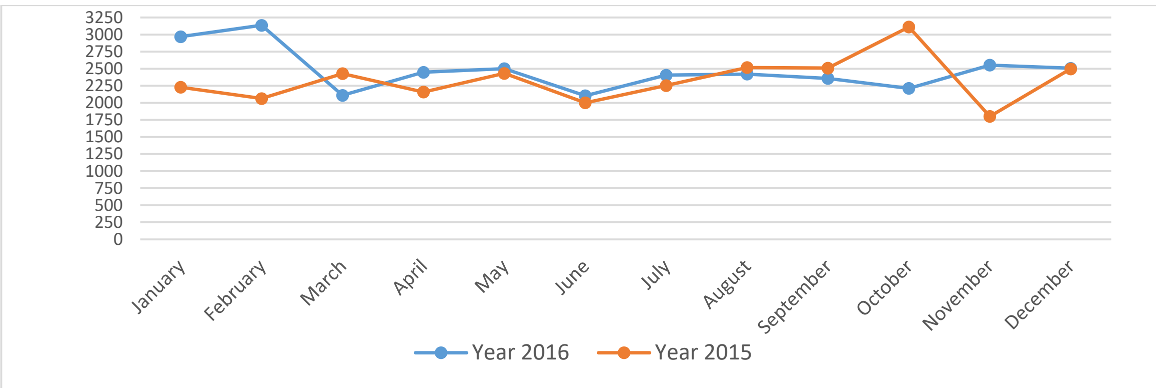


Figure IV.7 - The number of pediatric consultation per month during the two years (2015, 2016)

Figure IV.8 and Figure IV.9 present histograms of the numbers of treated patients, as well as the hospitalization numbers for adults and pediatrics, respectively. The average number of hospitalization for adults during the two years is about 180 patients per month, which is the twice of pediatrics admitted hospitalization numbers.

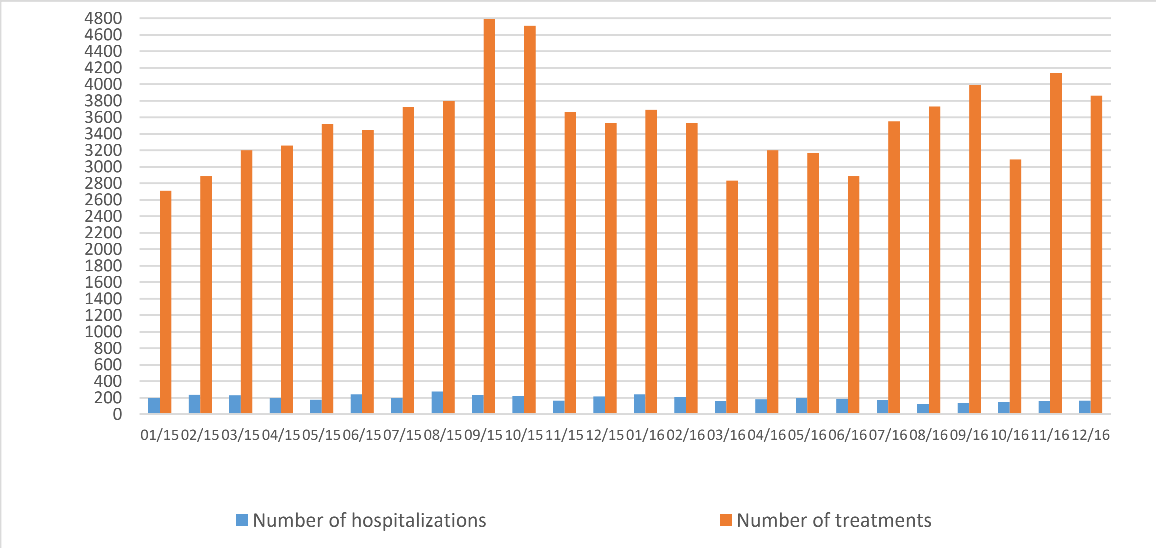


Figure IV.8 - The number of hospitalized and treated patients from January 2015 to December 2016 (Adults)

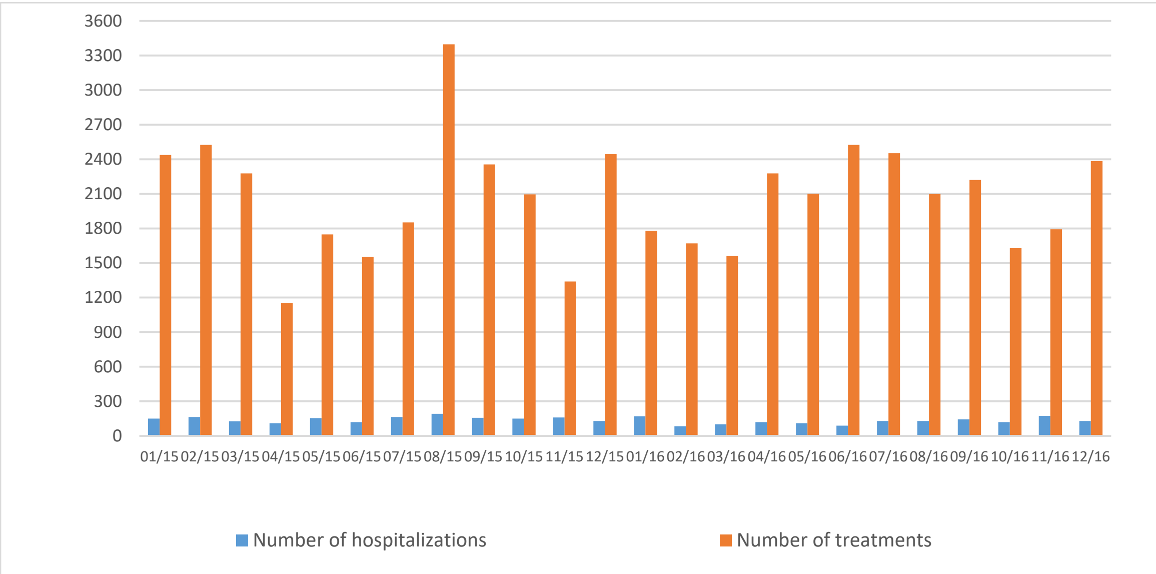


Figure IV.9 - Number of hospitalized and treated patients from January 2015 to December 2016 (Pediatrics)

Figure IV.10 shows the percentages of consultation by categories, which we believe that it will be helpful for future use.

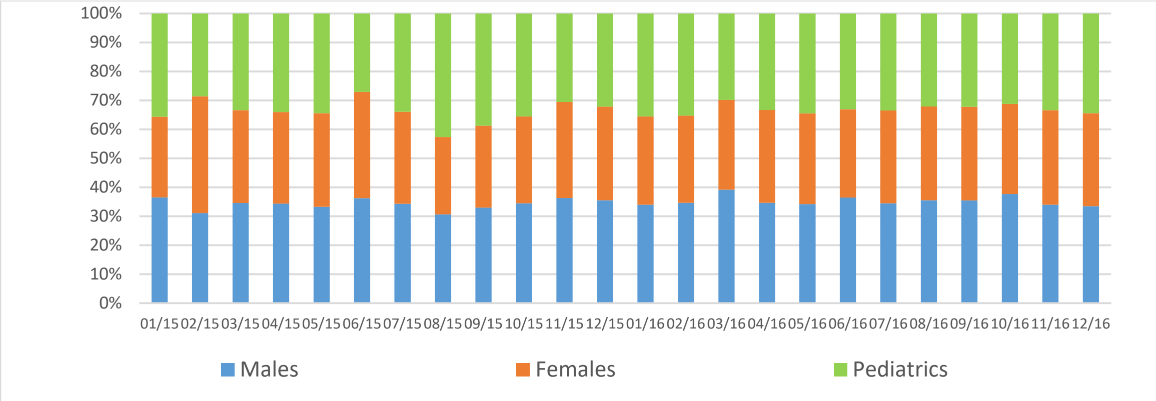


Figure IV.10 - Percentage of consulted patients by category from January 2015 to December 2016

One of the interesting axes, when we study such as system is the duration of operations, which reflect the performance and the quality of the current state of the system. Table IV.4 shown the important operations durations at the different stages of the patient admission process. We can observe that the total time spent by the patient in the ED has an average of 210 minutes without including hospitalization durations, which is a long period for non-urgent and minor cases. The extended time of LOS is caused in the first place by the long waiting time at the doctor, and in the second place by the extended period of complementary tests, which it has an average duration of 50 minutes. After a deep analysis and investigation, we found that the longer duration of waiting time at the doctor and complementary tests are caused by the lack of doctors and the absence of a radiology machine, respectively.

Table IV.4 - Operations duration at the different stages of the patient admission process

ED key performance indicators	***Duration (minutes)***
Average patient total length of stay	210
Nursing consultation waiting time	7
Nursing consultation duration	6
Medical examination waiting time	130
Medical examination time	12.5
Average complementary tests time	50

IV.6.2 Modeling phase of the patient admission process

In this section, we are going to model patients' admission pathways inside the presented emergency department using colored Petri nets. We mainly used the common components of the CPN Tool in the building phase of the model. Table IV.5 shows a detailed description of each component (places, transitions, and arcs). The presented flowchart in (Figure IV.5), offers excellent help in the construction of the model. It speeds up the process, e.g. each square and rhombus will be presented by a place and transition, respectively. Figure IV.11 shows the model of the emergency department using CPNs.

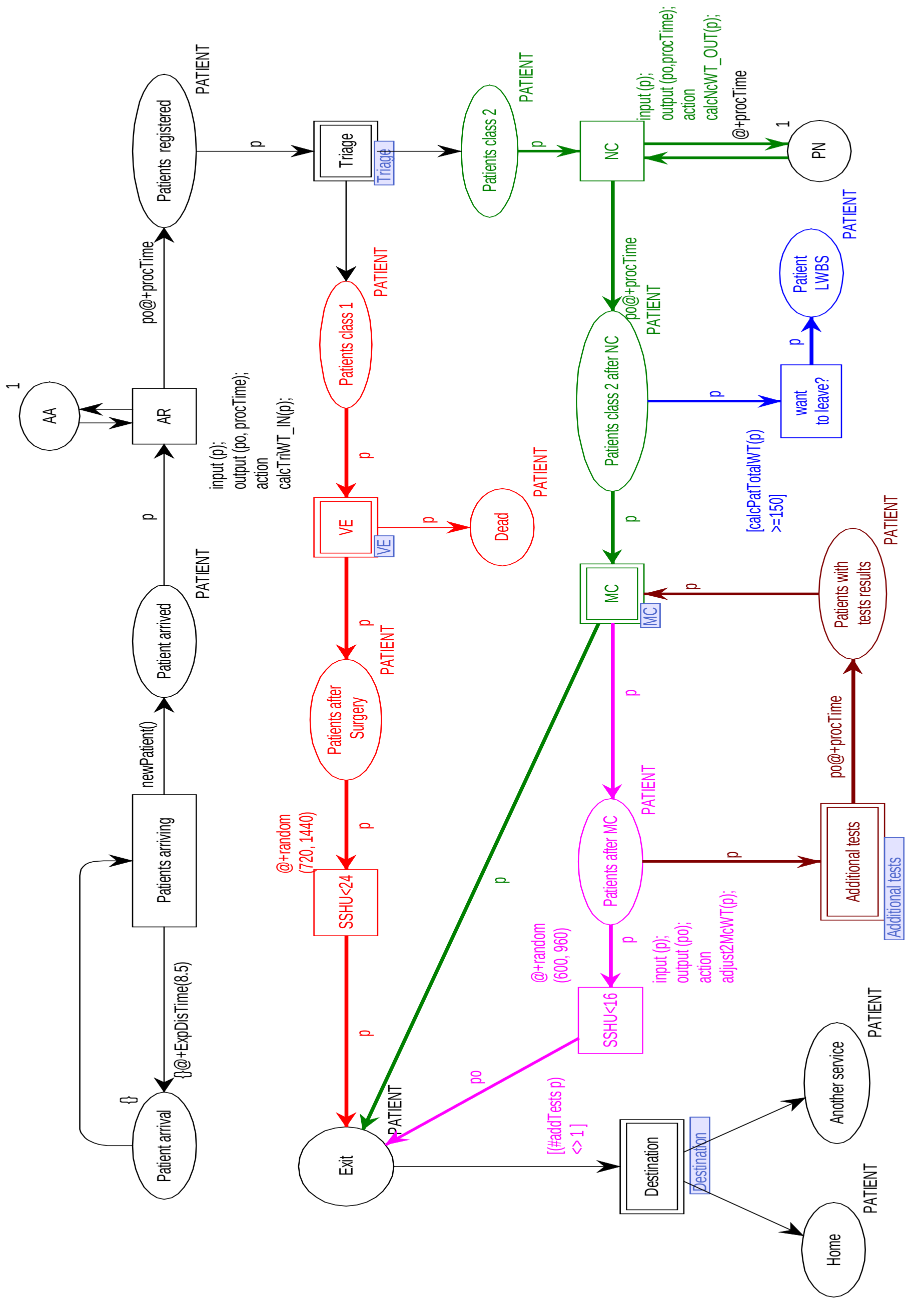
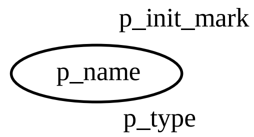
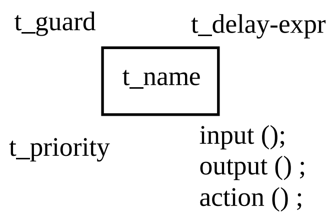
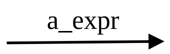


Figure IV.11 - Main page of the ED simulation model using CPN tools (Derni et al., 2019a)

The model includes a set of places and transitions linked by arcs. Each place represents the state where patients may be exposed there. Patient arrival at the ED is modeled by a colored token that contains a set of elements used to calculate patient waiting times and operation durations for each stage. A resource represented in the "triage nurse" place will affect each patient an ESI value. Then, depending on the affected ESI, the patient will move to the appropriated place, passing by transitions, which represent the medical treatment. Finally, a decision will be made by medical staffs to discharge patient or transfer him/her to another service in the hospital.

Table IV.5 - CPNs graphical components representation under CPN Tools

CPN Tools Graphical component	***Description***
	Place: • p_name: place name. • p_type: specify the colour set of the place. • p_init_mark: initial number of markers (tokens).
	Transition: • t_name: transition name. • input(), output() and action(): specify the transition, input, output parameters and the action to be performed on the input parameters. • t_delay-expr: transition time delay, it is added to simulation current time and assign to tokens stamp time. It has the following form "@+ delay-expr". • t_guard: A guard is a Boolean expression, used to ensure a condition on input arcs before firing a transition. • t_priority: A non-negative integer. The lower the value, the higher the priority.
	Arc: 1. a_expr: is the arc weight, which can be an expression simple or complex.

IV.6.3 Simulation model

The simulation model requires three sorts of data: patient arrival pattern, patient trajectory probabilities, and the duration of operations. Table IV.6 shows the different simulation input parameters for the concerned ED.

Table IV.6 - Simulation input distribution functions

Input parameters	*Simulation distribution functions in CPN Tools (time in minutes)*	*Description*
Patient arrival	Exponential (1/8.5)	The time between two patients' arrivals has a mean of 8.5 minutes. The inter-arrival time has an exponential distribution with parameter r=1/8.5.
Admission time	Discrete (1,2)	the duration for the patient admission process
Triage time	Discrete (1,4)	Triage time has a discrete uniform distribution with parameters a=1 and b=4.
Nurse consultation time	Uniform (4,8)	Nurse consultation time has a discrete uniform distribution with parameters a=4 and b=8.
Medical consultation time	Discrete (5,15)	Medical consultation duration takes between 5 and 15 minutes.
Additional tests time	Discrete (10, 20)	Additional tests (radiology, laboratory, etc.) duration, it takes a value between 10 to 20 minutes.
Surgery operation time (VE)	Uniform (60,180)	Surgery operation takes between 1 to 3 hours.
short-stay hospital unit (< 24hours)	1- discrete (720, 1440) 2- discrete (600, 960)	1- Critical state patients stay between 12 to 24hours. 2- Emergent patients stay between 10 to 16 hours.

The model was built from system observations, and interviews with various medical and administrative staffs; it is based on a deep understanding of current ED' processes. Figure IV.11 shows the structure of the simulation model. The basic steps of the process include triage, registration, surgery operation, initial consultation, medical treatment, and patient discharge.

The main layer of our model is illustrated in Figure IV.11. In the model, each place represents the state where patients may be positioned there. The patient moves from place to place until patient discharge. Table IV.7 and Table IV.8 show the simulation model places and transitions with their descriptions. Patient arrival at the ED is modeled by a token on the place "patient arrived". This place has the color set PATIENT, which is a CPN Tools record (see Table IV.9 for a detailed description of the color sets declarations). It includes numerous attributes used to calculate patient waiting times, and operation durations for each stage, additionally to the total length of stay in the ED. Patient arrival is modeled by an exponential distribution function with a mean of 8.5, which is calculated based on the collected data of two years (from January 2015 to December 2016). ESI is affected to each patient in the triage process; each severity level has a specific probability acquired from the actual data of the ED.

Table IV.7 - Places description of the simulation

Place	***Type (amount)***	***Description***
Patients arrived	Patient place	patient arrived to the emergency department
Patients registered	/	patients admitted in the “ED”
Patients class 1	/	place for patient with critical state
Patient Dead	/	dead patients after surgery failure
Patients after Surgery	/	patient after a success surgery operation
Patients class 2	/	place for patient with non-critical state
Patients class 2 after NC	/	patient after nursing consultation
Patients LWBS	/	patients Left Without Being Seen
Patients after MC	/	patient with medical results
Patients with tests results	/	patient with additional tests (labs, radiology, etc...) results
AA	Resource place (1)	Administrative Agent
TN	Resource place (1)	Triage Nurse
PN	Resource place (1)	Practitioner Nurse
GP	Resource place (1)	General Practitioner
SURG	Resource place (1)	Surgeon
SN	Resource place (2)	Surgical Nurse

Table IV.8 - Descriptions of the simulation model transitions

Transition	***Description***
Patients arriving	Represent the patient arrival process used to generate patient arrival pattern at the “ED”.
AR	Administrative reception process
Triage	A substitution transition of triage operation.
VE	Vital Emergency substitution transition it includes surgery operation.
NC	Nurse consultation transition.
MC	Medical consultation.
Additional tests	Substitution include a subpage present additional test processing.
SSHU (<16, <24)	Short Stay Hospitalization Unit for patients’ hospitalization and observation.

Table IV.9 - Detailed descriptions of the simulation model components

Simulation components	***Implementation under CPN Tools***	***Description***
Color sets	colset ESI = int with 0..5;	Declaration of the color set “ESI” used to store the patient Emergency Severity Index.
	colset WAITTIME = record tri:INT * nc:INT * mc1:INT * mc2:INT * at:INT;	WAITTIME is a record used to hold patient waiting times at different stages in the “ED”. It includes: “tri” (Triage), “nc” (Nursing Consultation), “mc1” (1st Medical Consultation), “mc2” (2nd Medical Consultation) and “at” (Additional Test) waiting times.
	colset OPERATIONTIME = record tri:INT * mc:INT * atest:INT;	OPERATIONTIME is a record used to hold operations durations at different stages in the “ED”. It includes: “tri” (Triage), “mc” (Medical Consultation), and “atest” (Additional TEST Requirement) operations durations.
	colset PATIENT = record esi:ESI * at:INT * qt:INT * opt:OPERATIONTIME * wt:WAITTIME * tt:INT * dtdt:INT * addTests:INT timed;	PATIENT record represents the color of the patient token. It includes : “esi” (Emergency Severity Index), “at” (Arrival Time), “qt” (Quit Time), “opt” (Operations Times), “wt” (Waiting Times), “tt” (Total Time), “dtdt” (Door To Doctor Time) and “addTests” (Additional Tests Requirement) which it takes 3 values with the following meaning : “0” -> patient does not need additional tests; “1” -> patient state requires additional tests; “2” ->

		patient already finished additional tests.
	colset PATDST = record dp:PATIENT * home:BOOL;	A record used to track patient destination. When “home” = “true” -> patient return to home else patient is transferred to another service.
Variable declarations	var p,pi,po : PATIENT;	“p”, “pi” and “po” are variables of type PATIENT used as input and output of transitions’ functions.
	var procTime: INT;	“procTime” (process time) is an integer used to hold process (transition) duration in minutes.
	var pd : PATDST;	“pd” (Patient Destination) used to store patient destination.
	var dead , home: BOOL;	“dead” and “home” are variables indicate patient state and its destination, respectively.
Transitions input and output functions.	fun random(a,b) = (if(discrete(1,2)) = 1 then a else b);	“random” function it takes two input parameters and it returns one of them with an equal probability.
	fun real2int(a) = round(a);	Function convert a real value to an integer value.
	fun ExpDisTime(mean) = real2int(exponential(1.0/mean));	This function generates an exponential distribution with a “mean” as a parameter.
	fun intTime() = IntInf.toInt (time());	“intTime” used to convert simulation time(clock) to an integer value, each unit represent 1 minute.
	fun newPatient() = { esi = 0, at= intTime(), qt = 0, opt = {tri=0, mc=0, atest=0}, wt = {tri = 0, nc = 0, mc1=0, mc2=0,	It is used to generate and initialize patient token.

	at=0 }, tt = 0, dtdt = intTime(), addTests = 0 };	

	fun exitPatient(pp:PATIENT) = {
	esi = (#esi pp),
	at = (#at pp),
	qt = intTime(),
	opt = (#opt pp),
	wt = (#wt pp),
	tt = intTime() - (#at pp),
	dtdt = (#dtdt pp),
	addTests = (#addTests pp)
	};
		"exitPatient" calculates "tt" (total time) based on current time (intTime()) minus "at" (Arrival time), it returns patient coloured token including calculated time.

	fun addTestsChoice(pp:PATIENT) =
	let
	val addTests_ = discrete(0,1);
	in {
	esi=(#esi pp), at=(#at pp), qt=(#qt pp), opt=(#opt pp), wt=(#wt pp), tt=(#tt pp), dtdt=(#dtdt pp),addTests=addTests_ }
	end
		Used to decide whatever patient needs additional tests or not, with a probability of 50% patient needs additional tests.

	fun calcTriWT_IN(pp:PATIENT) =
	let
	val proc_time = discrete(1,2)
	val wt_ = {
	tri=intTime()+proc_time,
	nc=(#nc (#wt pp)),
	mc1=(#mc1(#wt pp)),
	mc2=(#mc2 (#wt pp)),
	at=(#at (#wt pp))}
	in ({
	esi=(#esi pp), at=(#at pp), qt=(#qt pp), opt=(#opt pp), wt=wt_, tt=(#tt pp), dtdt=(#dtdt pp),addTests=(#addTests pp)}, proc_time)
		"calcTriWT_IN" function, it is used to store the arrival time of patient at the triage nurse and return admission duration in "proc_time" variable.

	end	

	fun calcTriWT_OUT(pp:PATIENT) =
	let
	val proc_time = discrete(1,4)
	val opt_={tri=proc_time, mc=0, atest=0}
	val wt_ = {tri=intTime()-(#tri (#wt pp)),
	nc=(#nc (#wt pp)),mc1=(#mc1 (#wt pp)), mc2=(#mc2(#wt pp)),
	at=(#at (#wt pp))}
	val ranNum = discrete(1,100);
	val esi_ = if (ranNum <3) then 1
	else if (ranNum >= 3 andalso ranNum < 10) then 2
	else if (ranNum >= 10 andalso ranNum < 38) then 3
	else if (ranNum >= 38 andalso ranNum < 63) then 4
	else if (ranNum >= 63) then 5 else 0 ;
	in ({
	esi=esi_, at=(#at pp), qt=(#qt pp),
	opt=opt_,wt=wt_,tt=(#tt pp), dtdt= (#dtdt pp),addTests= #addTests pp)},
	proc_time)
	End
		Used to calculate, triage waiting time by subtracting arrival time at triage nurse stored by “calcTriWT_IN” from the current time, assigning ESI to the patient, storing triage operation duration in “opt” attribute, and returning “proc_time” to make nurse resource busy for that amount of time.

	fun calcNcWT_IN(pp:PATIENT) = let val wt_ = {tri=(#tri (#wt pp)), nc=intTime(),mc1=(#mc1 (#wt pp)), mc2=(#mc2 (#wt pp)),at=(#at (#wt pp))} in ({ esi=(#esi pp), at=(#at pp), qt=(#qt pp), opt=(#opt pp), wt=wt_, tt=(#tt pp),dtdt=(#dtdt pp),addTests=(#addTests pp)}) end	“calcNcWT_IN” function, it is used to store the arrival time at the nurse in the patient token.

	fun calcNcWT_OUT(pp:PATIENT) = let val proc_time = real2int(uniform(4.0,8.0)) val wt_ = {tri=(#tri (#wt pp)), nc=intTime()-(#nc (#wt pp)),mc1= intTime()+proc_time, mc2=(#mc2 (#wt pp)),at=(#at (#wt pp))} in ({ esi=(#esi pp), at=(#at pp), qt=(#qt pp), opt=(#opt pp), wt=wt_, tt=(#tt pp),dtdt=(#dtdt pp), addTests= (#addTests pp)}, proc_time) End	Used to calculate, patient’ waiting time at the nurse by subtracting arrival time at the nurse from the current time, storing nursing consultation duration and calculating the arrival time (intTime()+proc_time) at the doctor in the which is used to calculate the waiting time at the doctor.
	fun calcMc1WT_OUT(pp:PATIENT) = let val proc_time = discrete(5,15) val dtdt_ = intTime() - (#dtdt pp) val opt_={tri=(#tri (#opt pp)), mc=proc_time, atest=0} val wt_ = {tri=(#tri (#wt pp)), nc=(#nc(#wt pp)) ,mc1= intTime() - (#mc1 (#wt pp)), mc2=(#mc2 (#wt pp)),at=(#at (#wt pp))} in ({ esi=(#esi pp), at=(#at pp), qt=(#qt pp), opt=opt_, wt=wt_, tt=(#tt pp), dtdt=dtdt_, addTests=(#addTests pp)}, proc_time) end	Used to calculate, patient’ waiting time at the doctor by subtracting arrival time at the doctor from the current time, storing medical consultation duration and returning “proc_time” to make doctor resource busy for a certain amount of time.

	fun calcMc2WT_IN(pp:PATIENT) =
	let
	val radio = discrete(1, 100)
	val pt = if (radio < 20) then 150 else 0;
	val proc_time = pt + discrete(10, 20);
	val opt_={tri=(#tri (#opt pp)), mc=(#mc (#opt pp)), atest=proc_time}
		“calcMc2WT_IN” function, it is used to store the arrival time of patient for the 2nd medical consultation.
		We calculate also additional tests duration which it takes a random duration between 10 to 20 minutes.

	val wt_ = {tri=(#tri (#wt pp)), nc=(#nc (#wt pp)),mc1=(#mc1 (#wt pp)), mc2=intTime()+proc_time,at=(#at (#wt pp))} in ({ esi=(#esi pp), at=(#at pp), qt=(#qt pp), opt=opt_, wt=wt_, tt=(#tt pp), dtdt=(#dtdt pp), addTests=(#addTests pp)}, proc_time) end	We add 150 minutes (wasted time) in the case when a patient needs a radiology test due to the absence of an X-ray machine. 20% of patients need radiology tests.
	fun calcMc2WT_OUT(pp:PATIENT) = let val proc_time = discrete(5,15) val opt_={tri=(#tri (#opt pp)), mc= (#mc (#opt pp)) + proc_time, atest=(#atest (#opt pp))} val wt_ = {tri=(#tri (#wt pp)), nc=(#nc (#wt pp)),mc1=(#mc1(#wt pp)),mc2=intTime()-(#mc2 (#wt pp)),at=(#at (#wt pp))} in ({esi=(#esi pp), at=(#at pp), qt=(#qt pp), opt=opt_, wt=wt_, tt=(#tt pp),dtdt=(#dtdt pp),addTests=(#addTests pp)}, proc_time) End	Used to calculate, patient' waiting time at the 2nd doctor consultation by subtracting arrival time at the doctor from the current time, storing 2nd medical consultation duration and returning "proc_time" to make doctor resource busy for a certain amount of time.
	fun adjust2MCwt(pp:PATIENT) = let val wt_ = if ((#addTests pp) = 0) then {tri=(#tri (#wt pp)), nc=(#nc (#wt pp)),mc1=(#mc1 (#wt pp)), mc2=0,at=(#at (#wt pp))} else #wt pp; in ({esi=(#esi pp), at=(#at pp), qt=(#qt pp), opt=(#opt pp), wt=wt_, tt=(#tt pp), dtdt= (#dtdt pp), addTests=(#addTests pp)}) End	This function resets the patient' waiting time at the 2nd medical consultation to 0 if the patient does not return to the doctor else it returns the waiting time value.

	fun calcPatTotalWT(pp:PATIENT) = let val mc1_wt = intTime() - (#mc1 (#wt pp)) val wt_ = (#tri (#wt pp)) + (#nc (#wt pp)) + mc1_wt + (#mc2 (#wt pp)) + (#at (#wt pp)); in wt_ end	Calculate patient total waiting time by accumulating all stored waiting times.

The model includes ten main transitions some of those with double border are called substitution transitions. Each of these substitution transitions has a subnet page, which corresponds to a task in the process. Each transition has four inscriptions that may be associated with, including transition name, guard, delay expression, and code segment inscription (for more details check Table IV.5).

For a more comprehensive vision of the model, Figure IV.12 shows the subpage of the transition Medical Consultation (MC), the patient has to wait until the resource GP become available. Then, the patient will be treated for a stochastic delay of time by a GP. Afterward, GP decides of discharging the patient or requesting for additional tests, in the case when GP request additional tests, the patient must return to the GP, for a second consultation or oriented to the SSHU, for a duration less than 16 hours.

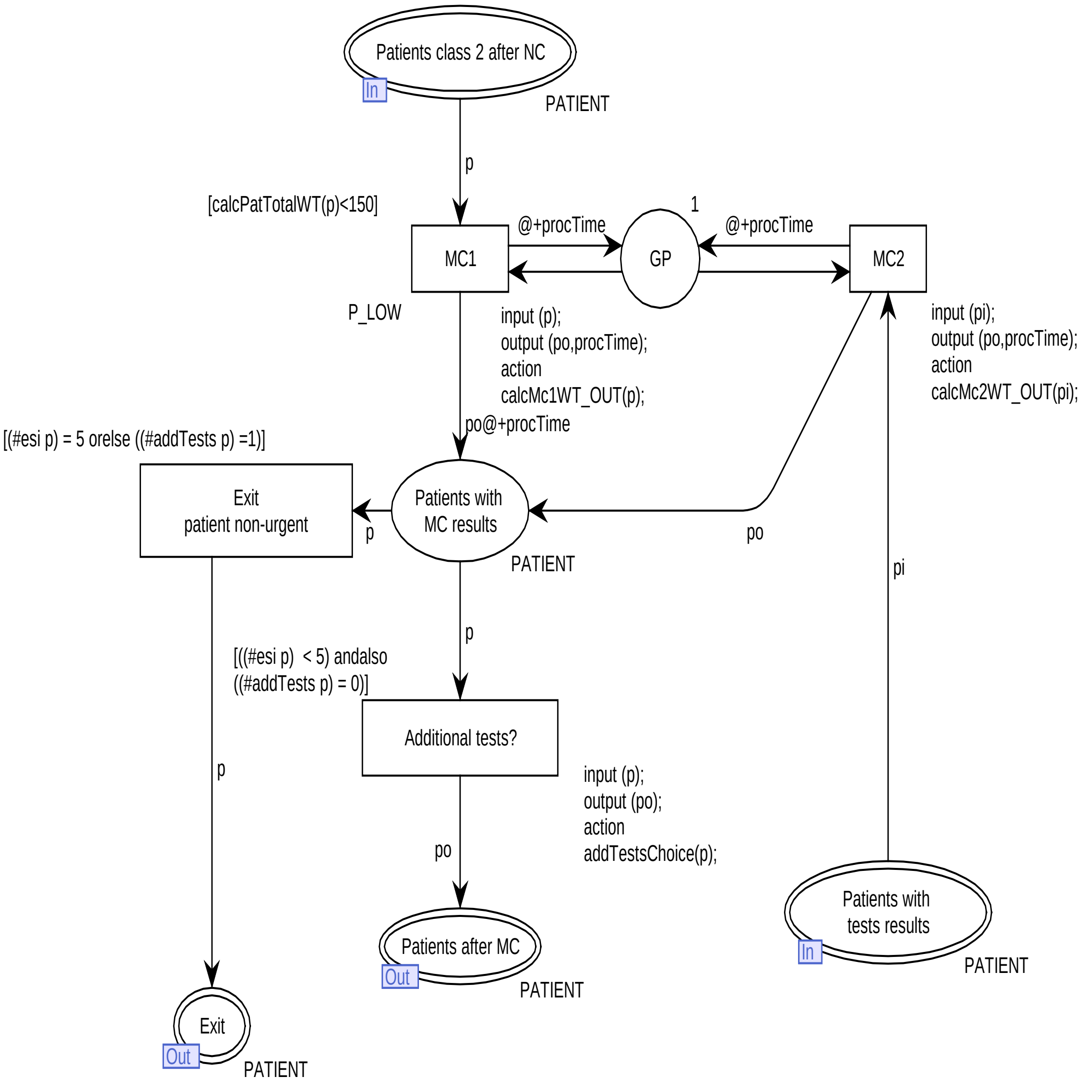


Figure IV.12 - Zoomed view of the substitution transition MC illustrated in Figure IV.11

At each stage, the waiting time of patients increases according to the amount of resource unavailable time. Figure IV.13 shows the subpage of the transition triage, the output function "*CalcTriWT_OUT*" assign an ESI for each patient based on probability (Table IV.9 point out each function implementation).

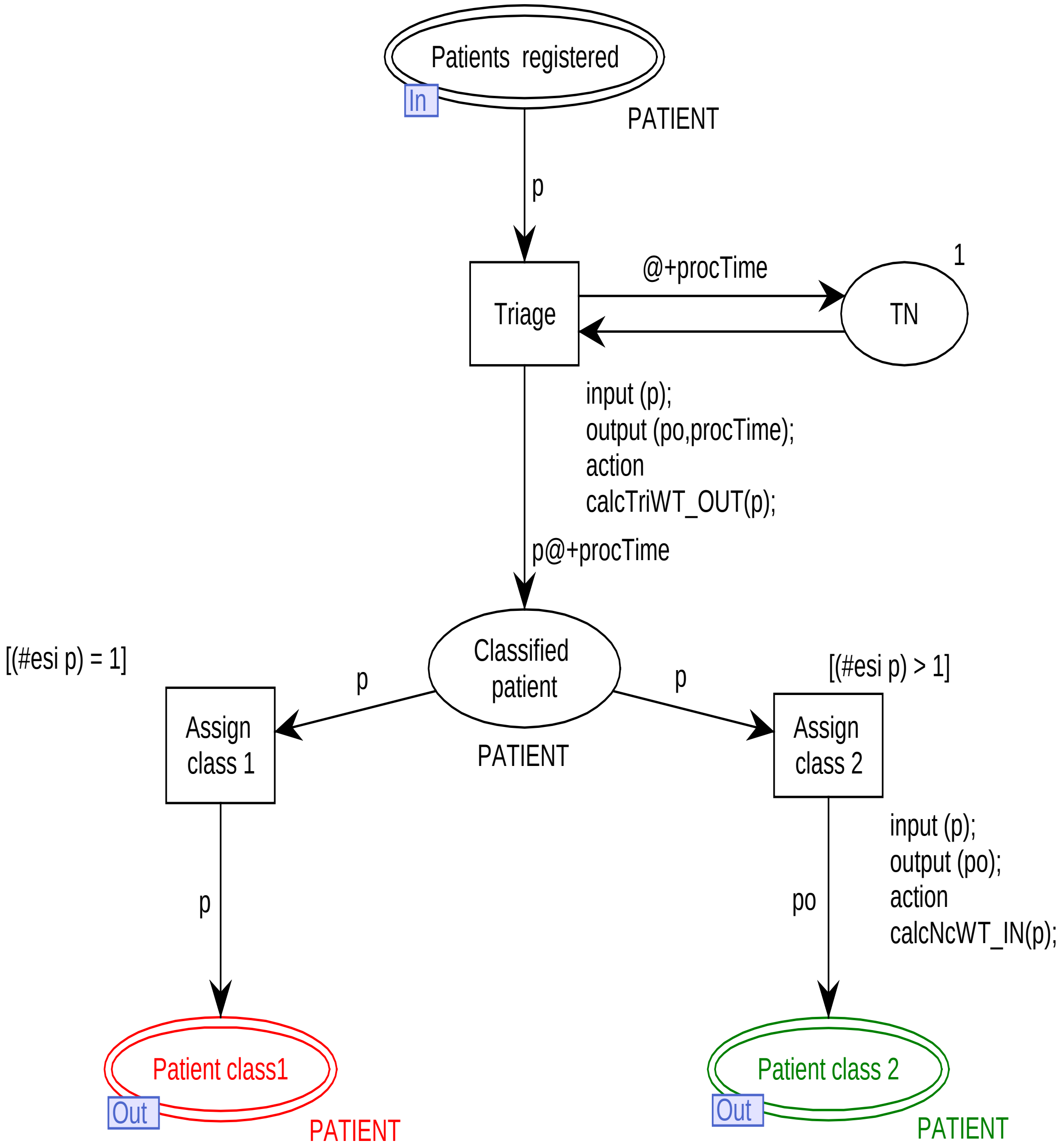


Figure IV.13 - Triage page of the substitution transition triage

While Figure IV.14 and Figure IV.15 provide a zoomed view of the substitution transitions VE and Destination, respectively.

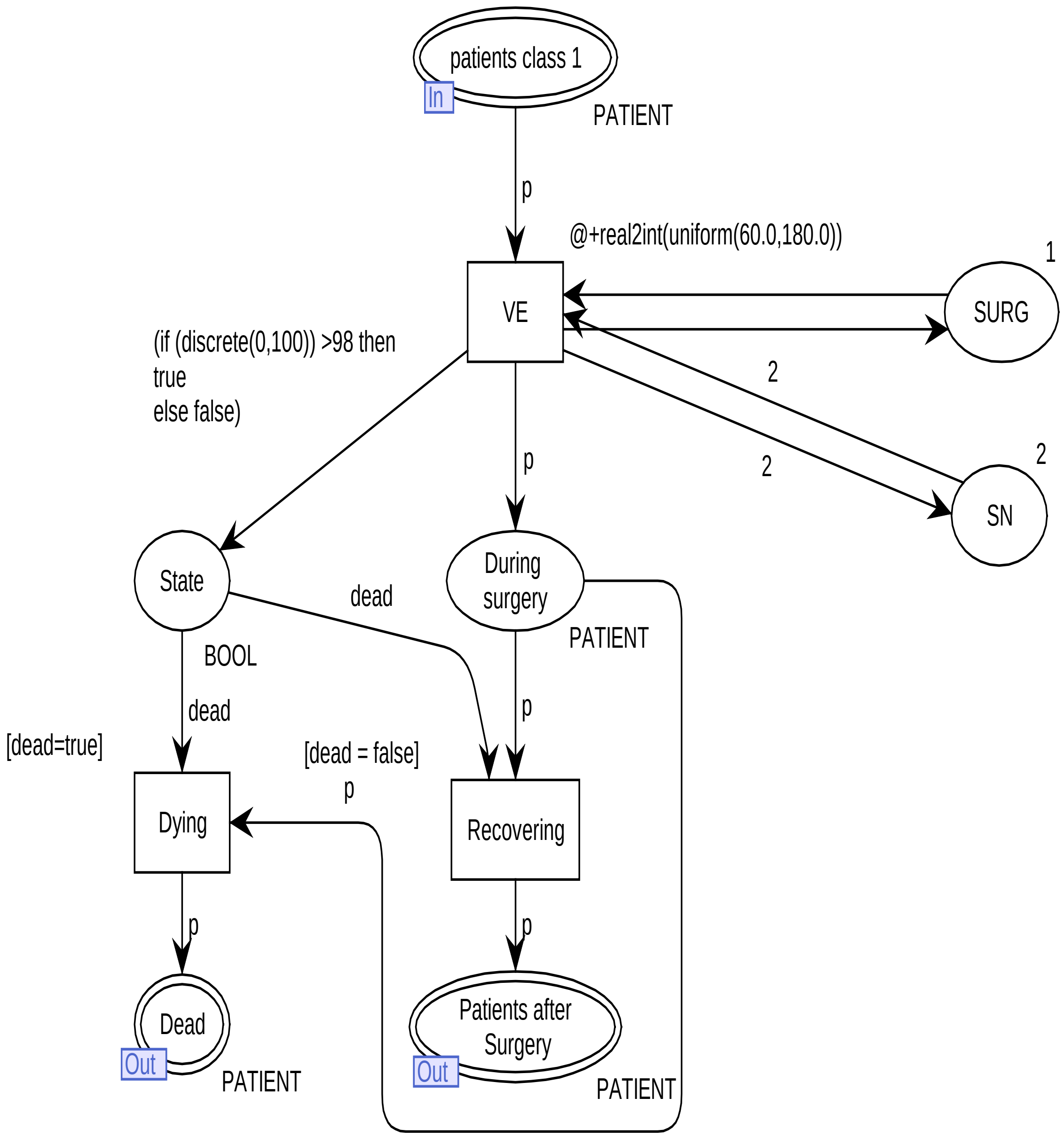


Figure IV.14 - Zoomed in of the substitution transition VE

Figure IV.14 shows the VE process, it illustrates resources places and the decision of the patient state based on probabilities.

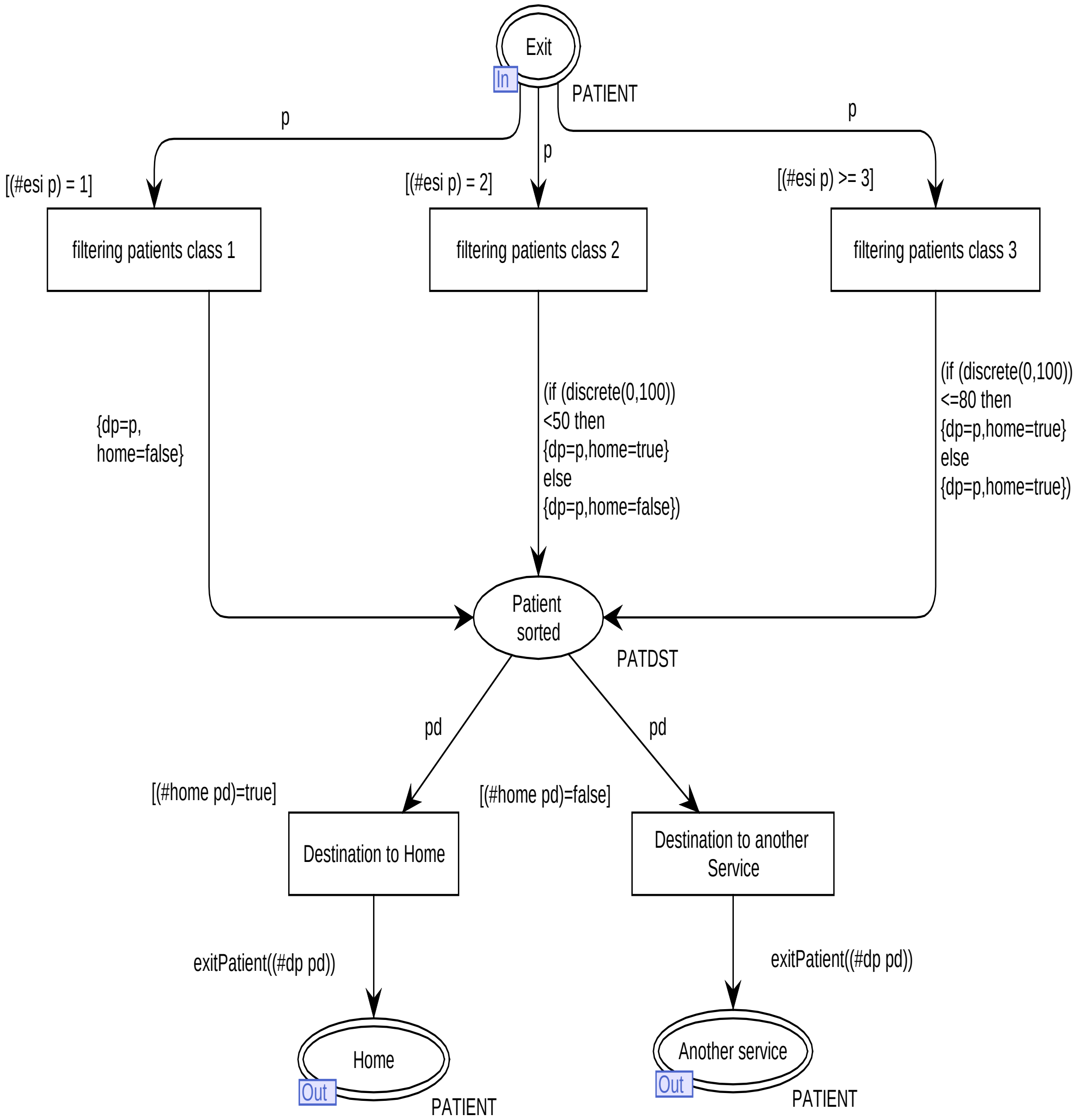


Figure IV.15 - Zoomed in of substitution transition destination

The subpage presented in Figure IV.15 illustrates the determination of patient destination, based on the ESI assigned to each patient. Finally, we validate the simulation model in two stages:

1. Emergency department doctors and staff were involved in the process of validation, due to their experience in the domain.
2. Simulation output results are compared with the collected data of the study system, as is shown in Table IV.10, the simulation outputs of the system give acceptable results compared to the collected data.

Table IV.10 - Comparison between real data and simulation data

System key performance indicators	*Patients ESI 1*		*Patients ESI 2,3,4*		*Patients ESI 5*	
	Real data	*Simulation Data*	*Real data*	*Simulation Data*	*Real data*	*Simulation data*
left without being seen rate (%)	--	--	0.25	0.4	3	3.7
door to doctor time(min)	--	--	20	22	20	21.69
total length of stay (min)	1200	1232	445	443	32	32.7
waiting time for triage(min)	0	0	0.8	0.89	0.85	0.91
waiting time for nurse consultation(min)	--	--	6.2	6.36	7	6.25
waiting time for the 1st medical consultation (min)	--	--	5.3	5.56	6	5.25
waiting time for the 2nd medical consultation(min)	--	--	1	1.02	--	--

IV.6.4 Simulation improvement scenarios

The main goal of this study summarized in the improvement of the emergency department, through reaching the optimal and feasible solution(s). By the following, we propose many improvement scenarios, these scenarios are chosen with the help of domain experts, concurrently with our observations of the system flaws. We proposed two types of scenarios: basic and hybrid scenarios:

- Basic scenarios are as follow:
  - scenario 1: represents the current state of the system, it used as a benchmark for the comparison of the different proposed scenarios
  - scenario 2: remove nurse consultation, so patient admitted directly by a doctor
  - scenario 3: increase medical staff by adding an emergency Specialist Practitioner (SP)
  - scenario 4: extend material resource by adding a general radiography equipment

  - scenario 5: replace triage nurse by another experienced nurse
  - scenario 6: add a doctor assistant (nurse)
- Hybrid scenarios are combinations of basic scenarios:
  - scenario A: scenario 2 + scenario 3
  - scenario B: scenario 3 + scenario 4 + scenario 5
  - scenario C: scenario 2 + scenario 6

In each scenario, we have added a resource otherwise we changed system structure. In scenario 2, we changed the system structure by removing nurse consultation, which it has no considerable effect on the patient treatment quality, due to domain experts' opinions. In scenario 4, we added a material resource, which is missed in the ED. For each of those nine scenarios, including scenario 1 (benchmark scenario) we run the simulation for a duration of 2 years. The obtained results are displayed in Table IV.11. The next section provides a discussion of those scenarios.

Table IV.11 - Simulation results of the proposed improvement scenarios (Total of ESI 2, 3, 4 and ESI 5)

Scenarios	*Simulation results (key performance indicators)*											
	LWBS (%)	*DTDT (min)*	*LOS (min)*	*Waiting times (minutes)*					*Operations times (minutes)*		
				Total	*Triage*	*Nurse consultation*	*1st medical consultation*	*2nd medical consultation*	*Triage*	*medical consultation*	*Additional tests*
scenario 1 (benchmark)	4.1	45.51	476.7	26.53	1.8	12.61	10.81	1.01	5.99	19.96	21.75
scenario 2	2.37	26.58	459.68	19.66	1.73	--	16.85	1.06	5.98	19.97	22.77
scenario 3	1.2	34.57	467.26	14.72	1.77	12.24	0.56	0.15	5.98	20.01	21.94
scenario 4	4.1	44.98	467.17	28.99	1.78	12.4	10.78	1	5.99	20.01	10.32
scenario 5	3.9	43.13	473.7	26.18	0.71	13.19	11.22	1.03	5.96	19.99	21.61
scenario 6	2.87	38.92	468.06	16.56	1.78	12.34	4.77	0.65	5.99	16.99	21.56
scenario A	0.51	11.55	445.38	3.78	1.77	--	1.77	0.23	5.99	20	21.45
scenario B	0.97	32.97	452.89	15.13	0.7	13.7	0.55	0.15	3.98	20.01	10.38
scenario C	1.3	18.85	449.34	11.6	1.78	--	9.07	0.74	6	16.99	21.50

IV.6.5 Results discussion

As shown in Table IV.11, for each proposed scenario we calculated the key performance indicators of the ED, which includes in our case LWBS, DTDT, LOS, waiting times, and operations times. Almost basics scenarios (2-6) have a partial improvement in the system. Scenario 2, has the highest improvement rate of 3.57% for LOS and 41.5% for DTDT, comparing with other basics scenarios. Otherwise, scenario 3 is the efficiency one in basics scenarios in terms of LWBS rate, which is reduced to 1.2% comparing to 2.37%, 4.1%, 3.9%, 2.78% of the reduction in scenarios (2,4,5,6), respectively. Hybrid scenarios (A, B, C), have the uppermost improvement rate, but at the same time, they impose additional costs. Scenario A, is the ideal one in term of improving LOS with rate of 6.57% and an improvement in DTDT up to 74%, which is satisfies comparing with (5%, 27%) in scenario B, and (5.73%, 58%) in scenario C. Besides LWBS rate, which is reduced to 0.51% compared to 4.1% of the LWBS rate of the actual system (benchmark scenario). In the next section, we will present the cost measurement of those improvement solutions.

IV.6.6 Scenarios costs measurement

Studying the cost of the implementation of those adjustments provides great help to the ED supervisors in the selection of the appropriate adjustment, related to the available budget. We study the cost of each scenario in the long term, to provide to ED' managers the knowledge about the cost of the implementation of the proposed solutions. Table IV.12 shows the cost of each scenario, adding resource is presented by an addition operation (+), and eliminating a resource is presented by a subtraction operation (-). For each basic scenario, we calculate the cost of the human resource, based on their average salaries in Algeria. For the material resource, we based on the price combined with material lifetime duration.

Hybrid scenarios costs are calculated by adding each cost of the appropriate basics scenarios. Time notion is included in the calculation of the costs, the presented costs in Table IV.12 are considered for a period of one year. As we can observe, the second improvement scenario has an advantage in terms of cost by minimizing 3,990 units. The third one (adding a specialist practitioner) is the costly one in basic scenarios, due to the high salary of an SP compared to GP. In hybrid scenarios, scenario A has a cost of 2,010 units, which is acceptable due to the remarkable reduction in the total and waiting time durations. Scenario B imposes a total of 8,333 units, which the most costly in the proposed scenarios. Its employment is related to the amount of the available budget. In contrast, the implementation of scenario C imposes no additional cost; it is the ideal one in case of a limited budget. Indeed, it would be interesting if we included the budget, which is unavailable due to some limitations.

Table IV.12 - Scenarios implementation costs

Scenario	**Cost (US dollar)**	**Description**
Scenario 1 (benchmark)	--	--
Scenario 2	-3990	3990 units are the average income for a nurse in one year.
Scenario 3	6000	6000 units are the salary of a specialist practitioner.
Scenario 4	1333	The cost for a new radiography machine is estimated by 40000 units; with a lifetime duration of 30 years.
Scenario 5	1000	An experienced nurse has a higher salary by 83 units than a novice nurse does.
Scenario 6	3990	The salary for a nurse during one year has an average of 332 * 12 units.
Scenario A	2010	Adding a specialist will not have a big increase in the cost, due to the reducing of a nurse.
Scenario B	8333	Combining scenarios 3, 4, and 5 has the highest cost of 8333 units.
Scenario C	0	This scenario does not apply any cost, because it consists just in moving a nurse from (Nursing consultation), and place her in (Medical consultation) as an assistant nurse.

IV.7 Conclusion

In this chapter, we started by introducing Petri nets and their different classes. Then, we presented some of the related works, which have used Petri nets in the modeling of hospital EDs. We explicitly focused on hierarchical colored Petri nets, which we mainly used it in our proposed approach, due to its facilitation of the modeling process, by structuring the net in subnet pages in a hierarchical manner. As well, a set of colored Petri nets tools were presented, and we justified our choice of CPN Tools as a modeling and simulation tool for our case study system.

A simulation model of a chosen ED was designed, to improve and lift the lid from significant flows of the studied system. The simulation model was built using CPN tools, which is a performance tool for simulating and analyzing concurrent systems.

Numerous improvement scenarios were proposed, to evaluate the system under diverse variations structural and non-structural, to provide various solutions for the managers of the ED. After comparing between the simulation results, we found that scenario A is the efficient one in terms of improvement in LOS, DTDT, and LWBS, which is the best choice for managers to improve the treatment quality, and patient satisfaction, as well as the number of the treated patients. Each of those adjustments has a cost; we proposed many scenarios to expand managers’ choice to implement the chosen scenario appropriate to their budget. In the next chapter, we are going to take another case study system. Then, we will apply on it a new approach combine between Fuzzy Logic and hierarchical colored Petri nets.

Chapter V

Modeling and optimization of the ED system: a case study in Benaouda Benzerdjeb Hospital

V.1 Introduction

The key duty of the hospital emergency departments, which is represented in saving lives by providing an immediate and high-quality treatment in the least possible period. These constraints make it an important field of research by highlighting the numerous causes and issues, which affect the ED' performances. Emergency departments responsible are facing many challenges, which are in a continuous increase, with the growing of the population, the appearance of new diseases with inconsistent symptoms, limited resources, and the difficulty of the prediction of overcrowding situations. Therefore, those facts lead to congestion, a long length of stay, and extend the patient waiting time. Recently, simulation has become a very flexible alternative modeling approach for the evaluation of competing for health care interventions (He et al., 2016). It helps also to conduct what-if scenarios to examine and analyze the impact of any adjustment before its implementation in the real world. The absence of effective management of patients' flows is one of the central reasons, which leads to ED overcrowding. In the last decades, several researchers such as (Sánchez et al., 2018; Garrett et al., 2018; Kelley III and Gravina, 2018) have significantly focused on optimization of patient flows at different stages of the ED.

The number of individuals admitted in most Algerian EDs is increasing, for a variety of reasons, comprising pauperization, growing in pediatric consultations, aging of the population, and an increase in the number of chronic diseases. Furthermore, free and direct admission to this facility and specifically consultation at any time of the day or night, whatever the reason, those facts raise the challenges.

In this chapter, we use a colored Petri net framework for modeling the case study system due to the complication of its nature, to lift the lid from the deficiencies of the actual ED. The main objective is presented in the enhancement of the performance of the considered ED by adding the appropriate amount of resources. However, the determination of the needed amount of resource is not an obvious decision it depends on the target improvement. Therefore, we design a Fuzzy Logic (FL) system to calculate the target improvement based on a set of inputs parameters represented in the resources amount and the number of incoming patients.

V.2 Fuzzy logic

Fuzzy logic is an extension of Boolean logic created by Lotfi Zadeh in 1965 (Zadeh, 1965) based on his mathematical theory of fuzzy sets, which is a generalization of classical set theory. By introducing the notion of degree into the verification of a condition, we allow a condition to be in another state than true or false. FL thus confers considerable flexibility on the reasoning that uses it, which makes it possible to take into account inaccuracies and uncertainties. One of the interests of fuzzy logic in formalizing human reasoning is that rules are stated in natural language.

V.2.1 Fundamental concepts

It is necessary to present the fundamental terms of FL before we start in the designing process of our Fuzzy Logic Control (FLC) system. In the next sub-sections, we are going to present the common and essential concepts used in the design of any FL system.

V.2.1.1 Fuzzy sets

FL is based on fuzzy set theory, which is a generalization of classical set theory. To say that the theory of fuzzy sets is a generalization of the theory of classical sets means that the latter is only a special case of the theory of fuzzy sets. To make a metaphor in set language, classical set theory is only a subset of the fuzzy set theory. Following the used term in the literature, the terms fuzzy subsets and fuzzy sets are used indifferently. Classical sets are also called net sets, as opposed to fuzzy, and similarly, classical logic is also called Boolean or binary logic.

V.2.1.2 Linguistics variables

The concept of the belonging function will allow us to define fuzzy systems in natural language, the membership function making the link between fuzzy logic and linguistic variable that we are going to define later in our approach. When we define the fuzzy subsets of a linguistic variable, the goal is not to define the linguistic variable exhaustively. On the contrary, we will only define the fuzzy subsets that will be useful later in the definition of the rules we apply to it.

V.2.1.3 Fuzzy operators

To be able to manipulate fuzzy sets, the operators of the theory of classical sets are redefined to adapt them to the membership functions specific to the fuzzy logic allowing values strictly between zero and one. Unlike the definitions of the properties of the classical sets that are always the same, the definition of the operators on the fuzzy sets is chosen, as the membership functions. Table V.1 shows the most commonly used operators.

Table V.1 - Common fuzzy logic operators

Operators	*Zadeh min/max (Zadeh, 1965)*	*Probabilistic prod/probor*
Intersection (AND) $\mu_{A\cap B}(x)$	$min(\mu_A(x), \mu_B(x))$	$\mu_A(x) \times \mu_B(x)$
Union (OR) $\mu_{A\cup B}(x)$	$max(\mu_A(x), \mu_B(x))$	$\mu_A(x) + \mu_B(x) - \mu_A(x) \times \mu_B(x)$
Complement (NOT) $\mu_{\neg A}(x)$	$1 - \mu_A(x)$	$1 - \mu_A(x)$

V.2.1.4 Inference rules

Fuzzy sets and fuzzy operators are the subjects and verbs of FL. These IF-THEN rule statements are used to formulate the conditional statements that include fuzzy logic. A single fuzzy IF-THEN rule assumes the form:

IF x is A THEN y is B

Where A and B are linguistic values defined by fuzzy sets on the ranges of the universes of discourse X and Y, respectively. The “IF” of the rule "x is A" is called the antecedent or premise, while the “THEN” of the rule "y is B" is called the consequent or conclusion. In general, the input to an IF-THEN rule is the current value for the variable input and the output is an entire fuzzy set. This set will be defuzzified, assigning one value to the output. The concept of defuzzification will be described later.

V.2.2 The fuzzy control system

A Fuzzy Intelligent System (FIS) is a system that implements human expertise and aims to automate the reasoning of human experts with complex systems. Fuzzy controllers consist of three main phases: an input phase, a processing phase, and an output phase. The input phase maps inputs, such as switches, thumbwheels, and so on, to the appropriate membership functions and truth-values. The processing stage invokes each appropriate rule and generates a result for each, then combines the results of the rules. Finally, the output phase converts the combined result back into a specific control output value.

V.2.2.1 Fuzzification

The fuzzification is the operation of making a classical entry into linguistic value. Input values are translated into linguistic concepts represented as fuzzy sets. Membership functions are applied to measures the degrees of truth, which are established for each proposal. Fuzzification consists of a fuzzy quantification of real values of one or a set of input variables. Then, applying a set of rules by an inference engine to obtain output results. Therefore, it is necessary to transform non-fuzzy variables from external mode into fuzzy subsets.

V.2.2.2 Fuzzy reasoning

In FL, fuzzy reasoning, also called approximate reasoning, is based on fuzzy rules that are expressed in natural language using the linguistic variables that we have mentioned previously. In logic, a rule is in the form:

IF [premises] THEN [conclusion] ELSE [another conclusion]

The result of applying a fuzzy rule depends on two factors:

- The definition of the membership function of the fuzzy set of the proposition located at the conclusion of the fuzzy rule.
- The degree of validity of the propositions situated on the premise.

V.2.2.3 Defuzzification

As with all fuzzy operators, the fuzzy system designer must choose from several possible defuzzification definitions. We will briefly present the two main defuzzification' methods: the average maxima method and the center of gravity method. The defuzzification average maxima define the output as being the average of the abscissas of the maxima of the fuzzy set resulting from the aggregation of the conclusions. While the center of gravity defuzzification is more commonly used. It defines the output as corresponding to the abscissa of the center of gravity of the surface of the membership function, which characterizes the fuzzy set resulting from the aggregation of the conclusions.

V.3 Fuzzy logic in the health field

The use of FL founds different applications in the area of control system design, where human expert knowledge, rather than precise mathematical modeling, of a process or a plant, is used to implement the required controller. Uncertainty and ambiguity are evident in many engineering problems.

Fuzzy logic control, therefore, provides a formal method of translating subjective and imprecise human knowledge into control strategies, thus facilitating better system performance through the exploitation and application of that knowledge. In the health field, several recent kinds of research (Hernández-Julio et al., 2019; Ali et al., 2018; Ostadi et al., 2019) have relied on FL for the optimization of healthcare systems. (Puente et al., 2003) studied the care delivery at hospital emergency departments. They start with a traditional approach, based on queuing theory and simulation models, and then applies a fuzzy approach to the system to analyze the certainty levels provided by the key parameters of the system.

In recent research (Azadeh, 2013), an integrated fuzzy simulation approach was applied, for the improvement of care quality in an ED of a large general hospital. The simulation model is developed to cover the complete flow of patients in the ED. Authors have used a fuzzy simulation for the purpose to find the best nursing schedule based on a minimum of patients' queue time.

(Ali et al., 2018) presented type-2 fuzzy ontology-aided recommendation systems for IoT-based healthcare to efficiently monitor the patient's body while recommending diets with specific foods and drugs. The proposed system aims to extract the values of patient risk factors and to determine the patient's health condition via wearable sensors, and then recommends diabetes-specific prescriptions for a smart medicine box and food for a smart refrigerator. As a consequence of their study, they proposed an efficient system for patient risk factors extraction and diabetes prescriptions.

(Hernández-Julio et al., 2019) have implemented and validated a framework for the development of decision system support based on a fuzzy set theory using clusters and dynamic tables. The validation process of the framework is realized using a fuzzy inference system. The proposed framework is applied in the clustering process, in the medical field and provides interesting results.

In the paper of (Ostadi et al., 2019), the authors have used the fuzzy logic in the Time-Driven Activity-based Costing (TDABC) to resolve the inherent ambiguity and uncertainty and determine the best possible values for cost, capacity, and time parameters to provide accurate information on the costs of the healthcare services. Their objective is to present a new Fuzzy Logic-TDABC model for estimating healthcare service costs based on uncertainty conditions in hospitals. After the implementation of their model in a sample hospital laboratory, the results show that the maximum difference in the prescribed costs was 4.75%, 3.72%, and 2.85% in the blood bank, microbiology, and hematology tests, respectively. Additionally, the proposed model helps hospital managers to make appropriate decisions about the use of capacity, capital budgeting, and cost control.

In another interesting research (Khalili et al., 2018), the authors have modeled the hospital admission system with a multi-server queuing system. Then, they used FL due to the uncertain nature of parameters, such as interest rate and hospitalization profit in various future periods. As a result, they provide a model for the selection of the optimal number of hospital beds.

V.4 Description of the case study ED of Benaouda Benzerdjeb Hospital

The studied emergency department belongs to the Benaouda Benzerdjeb Hospital (Oran Hospital University Center) which is one of the biggest hospitals in West of Algeria. The studied ED has two main sections; the first section is the Surgical Emergency Service (SES), while the second is the Medical Emergency Service (MES). The SES has a capacity of twenty-six rooms, distributed in numerous units. As it is shown in Figure V.1, the ground floor includes a reception room for administrative procedures; a Vital Emergency Room (VER), which is used for the treatment of patients under shock; two rooms for radiology examinations, actually only one is underuse; two examination rooms, one for an ultrasound and the other for a scanner.

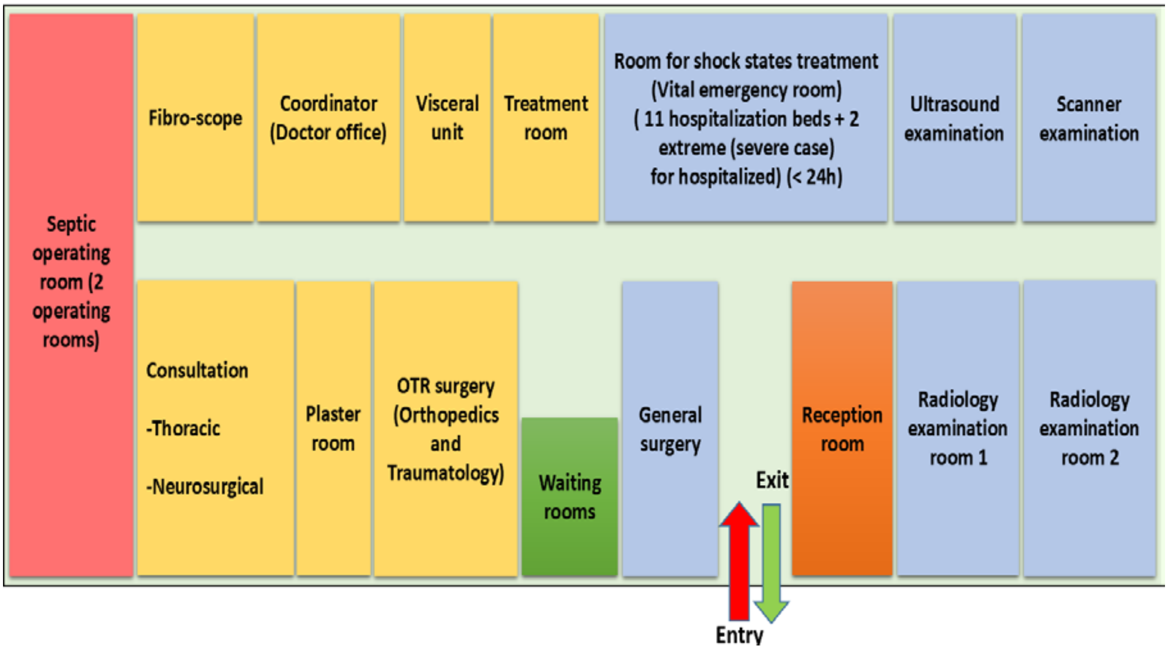


Figure V.1 - Physical structure of the Surgical Emergency Service (ground floor)

On the left side of the entry, we find a waiting room and a general surgery room, the last one includes a general surgeon, which has his/her subspecialty and performs more general work. Critical abdominal pain is the most common emergency presentation requiring surgery since the abdomen has various organs, which may be causing the pain. Moreover, it has a room for orthopedics and traumatology surgery and thoracic and neurosurgical examination rooms.

Furthermore, on the same floor, the ED contains a treatment room, fibro scope room, and a visceral unit for patients, who suffering pain from their internal organs, such as bladder, stomach, uterus, or rectum. At the most left side, we found the septic operating room, which includes two operating rooms. This room is the dedicated place to perform a surgical operation, for patients which their states need isolation to prevent the transmission of infection. It exists only one septic operating room in the whole west of Algeria.

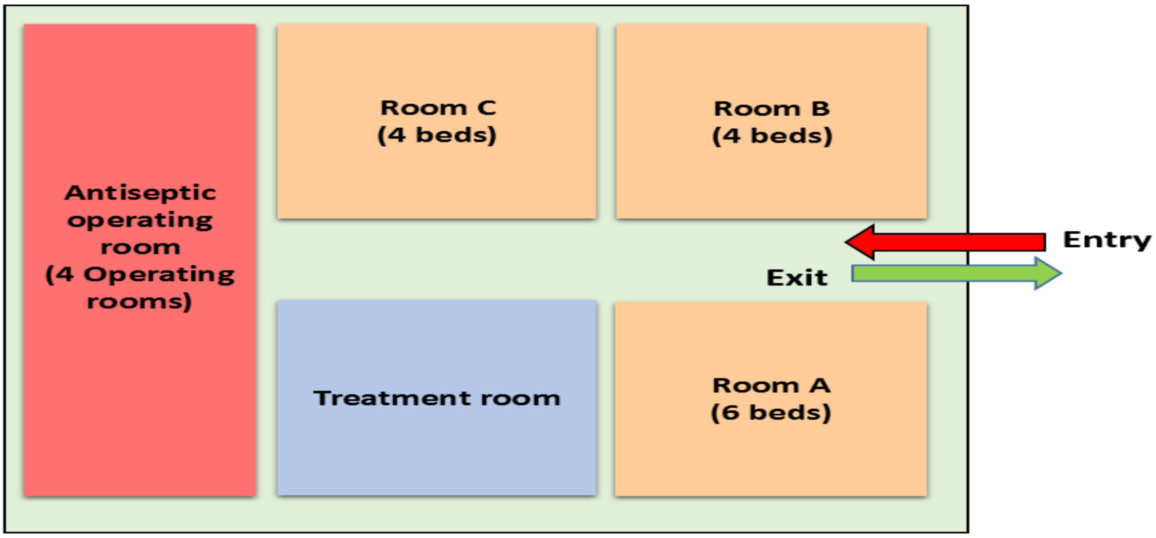


Figure V.2 - Physical structure of the Surgical Emergency Service (1st floor: Operating Room and Operational Post)

The first floor of the studied ED is dedicated to the surgical, and post operations (see Figure V.2). It includes a treatment room, 14 beds distributed between three rooms for post-surgery' patients before their orientation to another service, and an antiseptic operating room, which includes four operating rooms.

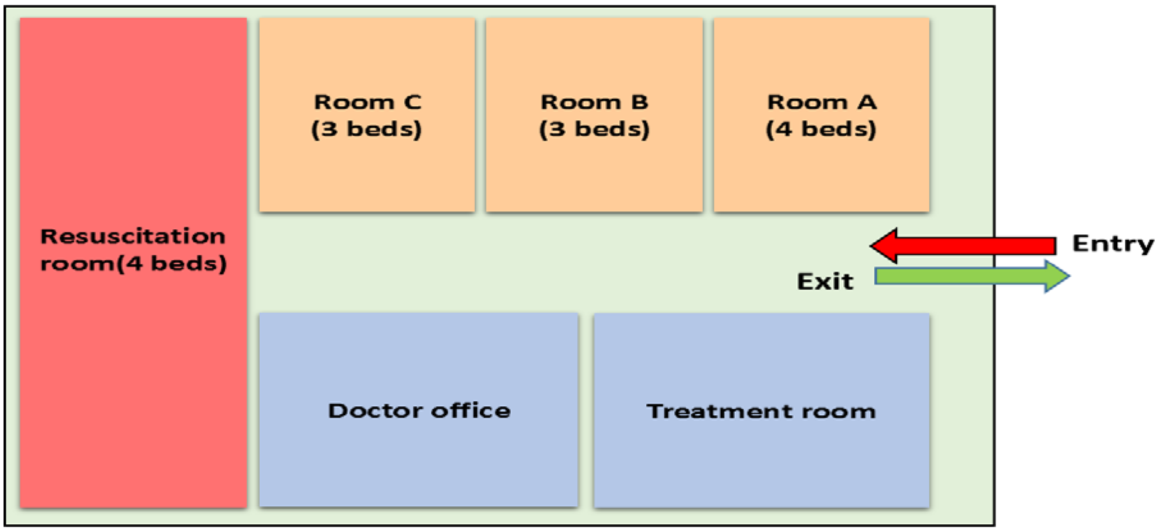


Figure V.3 - Physical structure of the Surgical Emergency Service (2nd floor: Resuscitation medical & Hospitalization [medical + surgical])

The second floor (shown in Figure V.3) is used for the hospitalization of patients under shock, as well as for the hospitalization of medical injury patients. This floor contains 10 hospitalization beds shared between the SES and MES sections.

The second section of the ED, which is the MES, it comprises a total of 12 rooms. As is shown in Figure V.4, at the entry we have waiting rooms, which are used simultaneously for the sorting process. Patients waiting for the availability of a general doctor. Inside the MES, we found two medical consultation rooms, one treatment room, and a resuscitator room occupied by a specialist. The MES contains three hospitalization beds for patients under observation for a duration that does not extend six hours, plus six hospitalization beds for patients who require a hospitalization period for more than 6 hours.

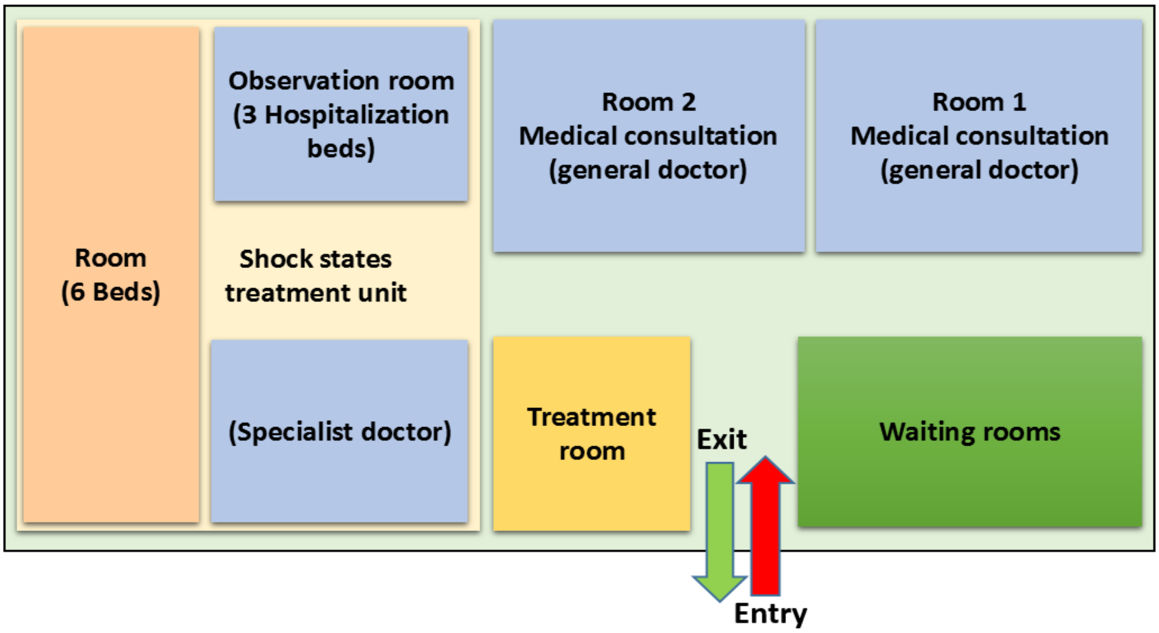


Figure V.4 - Physical structure of the Medical Emergency Service

The ED receives more than 12000 patients monthly; its doors are open 24 hours a day, 7 days a week. Medical staff works on two shifts times, “day shift” and “night shift”, the “day shift” takes place from 07:00 until 19:00 and includes two different teams, while the “night shift” starts from 16:00 until 08:00 morning and includes three teams, which works reciprocally. In the following section, we are going to present the patients' paths inside the ED, as well, the different classes of patients

V.4.1 Patient admission flowchart

Patients’ arrival to the ED is either walking (via the reception) or by an ambulance. Then, a sorting nurse will sort those patients based on their signs and symptoms. Next, according to their states, she will orient them to the appropriated section of the ED. In our study, we considered three main patients' classes; patients in different classes will have a different treatment, thus diverse paths inside the ED.

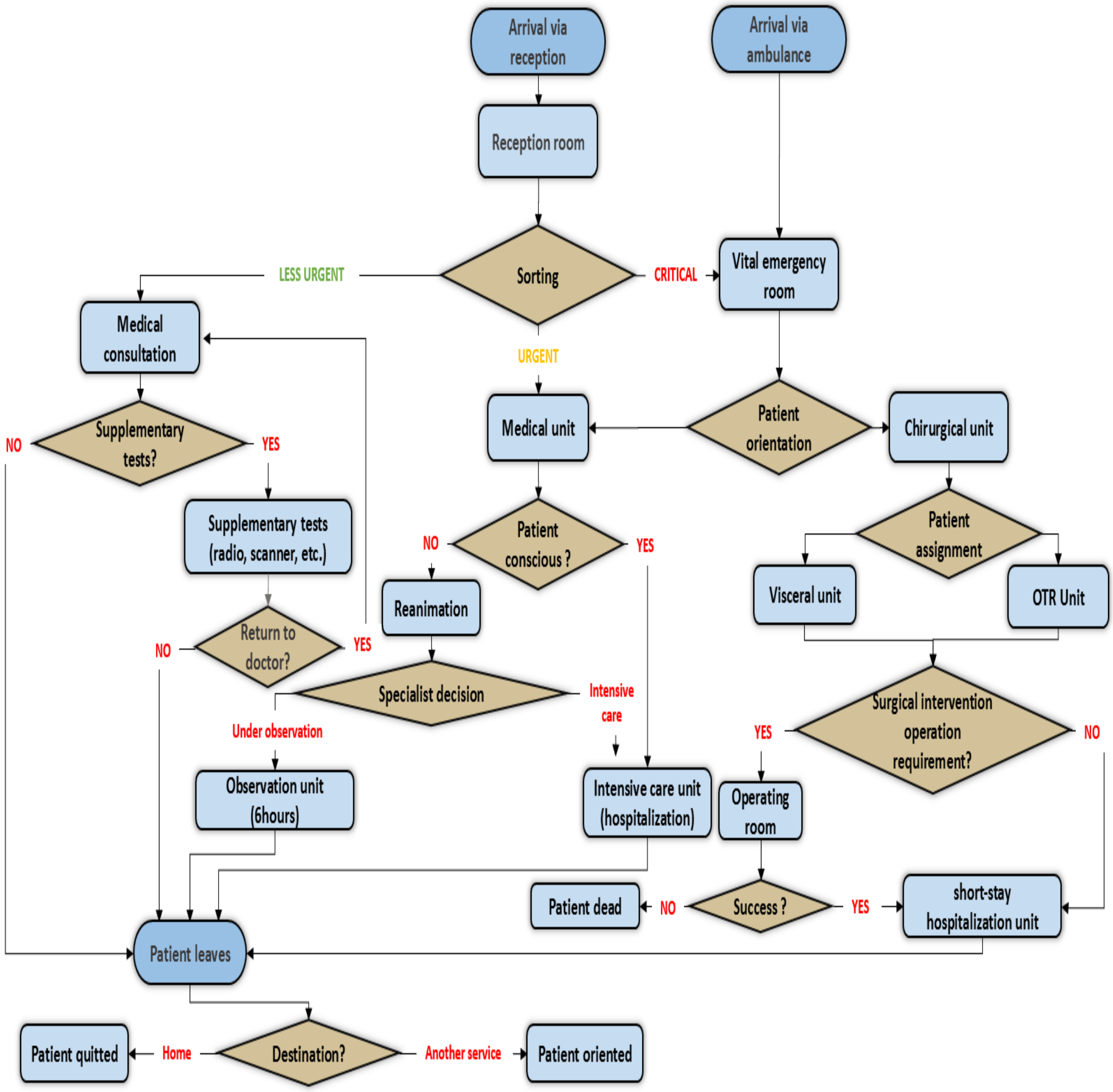


Figure V.5 - The different paths of patient admission process (Derni et al, 2019b)

Figure V.5 clarifies the possible pathways of patients in the considered ED. The flowchart provides a basis for the discrete event simulation model. It is realized based on the existing patients' flow inside the study system. Patients are classified based on their different paths as follows:

- Class 1: This class includes patients with a stable state or less urgent state; it represents more than 40% of the admitted patients based on the collected data of the two last years. Patients of this class are directly consulted by a General Practitioner (GP). Then, depending on each case, the GP may or may not ask for supplementary tests. In the case of the requirement of supplementary tests, patients take the necessary tests and then return to the GP to make its final judgment, before its orientation to another service or discharge to home.

- Class 2: It contains patients who require medical treatments, after the sorting operation, the patient will be oriented to the medical unit. In the case where the patient is in a non-conscious state, she will be admitted to the reanimation unit to stabilize its state. Then, based on a specialist decision, they put her under observation before its discharge or direction to the intensive care unit. In the other case where the patient is in a conscious state, she will be admitted directly into the intensive care unit, before its discharge to home or reorientation to another service.
- Class 3: Patients in a critical case are affected to this class, at the arrival of the patient via either reception or ambulance; she will be admitted in the vital emergency room, which includes a set of anesthesiologist and resuscitator doctors. This room is used to take care of the most serious situations in the emergency department. Then, depending on the case of the patient, she will be oriented to the medical unit or surgical unit. In the case when a patient needs medical treatment, she will follow the same path of the second class' patients. In the other case when the patient needs surgical treatments, she will be assigned based on her case to the Orthopedics and Traumatology (OTR) unit or the visceral unit. In the case when a patient needs a surgical operation, she will be oriented to the operation room, before her hospitalization in the short-stay hospitalization unit, before its transfer to another service.

V.5 Methodology

In this section, we will discuss our proposed approach for the improvement of patient care quality, which is applied in a case study emergency department. We based on the patient total length of stay and the rate of treated patients, as the main key performance indicators to measure the provided care' quality. The diagram in Figure V.6 illustrates the different steps of our proposed approach. We will use FL to demonstrate the relation between the amounts of available resource, the number of incoming patients, the patient total length of stay in the ED and the rate of treated patients, additionally to its help in the calculation of the target output values based on a set of inputs parameters.

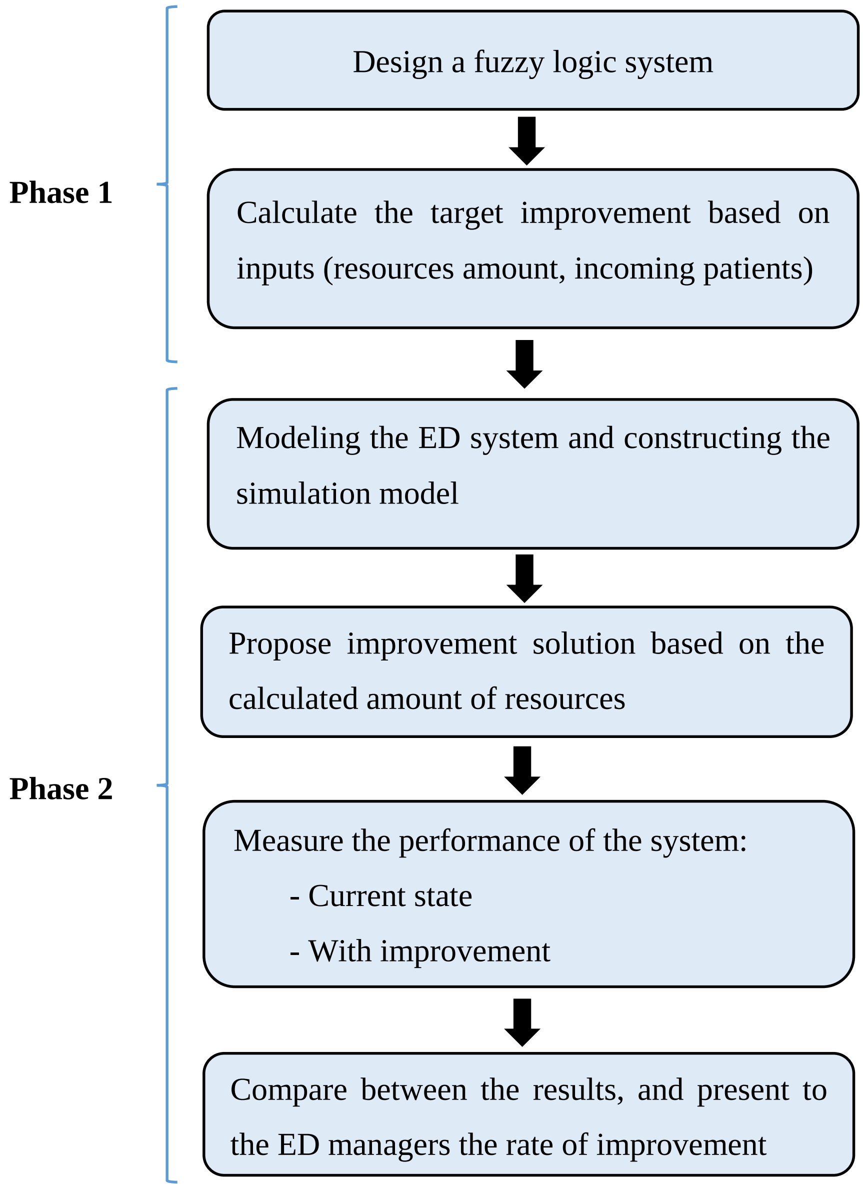


Figure V.6 - A diagram of the different steps of the proposed approach (Derni et al, 2019b)

After the building of the Fuzzy system, we will choose a set of input values appropriated with our objective improvement target. Next, a Colored Petri simulation model will be built to measure the proposed improvement solution, by adding a minimal amount of resources (Derni et al, 2019b).

V.5.1 Phase 1: Measurement of the optimization target values using Fuzzy Logic

In the current work, we use a two-input two-output Mamdani-type Fuzzy Logic Controller (Mamdani, 1977) as shown in Figure V.**7**. We are going to design an FL system, which helps us in the determination of the target outputs, based on inputs variables. To build an FL system, we need to start by defining the linguistic variables and terms. Then, we move on to the construction of membership functions, for the input and output variables. A knowledgebase is necessary which includes a set of rules represents the experience of one or many experts. Then, we realize the "fuzzification" phase, which consists of converting crisp data or values into fuzzy data using the defined membership functions. The core component is the inference engine, which evaluates the rules of the knowledge base. The final step consists of combining results from each rule. Then, convert output data into non-fuzzy or crisp values using the inference engine, this process is called "defuzzification".

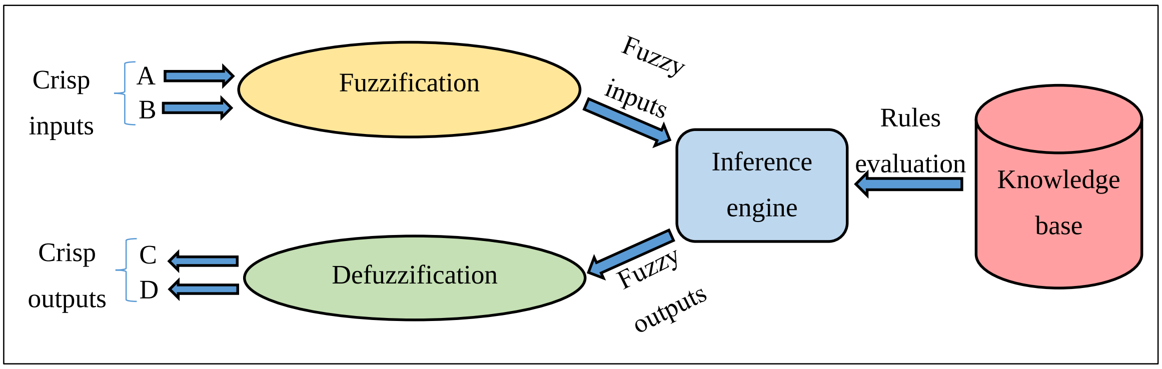


Figure V.7 - The relation between the four modules of the fuzzy inference system

Our objective by using an FL approach is to find the appropriated amount of resources to reach a target improvement (represented by output variables). In the following sub-sections, we will design the FL system.

V.5.1.1 Linguistic variables

Linguistic variables are input and output variables in the form of simple words or sentences. For inputs variables, we have the following linguistic variables:

- Resource amount = {low, medium, high, very-high}.
- Incoming patients = {low, medium, high}.

For outputs variables, we have:

- The patient total length of stay: {short, medium, long}.
- The treated patient' rate: {low, medium, high}.

Each of those variables is used in the construction of the knowledge base, using the IF-THEN rule.

V.5.1.2 Defining membership functions

Usually, membership functions (MFs) are required for the Fuzzy system; they allow us to quantify the linguistic variables or terms. In this study, the authors considered the Mamdani type function. This membership function helps for the mapping of elements (x) of the universe of discourse (U) to a value between zero and one. Considering the membership function μ_A:

$$\mu_A : U \to [0,1] \tag{1}$$

Where A is a fuzzy set, and U is the universe of discourse. As well, we can define a membership function as follows:

$$A = \{(x, \mu_A(x))\} \mid x \in U \tag{2}$$

We applied a simple Max-membership method. The max values of the Fuzzy set are collected, which leads to calculating a weighted sum. In our case, we consider two inputs (resource amount and incoming patients number), and two outputs represent the total length of stay and the rate of treated patients. Then, a general rule can be implemented as:

IF x_1 is medium AND x_2 is high THEN y_1 is long AND y_2 low

Where (x_1, x_2) and (y_1, y_2) are crisp type inputs and outputs variables, respectively. Later those variables are converted to fuzzy values by the "fuzzification" operation. In our case, we used a triangular membership functions for the inputs. The outputs are calculated using rules as:

$$\mu(y_1) = \max\left[\min\left[\mu(x_1), \mu(x_2)\right]\right] \quad (3)$$

$$\mu(y_2) = \max\left[\min\left[\mu(x_1), \mu(x_2)\right]\right] \quad (4)$$

We have taken two inputs and two outputs to calculate patients' total length of stay and the rate of treated patients. In the case study emergency department, the membership functions for the inputs and outputs variables are shown in the following figures:

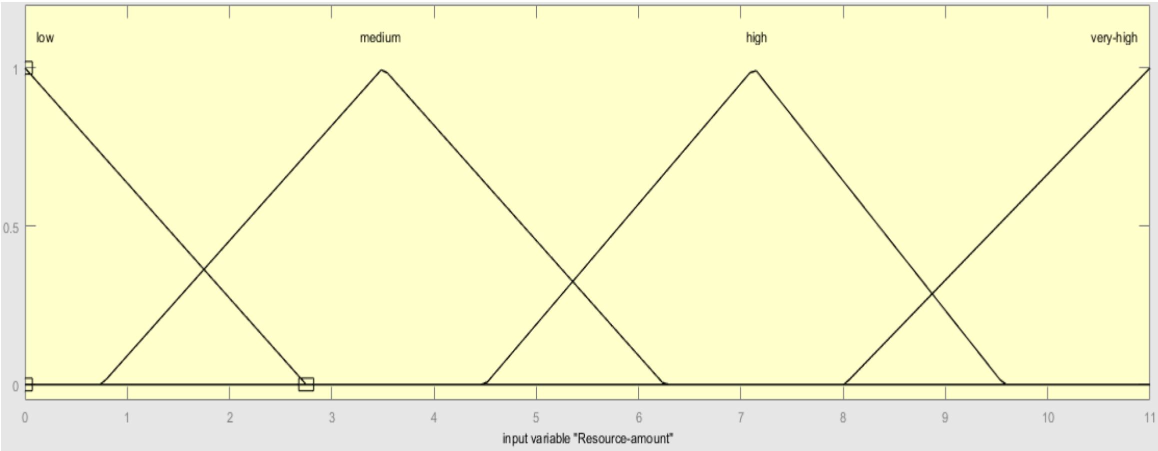


Figure V.8 - Resource amount membership function

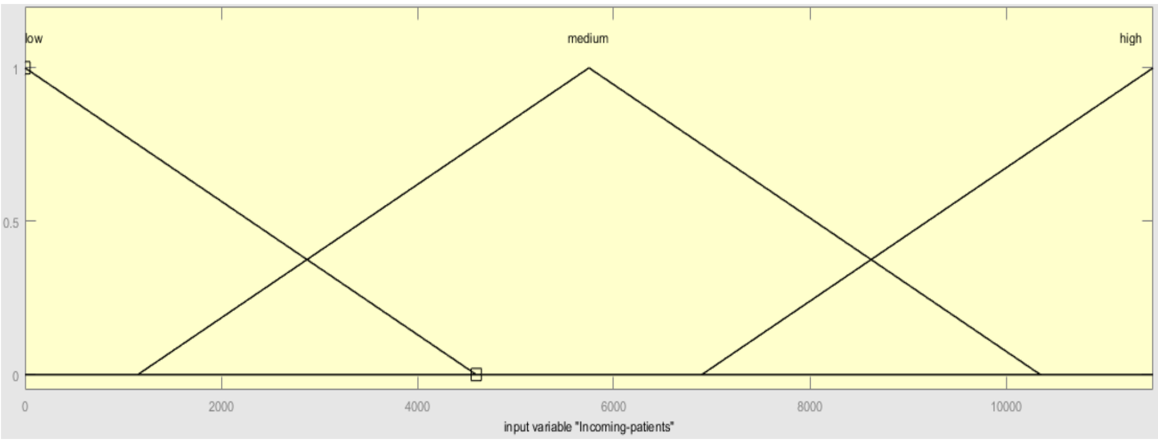


Figure V.9 - Incoming patients' membership function (estimated for one month)

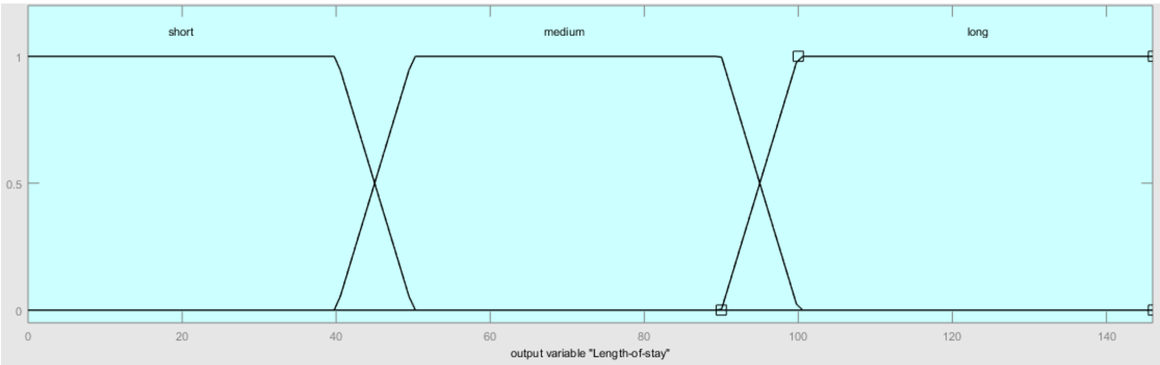


Figure V.10 - Patient length of stay memberships function (minutes)

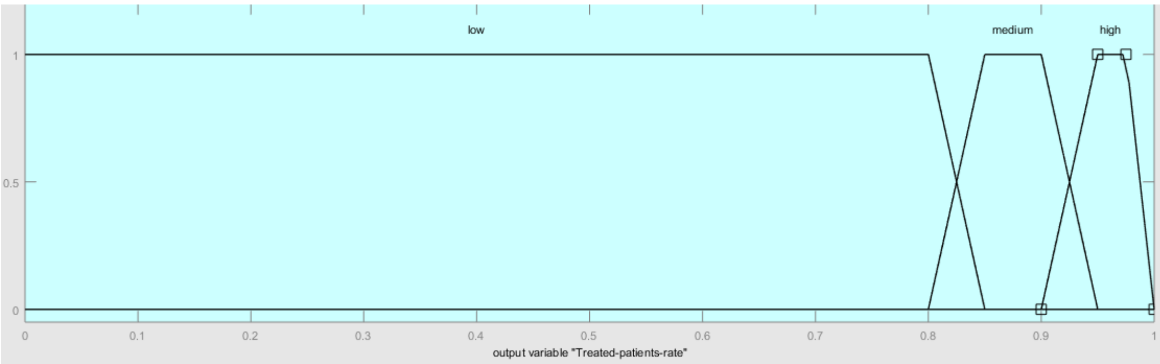


Figure V.11 - Treated patients rate membership function

V.5.1.3 Construction of knowledge base rules

Mamdani fuzzy inference (Mamdani and Assilian, 1975) is the most commonly seen fuzzy methodology and was among the first control systems constructed using fuzzy set theory. In this work, we applied Mamdani rule in the inference engine, which is mainly based on Max-min values as well as max-products. The Fuzzy system acquired suitable valuable output after applying the Mamdani type inference engine. The rules are written in the following format:

IF a is A AND b is B THEN c is C AND d is D

Where A, B are the inputs sets of linguistic terms and C, D are the output sets of linguistic terms. While (a, b) and (c, d) are inputs and output variables, respectively.

We have employed the IF-THEN rule, and developed a model according to FL, using FL Toolbox in Matlab. The knowledge base' rules are presented in Table V.2.

Table V.2 - Knowledge base rules

Rule number	Fuzzy rule
1	IF (Resource-amount IS Low AND Incoming-patients IS Low) THEN Length-of-stay IS Medium AND Treated-patients-rate IS Medium
2	IF (Resource-amount IS Low AND Incoming-patients IS Medium) THEN Length-of-stay IS Long AND Treated-patients-rate IS Low
3	IF (Resource-amount IS Low AND Incoming-patients IS High) THEN Length-of-stay IS Long AND Treated-patients-rate IS Low
4	IF (Resource-amount IS Medium AND Incoming-patients IS Low) THEN Length-of-stay IS Medium AND Treated-patients-rate IS Medium
5	IF (Resource-amount IS Medium AND Incoming-patients IS Medium) THEN Length-of-stay IS Medium AND Treated-patients-rate IS Medium
6	IF (Resource-amount IS Medium AND Incoming-patients IS High) THEN Length-of-stay IS Long AND Treated-patients-rate IS Low
7	IF (Resource-amount IS High AND Incoming-patients IS Low) THEN Length-of-stay IS Short AND Treated-patients-rate IS High
8	IF (Resource-amount IS High AND Incoming-patients IS Medium) THEN Length-of-stay IS Medium AND Treated-patients-rate IS Medium
9	IF (Resource-amount IS High AND Incoming-patients IS High) THEN Length-of-stay IS Medium AND Treated-patients-rate IS Medium
10	IF (Resource-amount IS Very-high AND Incoming-patients IS Low) THEN Length-of-stay IS Short AND Treated-patients-rate IS High
11	IF (Resource-amount IS Very-high AND Incoming-patients IS Medium) THEN Length-of-stay IS Short AND Treated-patients-rate IS High
12	IF (Resource-amount IS Very-high AND Incoming-patients IS High) THEN Length-of-stay IS Medium AND Treated-patients-rate IS Medium

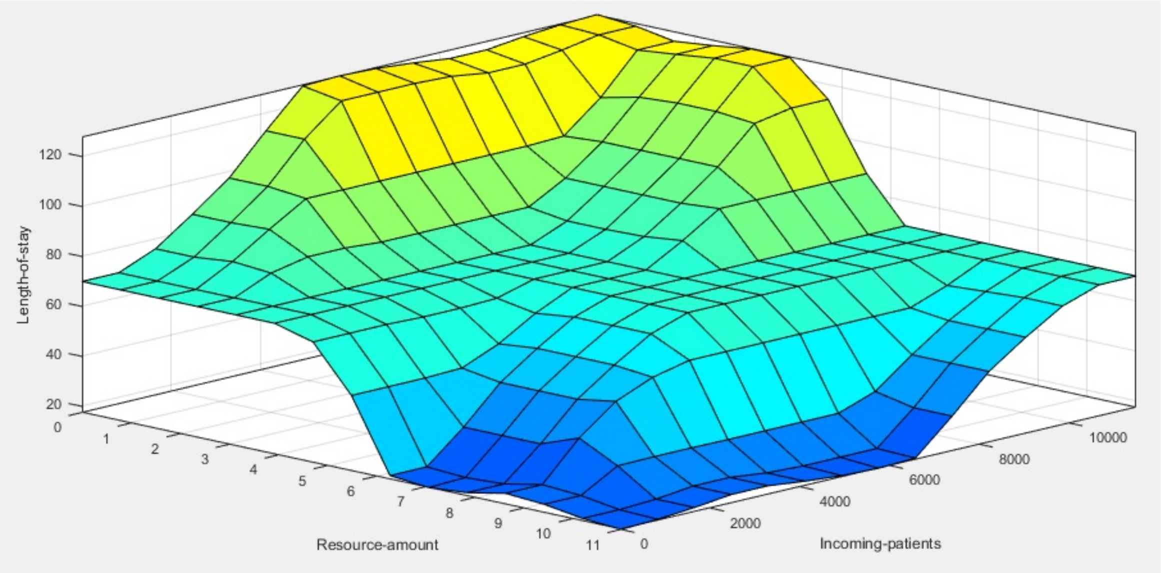


Figure V.12 - Plot under Matlab surface viewer of resource amount, incoming patients and the output variable length of stay based on IF-THEN rule.

Figure V.12 shows the plot graph of the rules; the first and the second axes represent the amount of resource, number of patients, respectively. While the third axis is the total length of stay.

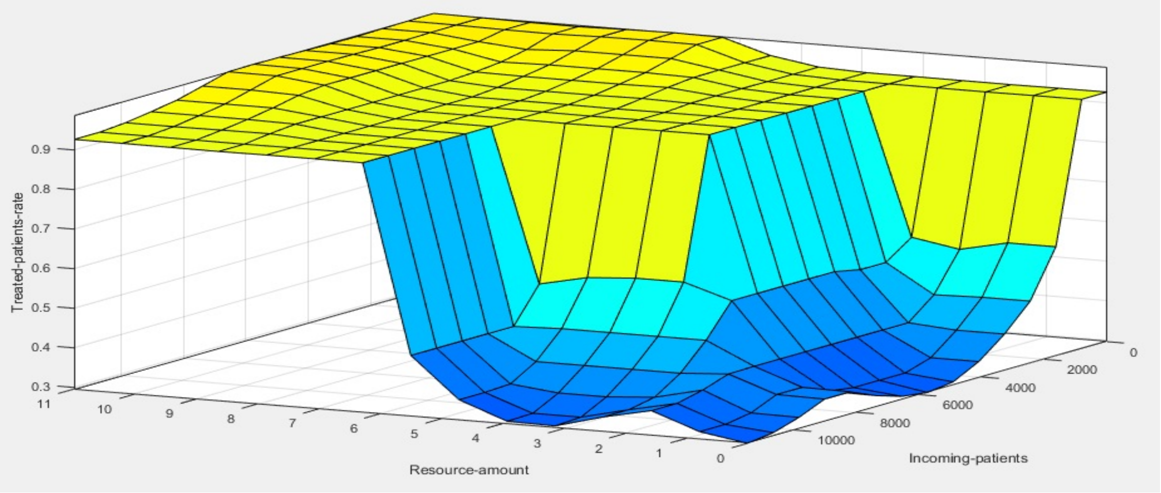


Figure V.13 - Plot under Matlab surface viewer of resource amount, incoming patients and the output variable rate of treated patients based on IF-THEN rule.

While Figure V.13 is the plot graph of the rate of treated patients. Although, the relationship graphs of the input and output variables are shown in Figure V.14 and Figure V.15.

From the figures, we can observe that patient length of stay decrease when resources amount increase and its value increase according to the number of incoming patients.

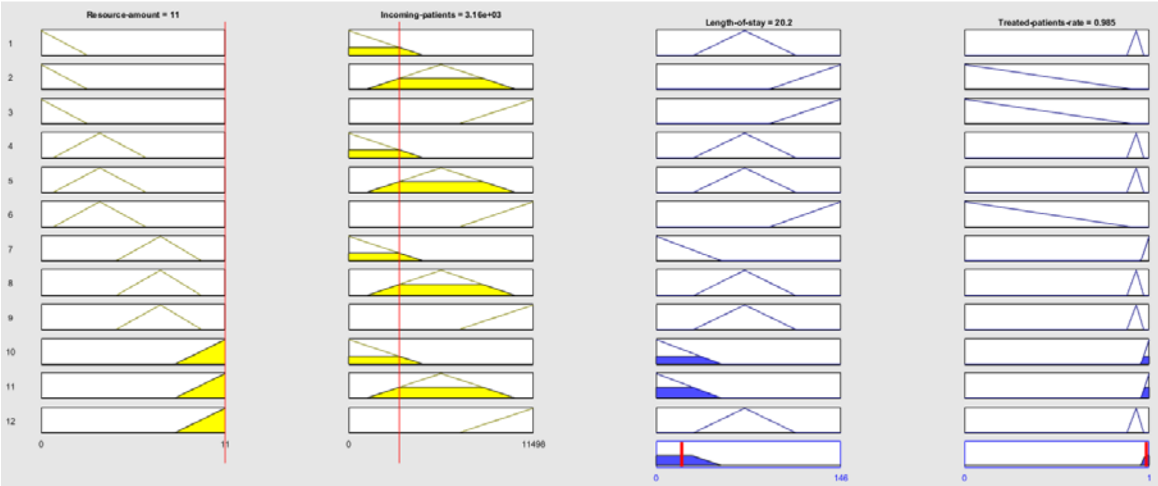


Figure V.14 - The relationship among Resource amount, Incoming patients, Length of stay and the rate of treated patients

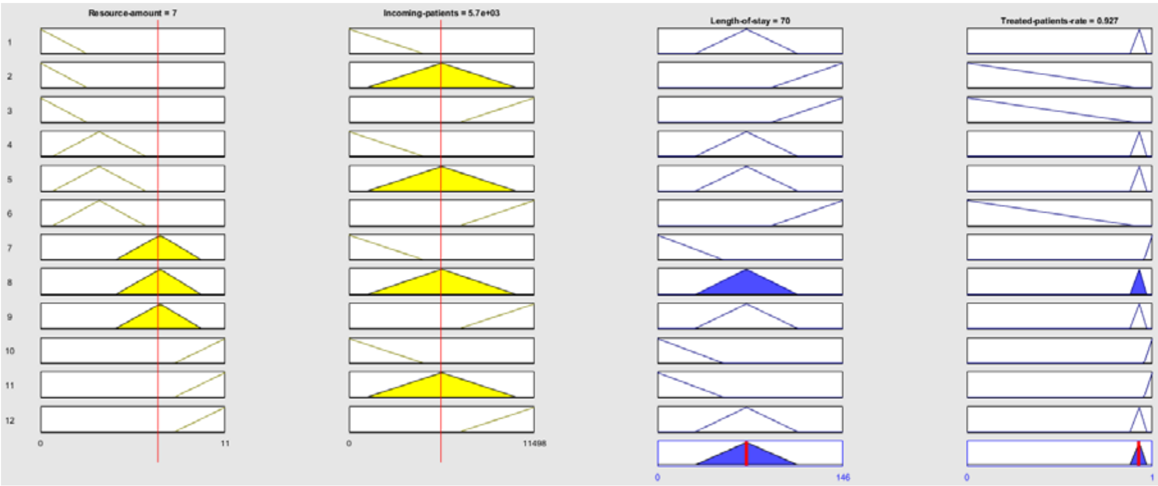


Figure V.15 - The relationship among Resource amount, Incoming patients, Length of stay and the rate of treated patients of the current system configuration

As we can see, based on the input variables, we have obtained output values, which represent the patient care quality inside the emergency department.

V.5.1.4 Fuzzification

The fuzzification consists of converting the crisp data into fuzzy data sets using membership functions. Fuzzy set operations evaluate the rules. The operations used for

“OR” and “AND” are Max (Union) and Min (Intersection), respectively. Then, we combine all the results of the evaluation to form the final result. The result is a fuzzy value. The three basis operators are defined as follow:

Union: $A+B=\max\{\mu_A(x),\mu_B(x)\}$ (5)

Intersection: $A\cdot B=\min\{\mu_A(x),\mu_B(x)\}$ (6)

Complementation: $\neg A=1-\mu_A(x)$ (7)

Where A,B are fuzzy sets, and μ_A,μ_B are their membership functions, respectively. The fuzzification can be completed in two ways:

1. In the case when A is a Fuzzy singleton, then an observation x_1 is transformed into a fuzzy set being a singleton with support { x_1 }, thus $\mu_A(x)$ is always zero except at $x=x_1$, $\mu_A(x)$ equal to one.
2. In the other case when A is a fuzzy set, if $x=x_1$ then $\mu_A(x)$ equal to one, else its value decrease from 1 while moving x_1.

After implementing the IF-THEN rule, we got the results shown in Figure V.14, Figure V.15, and Figure V.16, which represent the relationship graphs of the four input and output variables. From the figures, we can observe that the number of treated patients and the length of stay at the ED depend on the available amount of resources and the number of incoming patients. Figure V.16 illustrates the improvement reached in the output variables when we increase resource numbers and decrease the number of incoming patients to the emergency department. While Figure V.15 shows the current state of the system, which has a resource capacity equal to seven.

V.5.1.5 Perform defuzzification

The defuzzification process is realized to get crisp values; it applied the opposite operation of the fuzzification. Essentially, it is necessary to get the output which is needed for calculating and reaching our goal, using the Mamdani fuzzy inference based on rules, we have calculated and determinate a target output values using the FL Toolbox of Matlab software. As we can observe in Figure V.15, the current amount of available resource in the ED is equal to seven.

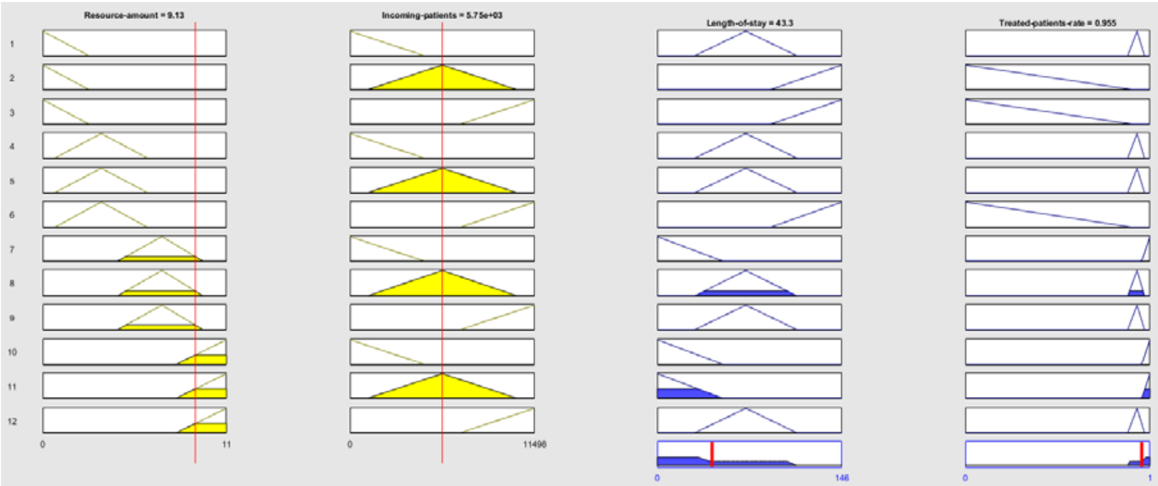


Figure V.16 - Calculated output values in the case of the augmentation of resources by two units on the current amount

In order to reach a significant improvement, ED' managers need to raise the number of available resources to nine instead of seven (Figure V.16 shows the reached output improvements). In the second phase, we will build a simulation model to measure the impact of a proposed improvement without extending the mentioned amount of resources.

V.5.2 Phase 2: System optimization using Colored Petri nets simulation model

After the determination of the necessary number of resources, needed to reach a significant improvement, we are going to propose an improvement solution without exceeding the predefined amount of resources. Then, we measure the system performance after the proposed solution and compare the results with the current system state. For that purpose, we start by modeling the case study system, using a Hierarchical Colored Petri Net (HCPN) (Jensen, 1992). Then, we build a simulation model of the current state of the ED using CPN Tools (Westergaard and Kristensen, 2009; Ratzer et al., 2003).

The model is designed based on collected data of one year from the concerned ED. Later, we run many simulations of the current system to compare the results with the collected data, and to validate the simulation model. Finally, we execute many simulation replications of the current system and the proposed improvement and make a comparison between the results based on a set of KPIs to demonstrate the reached improvement. The following sub-sections will explain in detail the previously described steps.

V.5.2.1 Simulation model

In the last decades, simulation becomes a widely spread approach in various research' fields, due to its use to measure the performance of existing and new designed systems before their implementation in the real world. It allows the designer to determine the correctness and efficiency of a design before the system is actually constructed. It offers a way to test the different configurations of many systems, without imposing a high cost.

In this study, we build a simulation model of a case study ED, the model was constructed based on system observations, and numerous interviews with the medical and administrative staffs of the ED. The model is established and validated to include the core functionalities of the current ED procedures. Hierarchical colored Petri nets were used to model the system, which provides an excellent tool for the modeling of such a dynamic system. CPN Tools is served to build the model, our choice of this tool is due to its extensible functionalities and it provides a powerful set of components for the simulation phase to accomplish the task in a swift and easy way. Figure V.17 shows the main page of our ED model.

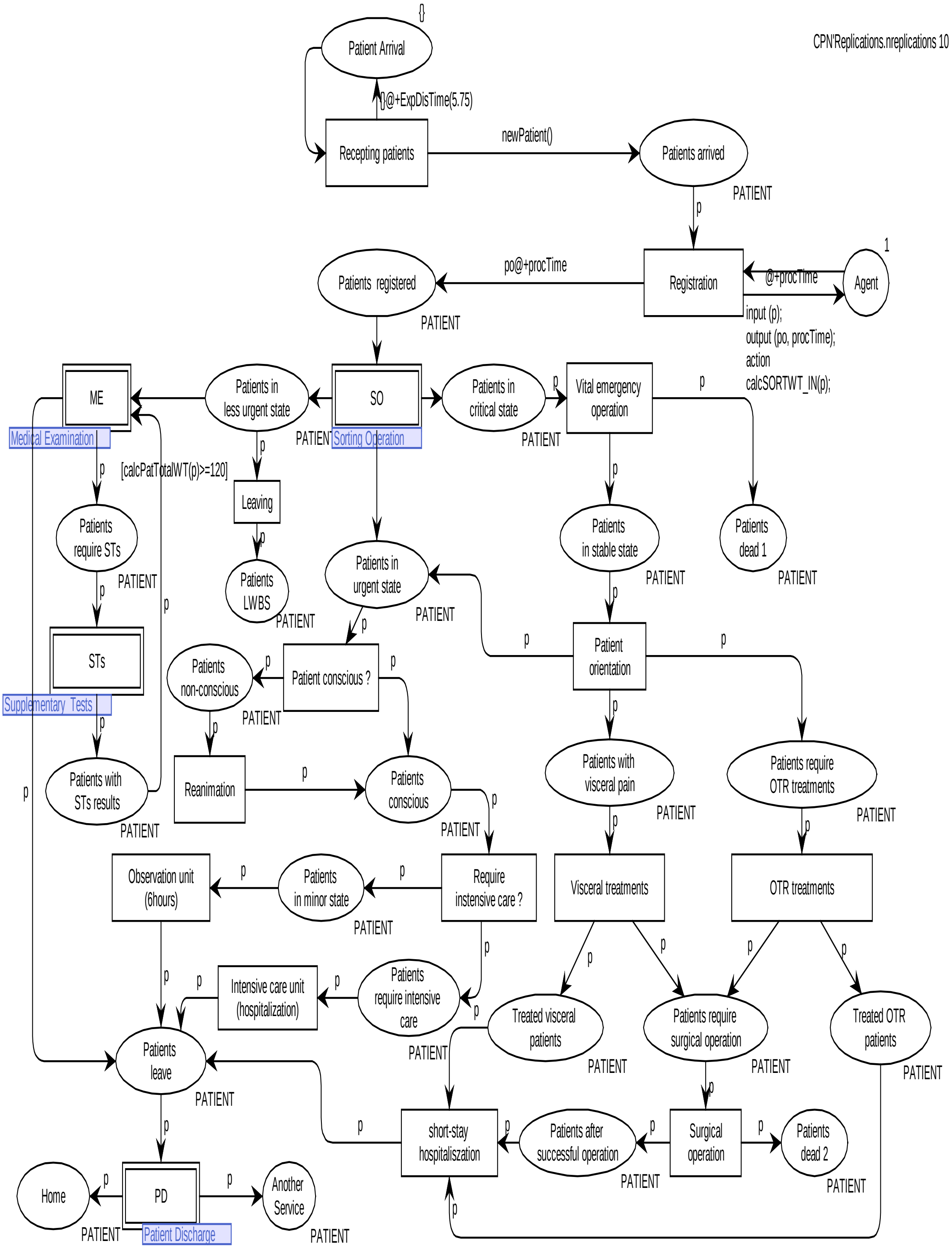


Figure V.17 - Main page of the simulation model under CPN tools

The basic stages of patient admission include sorting operation, medical examination, supplementary tests, etc. Each place of the model represents the state of patients' progress inside the system. The patient moves from place to place passing by transitions, which represent the different medical operations and decisions. The exponential distribution function is used to model the rate of patient arrival, which is adequate for this case. The patient is modeled by a colored token; it is composed of numerous attributes used for the collection of statistic information about the patient.

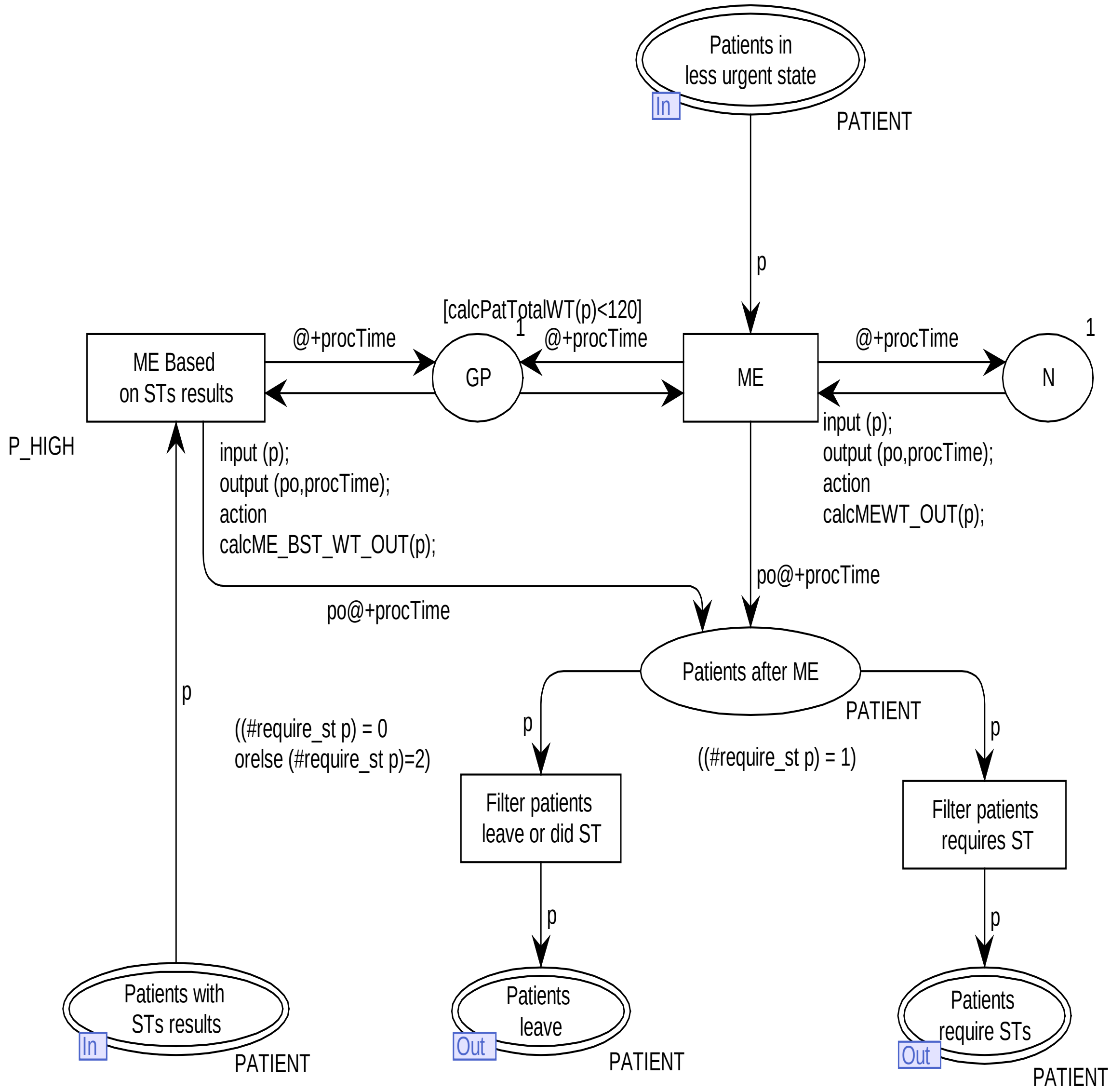


Figure V.18 - Medical examination (ME) substitution transition subpage

The model includes a set of places and transitions some of the transitions are double border we called them “substitution transitions”. Each of them represents a subnet page of the main page in a hierarchical manner. Figure V.18 and Figure V.19 show the substitution transitions of the medical examination and supplementary tests, respectively.

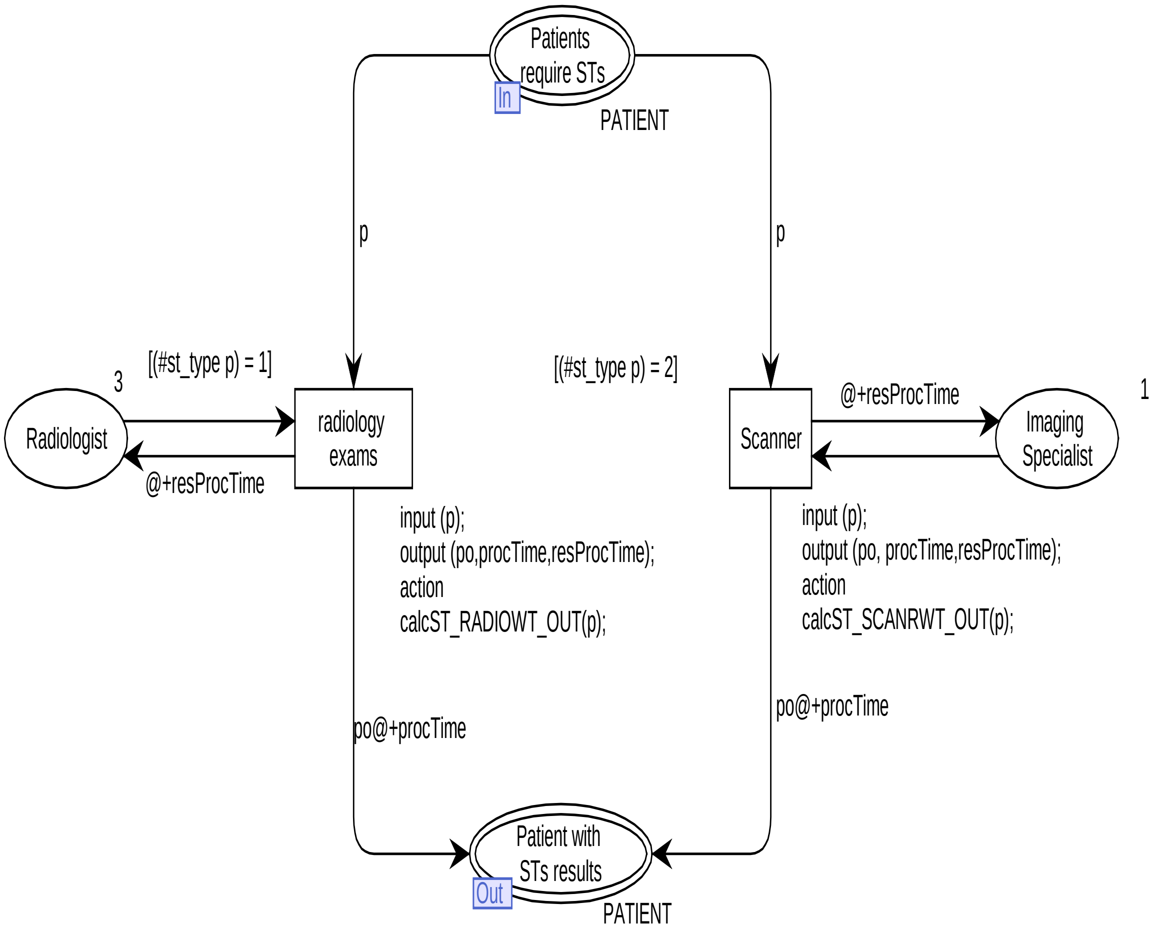


Figure V.19 - Supplementary tests (STs) substitution transition subpage.

Due to the enormous size of the emergency department, we are going to focus on the treatment pathway of class 1 patients, which represent more than 40% of the admitted patients. As it is exposed in Figure V.17, patients pass by a sorting nurse, which classifies patients based on their states. Then, they will be oriented to the "ME" place for medical examination. Depending on the patient state, she may require supplementary tests, so she moves to the place "STs". The final step is represented in, patient discharged home or transferred to another service.

Emergency department doctors and staff validated the proposed model. Additionally, to a comparison between the simulation results of the current system and the collected data (shown in Table V.3).

Table V.3 - Comparison between the collected data and the simulation results of the current system' state

ED key performance indicators	*Collected data*	*Simulation results*
DTDT (min)	30-40	35.347515
LWBS (%)	7	7.2
LOS (min)	70-75	72.895225
Sorting waiting time	0	0.287045352
Medical examination waiting time	30-40	35.75160904
Supplementary tests waiting time	0-1	0.575052854
Sorting duration	1-2	1.502320012
Medical examination duration	10-20	15.17067056
Supplementary tests duration	40-90	59.44341827

V.5.2.2 Proposed improvement and simulation result discussion

After we built the simulation model using an HCPN, we move on to the phase of system improvement. The main objective is to provide ED managers an efficient solution without a significant increase in the resource amount. The proposed improvement scenario is chosen based on our observations of system' flaws, with the help of domain specialists, without exceeding the amount of resource determined in the first phase. The solution consists of adding two medical staffs in the concerned area of the ED, represented in one general practitioner and a nurse. Then, we run the simulation of the proposed scenario for a duration of one month, with ten replications and we take the average results.

Table V.4 shows the simulation results of the current system' state with the proposed improvement scenario. For the current system and the proposed scenario, we calculated the key performance indicator, which includes in our case LWBS, DTDT, LOS, waiting times, and task durations.

Table V.4 - Simulation results of the current system' state with the proposed improvement scenario

ED key performance indicators	*Benchmark scenario*	*Improvement scenario*
DTDT (min)	35.347515	4.7336752
LWBS (%)	7.2	0
LOS (min)	72.895225	41.228922
Total waiting time	36.23203862	4.139907882
Sorting waiting time	0.287045352	0.297977983

Medical examination waiting time	35.75160904	3.432822657
Supplementary tests waiting time	0.575052854	1.210984336
Total tasks duration	36.66318665	37.08901447
Sorting duration	1.502320012	1.498742364
Medical examination duration	15.17067056	15.17848626
Supplementary tests duration	59.44341827	60.4202282

The rate of patients that LWBS is minimized by 7.2%, compared to the current system. Additionally, we have reduced door to doctor time from an average of 35.34 to 4.73 minutes, which represents an improvement percentage of 87%. Regarding the waiting times, on one side, medical examination waiting time has been reduced by 90% of the actual time. On the other side, due to the decrease of LWBS patients, the waiting time of supplementary tests has slightly increased from an average of 0.57 to 1.21 minutes. The total patient length of stay or LOS provides a global view of system performance. The proposed solution improves the LOS by 43.44% compared to the existing time.

V.6 Conclusion

In this chapter, we took a new case study hospital emergency department, and we applied our approach to improving the concerned ED. Simulation results show the efficiency of the proposed control architecture, which uses the Fuzzy controller to implement a hybrid approach based on hierarchical colored Petri nets and a fuzzy controller. The purpose of this combination is to optimize the number of treated patients and to minimize the total patient length of stay inside the ED. An FL system was designed to demonstrate the relationships between the number of resources, number of incoming patients, total patient length of stay and the rate of treated patients. Furthermore, FL provided aid in the determination of the needed amount of resources, based on the calculated outputs values. Then, a hierarchical colored Petri net was used to model the system, which helps in the identification of system' issues. Later, a simulation model was built using CPN Tools, to measure the impact of a proposed solution. As a result, we reached significant improvements of 43.44%, 87% in terms of LOS, DTDT, respectively. While the LWBS was minimized by 7.2%.

Chapter VI

A qualitative comparison of the studied cases

VI.1 Introduction

In the medical field, emergencies correspond to the generic term used to designate the hospital service that receipt patients, at any time of the day or the night. The need for studying such a system is essential due to the role, which plays this facility in saving lives and providing healthcare in a fast and precise way. In the last two chapters, we presented two different approaches with shared aims presented in the modeling and improvements of health systems, more precisely hospital emergency departments. The necessity of a qualitative comparison of the accomplished studies, with highlighting similarities and differences between the applied approaches and the chosen case study systems, will provide a comprehensive view of the proposed approaches and the divergence between the characteristics of the Algerian hospital emergency departments. In this chapter, we start by summarizing the precedent two chapters, by underlining the main points, which are presented in the characteristics of the chosen case study systems, collected data, patients flow and its characteristics, proposed approaches, and the obtained results. Then, based on those points we perform a qualitative comparison, to show the difference as well the similarity between the two studies.

This chapter is organized as follows. The first section presents a summary of the last two precedent chapters. The second section provides a comparison between the approaches based on several key points. Finally, the last section provides a conclusion.

VI.2 Summary of the presented studies

In the following sub-sections, we are going to summary our contributions in the precedent two chapters. We mainly based on numerous key points (case study systems, collected data, patient flow, proposed approaches, and obtained results).

VI.2.1 The selected case study emergency departments

In this study, we focus specifically to apply our approaches to Algerian hospital emergency departments. The necessity of modeling and improvement of those systems is crucial, due to the numerous kind of sociological, economic, and organizational issues, which those facilities are suffering from.

Chapter IV provided a detailed description of a case study ED, the selected ED belongs to a non-university public hospital establishment situated in Mascara City, Algeria. It has a limited capacity of sixteen patients' rooms, including one critical room for trauma patients or patients with deadly injuries. It contains two waiting rooms used for different tasks. Patients who require hospitalization are taken to the hospitalization section, which includes five rooms for short stay hospitalization, with a global capacity of 11 beds. The studies ED receive an average of 5000 patients per month, based on archived data of two years.

In Chapter V we have chosen a second case study of an Algerian ED. The ED is located in Oran city and it is one of the biggest ED in the West of Algeria. It receives an average of 12000 patients monthly; its doors are open 24 hours a day, 7 days a week. Medical staff works on two-shifts times, "day shift" and "night shift". The ED has two main separated sections; the first one is the surgical emergency service, while the second is the medical emergency service. The first section has a capacity of 26 rooms, distributed in numerous units. While the second contains 12 rooms used for diverse operations. The ED has a sum of 19 hospitalization beds used for short hospitalization for post and pre operator patients, additionally to the patient who suffering from critical injuries. For a detailed description of these facilities, see sections IV.6.1 and V.4.

VI.2.2 Collected data

Data provides a close view of the state of any system, as well as the studies EDs. It is also one of the important and harder phases due to the miss, and absence of complete data in both studied services. Authors have based on ED archives and interviews with medical staff to collect the necessary data. Table VI.1 summaries the collected data of the selected systems.

Table VI.1 - Collected data of the case studied systems

Designation	***1st Case ED***	***2nd Case ED***
Average number of monthly consultation	5000	12000
Average patient total length of stay (minutes)	210	372
Nursing consultation waiting time (minutes)	7	--
Nursing consultation duration (minutes)	6	--

Medical examination waiting time (minutes)	130	35
Medical examination duration (minutes)	12.5	15
Average complementary tests time (minutes)	50	59
The rate of patient left without been seen (%)	4.1	7.2
Door to doctor time (minutes)	45.51	35.34

VI.2.3 Patients flow

Due to the difference between the size of both systems, and the class of the hospitals (non-university hospital vs. university hospital center) patient flow characteristics diverge from one system to another. Patients' arrival to the ED is either walking or by an ambulance. Then, a sorting nurse will sort those patients based on their signs and symptoms. Next, according to their states, she will orient them to the appropriated section of the ED. In the first case system, we distinct five classes of the patient based on their different pathways. The first class is for the patient who suffering from critical injuries and their state need immediate treatment by a surgeon. The second one is for patients who need a nursing consultation before admitted by a general practitioner. The third class is for patients non-urgent or have a minor injury; they are guided directly to the waiting room to wait for a nursing consultation. Then, they have to wait also for the availability of the doctor, before he admits them for medical consultation. The second case study system has similar classes of patients compared to the first one. We have modeled patient flow into three main classes.

The first includes patients with a stable state or less urgent state; it represents more than 40% of the admitted patients based on the collected data of the two last years. While the second class contains patients who require medical treatments, after the sorting operation, the patient will be oriented to the medical unit. The last class is for patients in critical cases, at the arrival of the patients via either reception or ambulance; they will be admitted in the vital emergency room, which includes a set of anesthesiologist and resuscitator doctors. Then, depending on the case of the patient, he/she will be oriented to the medical unit or surgical unit.

VI.2.4 The proposed approaches

The applied approaches have a shared goal represented in the improvement of healthcare service. Our first approach is based on a colored Petri net, which is a performance mathematical model in the modeling of such concurrent systems. We used CPN for modeling the hospital emergency department system.

CPNs have several interesting features such as modeling and visualization of parallel behavior, modeling, and resource sharing. Initially, we started by the phase of data collection from a selected ED, and then we built the simulation model of our case study system, using CPN Tools components. Next, we passed to the simulation phase; we proposed numerous improvement scenarios, then we measured the impact of each scenario. Next, we compared these scenarios' results, to select the efficient one in terms of the reached improvement on the system, the comparison is done based on several ED KPIs. Furthermore, we measured the implementation cost of each scenario, which provided to ED managers a clear view of the required budget.

The second approach is mainly based on the minimizing of the patient total length of stay and the rise of treated patients rate, as two main key performance indicators used to measure the provided care' quality. We used Fuzzy Logic to demonstrate the relation between the amounts of available resource, the number of incoming patients, the patient total length of stay in the ED and the rate of treated patients, additionally to its help in the calculation of the target output values based on a set of inputs parameters. After the building of the Fuzzy system, we chose a set of input values appropriated with our objective improvement target. Next, a hierarchical colored Petri simulation model is built to measure the proposed improvement solution, by adding a minimal amount of resources.

VI.2.5 Obtained results

Several interesting improvements are reached by applying the proposed approaches in real case systems. The obtained improvement rates of the approaches are calculated using the following formula:

$$ImproRate = \frac{(CurrentState\ - ReachedImpro)}{CurrentState} * 100$$

Where $ImproRate$ is the rate of improvement; $CurrentState$ is the actual system performance; $ReachedImpro$ is the obtained improvement from applying our approaches. Table VI.2 presents the obtained results of the applied approaches.

Table VI.2 - The rates of the obtained improvements of the proposed approaches

Key performance indicators	***The rate of the obtained improvements (%)***	
	1st approach	***2nd approach***
Average patient total length of stay	6.57	43.44
Door to doctor time	74.62	86.61
The rate of patient left without been seen	87.56	100
Total waiting time	87.75	24.83
Total operations time	0.54	-1.14

VI.3 Analogy between the two studied cases

In this section, we are going to compare the two studies based on the mentioned points of the last sub-sections. We mainly based on two main axes presented in similarities and divergence between the two methods. Table VI.3 summarized the similarities and differences between the two cases.

Table VI.3 - Common similarities and differences between the two studied cases

Key points	***1st case***	***2nd case***
Selected hospital emergency department	• Belongs to a non-university hospital (medium size). • Receiving 5000 patients monthly. • The nearest hospital is far by twenty-one kilometers.	• Belongs to a university hospital center (huge size). • Receiving 12000 patients monthly. • Surrounded by at least three big hospitals.
Approaches	• Modeling using colored Petri nets. • Decision support. • Improvement based on resources extending.	• Fuzzy logic used for the determination of the amount of resources. • Modeling using colored Petri nets.

		• Decision support. • Improvement based on resource extending.
Obtained results	• Global system improvement. • Low improvement in LOS. • High improvement in terms of DTDT, LWBS, and total waiting time.	• Partial improvement. • Major improvement in terms of LOS, DTDT, and LWBS. • Acceptable improvement in term of total waiting time.

The size of the emergency department plays an important role, in the determination of the needed budget, as well as the number of resources required to meet population needs. We reached a global improvement in the first case study, while due to the huge size of the second emergency department system; we focused mainly on a specific class of patients. Both approaches provided high-quality solutions, the use of a colored Petri net framework was suitable for the modeling and even in the measurement of the impact of the proposed solutions. The obtained improvement results for the first case study provided a high amelioration of the system, due to the significant minimizing of the total waiting of patients in different stages of its admission. While in the second case, the results show a major improvement of the patient total length of stay, door to doctor time, and eliminating the cases where patients leave the ED without been seen by a doctor.

VI.4 Conclusion

This chapter has provided an overall summary of the last two chapters, which were dedicated to the study of two different health systems. The summary has included several important points, represented in the nature of the case study systems, collected data, patient flow, and its characteristics, proposed approaches, and the obtained results. Then, as we have seen in Table VI.3 we provided the common similarities and differences between the two studied cases. Summarizing and highlighting the principal points of our contributions and the services of the taken case will provide a comprehensive view of the proposed approaches and the dissimilarities between the characteristics of Algerian hospital emergency departments, which we believe it will be useful as a starting phase for any future research of this field.

General conclusion and perspectives

In current health systems, hospital emergency department plays an important role in the process of patient care. It represents the main gateway for all patients, which their states need fast and immediate treatments. The emergency department's primary goal is to offer patients not only swift treatments but also a high-quality medication to meet the population needs. Furthermore, we cannot neglect the changes that have affect hospitals in the last decades. The state of hospital systems progressively requires more organizational efforts and decision support tools, to reach more effective benefits from the available resources whatever human or material, and adequate management of the budget based on scientific studies. The mentioned points must not affect the conditions of the work of those establishments. Algerian hospitals and emergency departments are not an exception; they are suffering from several organizational, structural, and logistic issues as any establishment throughout the world.

The accomplished research in this thesis is organized into six chapters. In the first chapter, we started by exposing the research context and problematic from a general to a specific context. We pointed out the common existence problems and their impact on population daily life. Then, we expressed the context of this thesis' research, with an overview of our contributions.

The second chapter put the light on socio-economic problematic context; we mainly focused on the healthcare area, due to its crucial effect on the evaluation level of any nation. Furthermore, the necessity of high-quality treatment services has a major priority for every human being. The influence of health care systems on social inequalities in health remains controversial. Consequently, in chapter three we started by presenting a survey of the modeling and optimization technics applied in the health field. We completed the chapter with a comparison between the different modeling and optimization technics used in the literature, by highlighting the advantages and limits of each technic. We chose two emergency services to provide an extensible view of Algerian health services.

In chapter 4, we presented our contribution, and we applied our modeling and optimization approach in a case study emergency department. The proposed approach is based on a colored Petri net model of the selected emergency department. As a result, we obtained satisfying results and we offer to the concerned service' managers several realizable improvement solutions. The initial version of the approach has been communicated in a conference (Derni et al, 2019d), then it been extended and published in an international journal (Derni et al, 2019a).

In chapter 5, we have proposed a new advanced heuristic approach for the optimization of patient flow in the hospital emergency department. The approach was applied in another case system; the reached improvements were precious for the amelioration of the care quality. This work has been published in an international journal (Derni et al, 2019b).

The last chapter provides a comparative study of the realized studies, with highlighting similarities and differences between the chosen case study systems. Furthermore, we offer a comprehensive view of the proposed approaches and the divergence between the characteristics of Algerian hospital emergency departments. The chapter offers an excellent overview and analogy between the different taken cases EDs in this thesis.

As result of this research, we have proposed two different approaches with shares aims represented in the modelling and optimization of hospital emergency departments. The 1st approach has been applied in a medium size case study ED, and it has provided the improvements of 6.75%, 74.62%, and 87.56% in terms of LOS, DTDT, and LWBS, respectively. While a second new approach has been proposed and applied in a huge size case study ED. The approach has provided an acceptable improvements of 43.44%, 87% in terms of LOS, DTDT, respectively. With a minimization of 7.2% in term of LWBS.

Among the boundaries of this research, we mention the non-existence of an exhaustive analysis of the selected service' data, due to the encountered obstacles and complications in the process of data collection, sometimes because of access difficulties, and other times due to the absence of a well-designed information system. The scarcity or the absence of similar researches accomplished in Algerian emergency departments has deprived us of making a comprehensive comparison of the works who focused on the modeling and improving such systems.

Several perspectives are already taken into consideration for our future work, following the accomplished study of this thesis. Among them, a graphical user interface software for the selection of the needed amount of resources depending on many factors such as the number of incoming patients, available resources, overcrowding situations, etc. will be useful due to the dynamism of the system. Moreover, interesting work can be done by providing and focusing on scheduling problems, staff, medicals teams, shift times, etc.

Alternatively, including resource utilization, and taking into account the costs of each activity will facilitate the employment of solutions in the real world. Besides, it would be interesting to focus on different diagnostics tests resources, including laboratory staff and radiology materials. As an extension of the presented study in Chapter V, taking into account the different classes of patients (critical, urgent), by applying an extensible version of the approach will provide an interesting improvement on the system.

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Abstract

Modeling and Optimization of People Flow Management Systems: Application to Socio-Economic Areas

People's flow management is one of the interesting areas of research due to its effect on the productivity and performance of organizations in numerous areas. Care quality is a key factor in the quality of human living in any nation. This aspect is one of the main parameters for measuring the socio-economics' status. In this context, we mainly focused on studying the flow of patients in a specific department: the hospital Emergency Department (ED). The selection of this service is based on the huge daily volume of patients it receives. Our objective is to improve the care quality compared to a managerial component and the performance of the system using methodologies that allow scientific management. In this thesis, we initiate by highlighting the context and the problematic of the socio-economic systems, then we focus on the chosen study field by presenting a survey on the realized studies. We have taken two cases of emergency departments belonging to different kinds of Algerian hospitals. Next, we have proposed two different approaches with shared aims represented in the modeling and improvement of EDs. In the first approach, we take a medium size ED and we model the system using colored Petri nets to identify the problems and failures in the system. After identifying different problems, we propose a set of solutions and we study the impact of each one. As a result of our research work, a set of feasible solutions with their implementation costs have been proposed to the managers of the service. This momentum will contribute to improving the quality of care and it can be applied at the level of any service. It only requires a slight adjustment of some parameters. The second approach exploits the use of Fuzzy Logic in determining the number of resources needed to achieve a target improvement; it has been applied in one of the biggest hospital emergency structures in the Algerian west. The obtained results have proved the effectiveness of the approach. Finally, a qualitative comparison between the two studies is presented in the last chapter to provide a clear and complete vision of the accomplished works.

Keywords: Hospital emergency department, patient flow, processes, system modelling, optimization, simulation, patient waiting times.

ملخص

نمذجة وتحسين نظم إدارة تدفق الأفراد: تطبيق على المجالات الاجتماعية والاقتصادية

تعد إدارة تدفق الأفراد أحد مجالات البحث المهمة نظرًا لتأثيرها على إنتاجية المؤسسات وأدائها في العديد من المجالات. إن جودة الرعاية الصحية هي عامل رئيسي في جودة الحياة البشرية في أي دولة. هذا الحد هو أحد المعايير الرئيسية لقياس حالة الاقتصاد الاجتماعي. في هذا السياق، ركزنا بشكل أساسي على دراسة تدفق المرضى في قسم معين: قسم الطوارئ الاستعجالية بالمستشفى. يعتمد اختيار هذا القسم على الحجم اليومي الضخم للمرضى الذي يستقبلهم. هدفنا هو تحسين جودة الرعاية بالنسبة للمكون الإداري وأداء النظام باستخدام منهجيات تسمح بإدارة علمية. في هذه الأطروحة، نبدأ بتسليط الضوء على السياق وإشكالية النظم الاجتماعية والاقتصادية، ثم نركز على مجال الدراسة المختار من خلال تقديم دراسة استقصائية عن الدراسات التي تم انجازها. لقد قمنا بأخذ حالتين لقسمين للطوارئ الاستعجالية تابعة لفئتين مختلفتين من المستشفيات في الجزائر. بعد ذلك، اقترحنا نهجين مختلفين مع أهداف مشتركة متمثلة في نمذجة وتحسين أقسام الطوارئ. في النهج الأول نأخذ قسم طوارئ متوسط الحجم ونقوم بنمذجة النظام باستخدام شبكة بيتري الملونة لتحديد مشاكل وقصور النظام. بعد تحديد المشاكل المختلفة، نقترح مجموعة من الحلول ونقوم بدراسة وقع التأثير لكل منها. كنتيجة لعملنا البحثي، تم اقتراح مجموعة من الحلول الممكنة على مسؤولي الخدمة مع تكاليف التنفيذ لكل حل. سيساهم هذا الزخم في تحسين جودة الرعاية ويمكن تطبيق النهج المقترح على مستوى أي خدمة إذ يتطلب فقط تعديل طفيف لبعض الإعدادات. يستغل النهج الثاني استخدام المنطق الضبابي في تحديد عدد الموارد اللازمة لبلوغ نسبة تحسين مستهدفة؛ تم تطبيق هذا النهج على واحد من أكبر أقسام طوارئ المستشفيات في غرب الجزائر. وقد أثبتت النتائج التي تم الحصول عليها على فعالية النهج المتبع. في الأخير يتم تقديم مقارنة نوعية بين الدراستين في الفصل الختامي من أجل عرض رؤية واضحة وكاملة للأعمال المنجزة.

الكلمات المفتاحية :قسم طوارئ المستشفى، تدفق المرضى، العمليات، نمذجة النظام، التحسين، المحاكاة، مدة انتظار المرضى.

Résumé

Modélisation et optimisation des systèmes de gestion de flux de personnes : Application aux domaines socio-économiques

La gestion des flux de personnes est l'un des domaines de recherche intéressants en raison de son effet sur la productivité et les performances des organisations dans de nombreux domaines. La qualité des soins est un facteur clé dans la qualité de vie humaine de n'importe quel pays. Cet aspect, constitue l'un des principaux paramètres de mesure du statut socio-économique. Dans ce contexte, nous nous sommes principalement focalisés à étudier le flux de patients dans un service spécifique : à savoir le Service des Urgences (SU) hospitalier. Le choix de ce service est basé sur le volume quotidien énorme de patients qu'il reçoit. Notre objectif est d'améliorer la qualité des soins par rapport à un volet managérial et la performance du système en s'appuyant sur des méthodologies qui permettent une gestion scientifique. Dans cette thèse, nous commençons par mettre en évidence le contexte et la problématique des systèmes socio-économiques, puis nous nous concentrons sur le domaine d'étude choisi en présentant un état de l'art sur les études réalisées. Nous avons pris deux cas des services d'urgences d'hôpitaux appartenant à différentes structures hospitalières en Algérie. Ensuite, nous avons proposé deux approches différentes avec des objectifs partagés représentés dans la modélisation et l'amélioration des SUs. Dans la première approche, nous prenons un SU de taille moyenne et nous modélisons le système en utilisant les réseaux de Pétri colorés pour identifier les problèmes et les défaillances dans le système. Après l'identification des différents problèmes, nous proposons un ensemble de solutions et nous étudions l'impact de chacune d'elles. Comme aboutissement de notre travail de recherche, un ensemble des solutions réalisables avec leurs coûts de mise en œuvre ont été proposées aux gestionnaires du service. Cet élan contribuera à l'amélioration de la qualité des soins et peut être appliquée au niveau de n'importe quel service. Il ne nécessite qu'un léger ajustement de certains paramètres. La seconde approche exploite l'aide de la Logique Floue dans la détermination du nombre des ressources nécessaires pour atteindre un objectif d'amélioration ; il a été appliqué dans l'une des plus grandes structures d'urgence hospitalière de l'ouest algérien. Les résultats obtenus ont prouvé l'efficacité de l'approche. Enfin, une comparaison qualitative entre les deux études est présentée dans le dernier chapitre afin de fournir une vision claire et complète des travaux accomplis.

Mots clés : Service d'urgence hospitalier, flux de patients, processus, modélisation de système, optimisation, simulation, temps d'attente des patients.