UNIVERSITY POLITEHNICA OF BUCHAREST

Faculty of Entrepreneurship, Business Engineering and Management

DOCTORAL SCHOOL OF ENTREPRENEURSHIP,BUSINESS ENGINEERING AND MANAGEMENT

USING COLORED PETRI NETS TO IMPROVE PROCESSES IN EMERGENCY DEPARTMENTS

PhD Thesis Summary

PhD Supervisor,

Prof. Phd.Eng. Militaru GHEORGHE

Author,

Eng. Iustina-Cristina COSTEA-MARCU

Fundamental field: Engineering Sciences

Doctoral field: Industrial Engineering

Bucharest 2023

TABLE OF CONTENTS

Keywords: *Petri nets, medical services, emergency departments, process modeling, CPN Tools, discrete event simulation*

SUMMARY OF CHAPTERS

In **Chapter 1** the current context of the topic and its scientific importance and relevance have been described. Several scientific papers that addressed the use of Petri nets in the modeling of processes within Emergency Reception Units were analyzed. The main problems that have been reported refer to the long waiting times in the Emergency Departments, the allocation of resources (material and human) and overcrowding in the ED. At the same time, some researchers use Petri nets to evaluate the performance of healthcare delivery systems.

Chapter 2 presents in detail the basic characteristics of services and their types, emphasising their importance in society. Also, the services offered by hospitals were analyzed, presenting their classification. The final part of the chapter provides a clear picture of the current situation of the medical system in Romania, through the most important statistics in the health department. All this information is useful for understanding the importance of medical services and how they can be improved in order to provide a positive impact on society. In Romania, patients often call the Emergency Department of hospitals if they need medical assistance even if their case is not an emergency, which leads to overcrowding in the ED. According to statistics, the most calls to dispatchers are registered in Greece and Norway, Romania ranking 6th in Europe.

In **Chapter 3,** process modeling concepts were defined. Special attention was given to Colored Petri Nets, which are a suitable tool for analyzing and modeling processes in Emergency Departments. They provide a clearer understanding of the whole system and how different components of the system interact, so that the quality of services provided to patients can be improved. An Emergency Department may involve several processes and activities running in parallel. Petri net models are effective in simulating these competing behaviors and allow visualization of the work flow between the various processes and activities. Also, in the ED there may be events that are non-deterministic, which means that they cannot be fully predicted or controlled.

In **Chapter 4**, the satisfaction of patients in the ED was analyzed. In this sense, two distinct researches were carried out. The first research was a qualitative "focus-group" type, which aimed to determine the main problems encountered by the medical staff,

but also by the patients found in the emergency units. To achieve this objective, three specific objectives were achieved:

- O1 – Determination of the main attributions and characteristics of the medical staff within the ED;
- O2 – Determining the main complaints of patients within the ED;
- O3 – Determination of the main problems encountered by the medical staff within the ED.

The results of this qualitative research reveal the fact that the total time spent in the ED, the waiting time until receiving the results, but also the waiting time until the patients have a consultation with a doctor, are the main dissatisfactions of the patients. Regarding the main factors identified that influence the level of patients' contentment in the ED, they include: waiting times, tangible resources, human resources, the IT system, the temperament of other patients, trust in the medical staff, solicitude, safety for patients and empathy.

The second research is a quantitative research, which was based on the results of the "focus-group" research and had as its main objective the identification of the main factors that influence the level of satisfaction of patients in a ED unit. The interaction with the doctor, the way he communicates with the patient giving him due attention and respect, as well as their availability to answer the patients' questions are important aspects that influence the level of satisfaction of the patients who arrive at the ED.

The research results also indicate that not necessarily experience within the medical unit, but rather the empathic side of doctors is an important attribute for patients. The level of satisfaction that patients have in their interaction with nurses is also influenced by the nurses' empathy and solicitude; for patients it is very important that the nurses answer them politely and patiently to the questions they have. Moreover, the results of this research highlight the fact that the information process is a problematic one within emergency reception units, this being one of the main factors influencing the level of patient contentment. What bothers the patients the most are the aspects related to the way in which the test results are explained and the lack of information related to existing alternative treatments for the ailments they have, these aspects being more disturbing than the way the medical examination proceeds. The results of the research also highlight the role of hospital conditions, these becoming an even more relevant

factor than the interaction between patients and nurses when it comes to patient satisfaction, patient satisfaction being positively influenced by the functionality of the health groups. Regarding the waiting time and how it influences the level of patient satisfaction, the waiting time until receiving the results, as well as the waiting time in the ED, have a weak, negative impact on the level of patient satisfaction. The results of the research indicate that the waiting time until the medical examination is what bothers the patients the most.

In Chapter 4, the main dissatisfactions and factors influencing the level of patient satisfaction in the ED were identified, such as waiting time, material and human resources, communication, etc. These results are essential to understanding the problems and needs of patients in the ED and to propose solutions to improve medical services. The next chapter analyzes the processes within the Emergency Department in order to build a model using colored Petri nets. Such a model can lead to the improvement of medical processes, waiting times, resources allocation thus increasing the level of patient satisfaction in the ED.

In **Chapter 5**, the pathway that a patient can have within the ED was analyzed. Based on bibliographic reviews, protocols and direct observations, a model for processes within emergency departments was proposed. It provides for the division of ED into two categories: unstable emergencies (level 1, 2 critical emergencies) and stable emergencies (level 3, 4, 5), which in turn are divided into other subcategories. The main elements within the ED are represented by: triage, the area of vital emergencies (critical), the area of stable emergencies, the area of minor emergencies, the area of specific medical examinations (emergency rooms for different specialities), the area of investigations, the area of surveillance. Based on the model, the colored Petri net was developed, using CPN Tools (Figure 5.9).

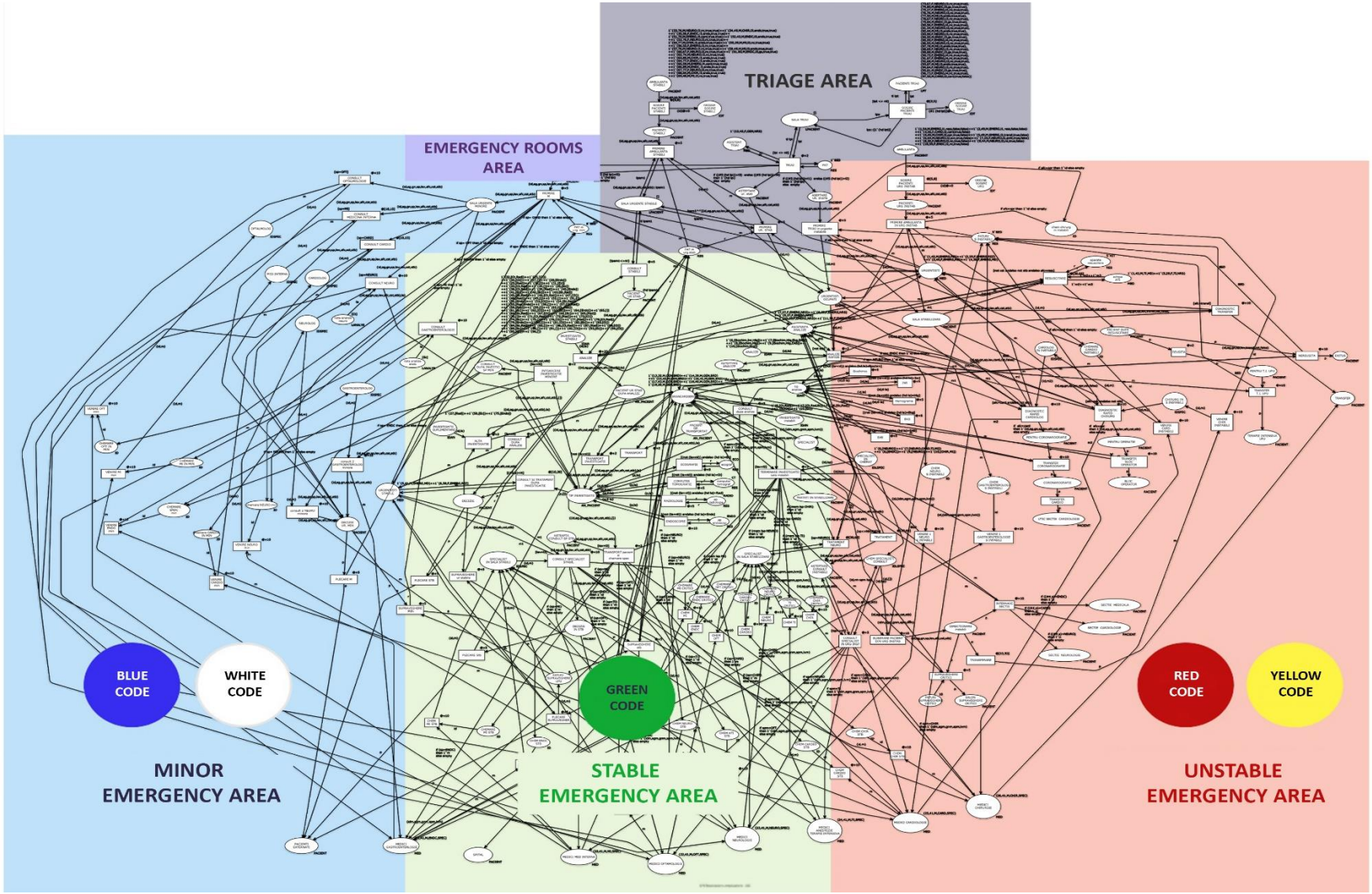

Figure 5.9. Identification of the main emergency areas of the ED, in the Colored Petri net created in CPN Tools program

In Chapter 6 the model was validated by simulating several cases with different emergency levels. At the same time, the system was loaded with 87 patients for whom attributes were chosen in order to create scenarios for validating the model and for evaluating the modeled system in situations of resource exhaustion. 100 simulations were performed in the network populated with the 87 patients.

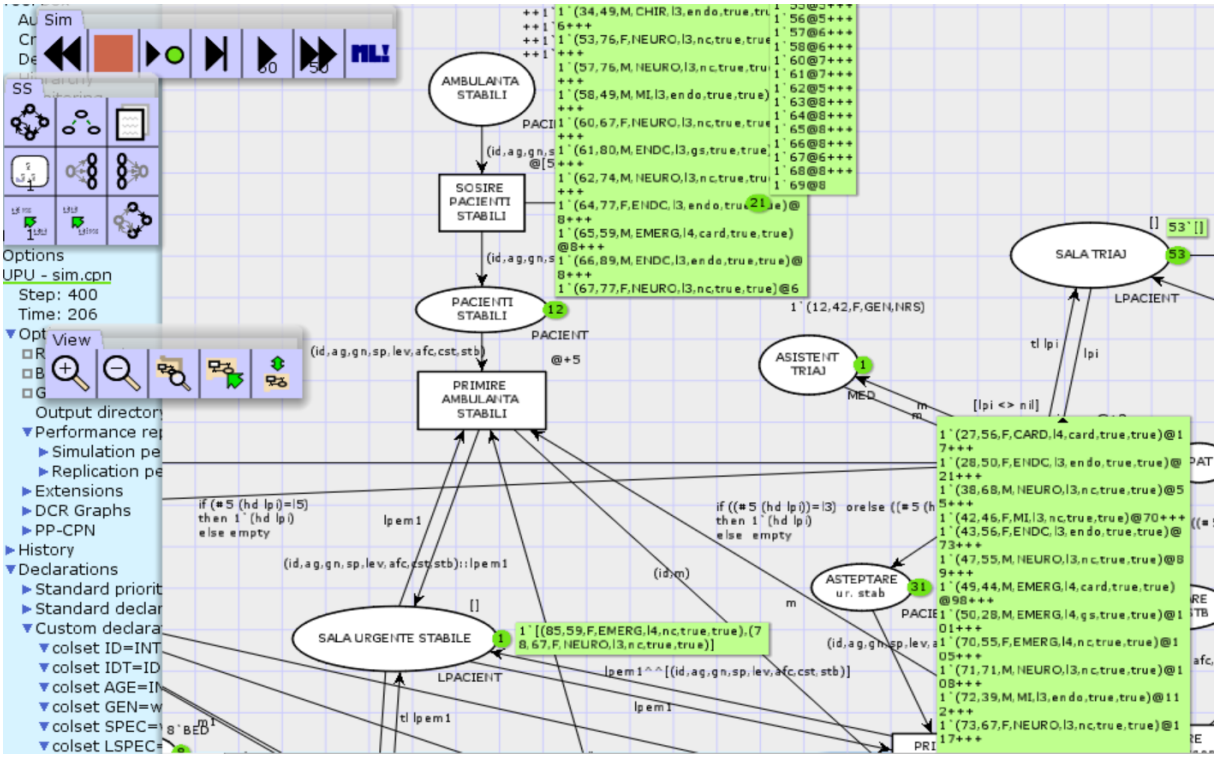

Figure 6.63 Captured Moment in Simulation - Patient Triage in Petri Net (CPN Tools Capture)

Due to the stochastic nature each simulation required a different number of steps, and the time until the last patient left the ED had a statistical distribution with a mean of 659.43 minutes and a standard deviation of 18.81. All simulations stopped due to the fact that there were no more active transitions in the Petri net model. In all simulations, the markers show that all patients were treated ("processed" by the system), that is, they reached the final places of the network, which means that for the analyzed cases the system behaves qualitatively correct. Also, the distribution of the total time is consistent with the times observed in practice, which means that also from a quantitative point of view, the model approximates reality well. Qualitatively, the model follows the procedures in the actual observed system. The distribution of material and human resources was performed properly in the simulated cases.

State space is a feature of CPN Tools, a set of software tools for analyzing and simulating colored Petri nets (CPN). The state space represents all possible states that

a colored Petri net model can take during execution. The report generated after computing the state space (Appendix 4) can be used to analyze the behavior of the model and to identify potential problems in the design of the colored Petri net, such as identifying bottlenecks (states where the model cannot make any movement) and to determine the sequences of events leading to these crashes. Thus, by identifying problems, system performance can be improved.

Also, the exploration of the state space allows the formal check up of the system. One can verify and prove whether the system has certain properties or whether certain states can be reached or not in its evolution. This can allow testing of certain protocols in the ED to see if there are resource allocation issues and network bottlenecks.

CONCLUSION

In its current form, the network that has been built allows the determination of the total time spent by the patient until complete diagnosis and redirection and the time spent in a certain area. Time spent in a certain position can mean waiting time for the patient, time for treatment, time for investigations, idle time or transit time for medical personnel.

Based on the mentioned times, one can optimize:

- the total transit time of a patient
- time to critical intervention
- waiting time at certain stages – for example, waiting time for specialists or waiting for test results or investigations.

Tokens are the elements that circulate in the network and represent patients. The productivity or "output" of the system (how many patients can be solved per unit of time), can be measured by counting tokens and extracting the time of the last patient. This measure of productivity can be useful to evaluate system performance and identify potential problems or bottlenecks that could prevent optimal patient flow through the emergency department. Measuring productivity can also help improve the planning and scheduling of medical activities so that more patients can be treated in a given time frame. All these parameters can be chosen as system optimization criteria or

constraints for optimization. The fact that there is a model that can be simulated can be used in a heuristic optimization approach.

It is preferable that the verification of some protocols and procedures that can be proposed in an Emergency Department, be done with the help of such a network, considering that in the real system it would be difficult to test and maybe even risky. At the same time, properties of the system can be predicted and guaranteed (according to the ED protocols, no patient is stuck in the system, all patients who enter the system are treated, if the protocols are followed).

A Colored Petri Net model can be used to identify problems or bottlenecks. If processes in the ED are to be improved, Colored Petri Nets can be used to identify areas where there are problems with resource allocation, waiting times in certain locations, or problems with delays that may affect the health of patients in the system. Thus, this will support the healthcare facility to make informed decisions and allocate resources effectively to improve processes and reduce patient waiting times. By using this model, it is possible to gain a better understanding of the real system in which the processes interact and to improve the efficiency and quality of medical services.

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