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Design a Petri Net Model for a Smart Hospital System

Sasan Harifi
Department of Computer Engineering, Karaj Branch,
Islamic Azad University,
Karaj, Iran
s.harifi@kiau.ac.ir

Alireza Nikravanshalmani
Department of Computer Engineering, Karaj Branch,
Islamic Azad University,
Karaj, Iran
nikravan@kiau.ac.ir

***Abstract*— Today, the world is moving towards becoming smart. Tools and equipment are somewhat smart and now it's time to use them for making smart the organizations and special places. Integration of smart devices and using them in a special place makes it to be smart place. Human is always looking for the best decision as soon as possible in an emergency situation. This becomes more important when we speak about human lives. Having a smart system for hospitals can reduce the concerns. In this paper first the ideas to have a smart hospital are presented and then a Petri Net model is designed for it. The detailed rules for design of Petri Net model make it easy to transform the initial heuristic selection criteria in formalized procedures of model construction. The model proposed in this paper can be used in different levels with proper and purposefully development.**

Keywords*— *petri net; modeling and simulation; smart hospital; healthcare; petri model; decision support system; DSS;

I. INTRODUCTION

Smart environments can improve people's experience and behaviors in a physical space. They achieve the improvement through knowing enough information of individuals with the use of new technologies, such as wireless sensor network, smart systems, cloud technologies and some kinds of smart devices [1]. The smart environment can infer action from people's context and then influence collective behavior of individuals in the environment.

Nowadays, healthcare organizations of all sizes faces a exigent need to manage and integrate clinical, financial and operational information [2]. In the current regulatory and economic ambience, hospitals must focus their efforts on performance initiatives that are essential in the short term and that will also remain critical for long term success. By delivering the right information to the right person at the right time, any enterprise will be able to improve the delivery of the healthcare services and make processes more efficient. This is what transforming Information into intelligence.

To change hospital management system into smart hospital management system needs to take help from various smart devices. These various devices will help organization with seamless flow of data between disparate systems and business units can deliver better care and enhanced satisfaction to patients, care providers and also the attendants.

Electronic health record (EHR) systems enable hospitals to store and retrieve detailed patient information to be used by healthcare providers, and sometimes patients, during a patient's hospitalization, over time, and across care settings [3]. In addition, EHRs can help hospitals monitor, improve, and report data on healthcare quality and safety.

EHRs are reliant on electronic medical records (EMR) being in place, and EMRs will never reach their full potential without interoperable EHRs in place [4]. It is important to understand the differences, and to reduce confusion in the market. The EMR is the legal record created in hospitals and ambulatory environments that is the source of data for the EHR. EMR systems efficiently and reliably store patient data electronically in a central data repository that can be accessed by various people at the same time, as seen in the examples in Figure 1.

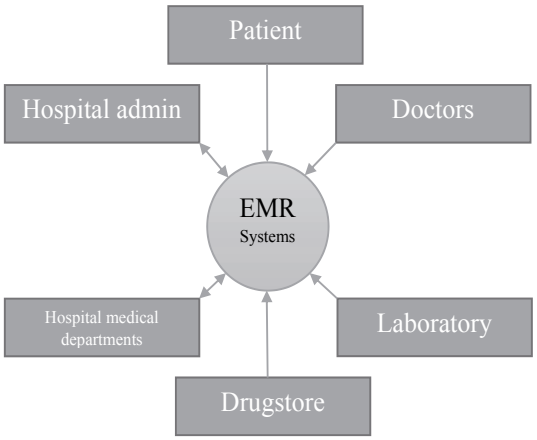

Fig. 1. A simple EMR system

In a smart hospital, EMR and EHR systems are the basic and predetermined requirements and must be existed. A smart hospital with high-performance cannot be created without an EMR. In this paper, the EMR system is already assumed that exists in designing of Petri Net model of a smart hospital.

Petri Nets have become an important computational paradigm to represent and analyze a broad class of systems [5]. They have been gaining a growing interest among people in artificial intelligence due to their adequacy to represent

knowledge and reasoning processes graphically in DSSs. The Petri Net model proposed in this paper presents a model of a simple smart hospital system. The controllable parameters in the model are associated to alternative structural configurations.

Rest of the paper is structured as follows: section II consists of related works, section III describes smart hospital and its features. Section IV includes Petri Net design and other related items. Section V represents conclusions.

II. Related Works

Petri Net model is used in many different areas [5]. In the healthcare area, Wang et al. [6] proposed a method for the medical diagnostics service chain. The case study shows that the competition relationship in the medical diagnostic process can be resolve through adding dummy transitions into the Petri Net, which reflects adding appropriate diagnostic nodes and data transmission in the medical diagnostic service chain in practice. For more details see [6].

Kirchner et al. [7] introduced a novel method to conformance checking that computes fitness of individual activities in the setting of sparse process execution information. They embed their method into a process intelligence approach for hospitals without workflow engines, enabling process monitoring and analysis.

Fanti et al. [8] presented the architecture of an integrated system devoted to manage at the operational level the healthcare at home. The components of their system are modelled based on timed Petri Net. They believed that the structure modularity guaranties the generality of the system that can include additional detection and control modules without modifying its architecture.

Hamana et al. [9] had a paper that addressed the performance evaluation and verification of territorial healthcare information systems. For this purpose, they proposed a new class of timed Petri Nets, called Territorial Healthcare Information Systems Nets, which formally describes patient care-pathways, relevant information flows and their interactions. For more details see [9]. They show that advanced information system allows earlier start of the medical consultations and thus a more efficient care pathway.

Lima et al. [10] presented a simulation of an ambulatory processes using timed Petri Net. The simulation considers the flow of patients in the biggest Brazilian cardiology hospital. The timed Petri Net is used as a decision support system (DSS) in order to improve the processes, to reduce the waiting time of the patients in the ambulatory and in this way to assure a high quality service to the patients. They believed that the improvement of the services by reducing the times should improve the quality of the attendance of the patients.

Efstratia et al. [11] presented an approach to model the inpatient's charging procedure in terms of high-level Petri Nets. To demonstrate the effectiveness of the introduced methodology, a case study was conducted and satisfactory results have been observed in the systems integration and the performance.

In Pla's paper [12] a new Petri Net extension for modelling workflow activities together with their required resources was presented: resource aware Petri Nets. Resource aware Petri Nets include time and resources within the classical Petri Net workflow representation, facilitating the task of modelling and monitoring workflows. The workflow management system monitors the execution of workflows and detects possible delays using resource aware Petri Nets.

Suzuki and Hamagami [13] proposed evolutionary Petri Net consisting of units in order to obtain a structural model of team medical care automatically. For more details see [13].

Dotoli et al. [14] proposed a timed Petri Net model for a hospital department. Their proposed model can be used as a starting point for setting up a decision tool for the design and dimensioning of hospital departments.

In the next section smart hospital features and requirement are described.

III. Smart Hospital Description and Features

In recent years, many pervasive systems for healthcare have been proposed and sometimes realized. Pervasive healthcare is highly multifaceted, with many applications focusing on interoperability with the legacy hospital assets, the traditional hospital, the security and privacy of sensitive information and the usability of end users. Collaboration among various stakeholders, numerous interconnected assets and high flexibility requirements do not only lead to complexity and dynamics but also to blurred organizational boundaries. Due to the great number of significant assets at stake (patient life, sensitive personal information and financial resources) sagacity is a key issue for hospitals.

In a smart hospital, can communicate between patient and hospital wards with the best way and the shortest time possible, and supervise the patient's demands. For this purpose, along with observance of hospital laws, by using advanced technologies, all information about illness can be checked on monitor by the patient. The monitor containing patient's information can be installed in the special places for example at the top of patient's bed. Implementation of a smart system in the hospital creates a sense of calm and trust and ease in obtaining public and private services, and also cause positive reactions to improve illness. Also this system can connect different hospital wards together as soon as possible. Generally through a smart hospital, improving the quality of clinical and health services, facilitating the use of medical care for patients and hospital personnel, management of energy consumption, and increasing productivity can be achieved.

The main prerequisite for using the amenities of a smart hospital is creating a unique identity for each of the patients, doctors, nurses and other personnel. To achieve this goal a token or fingerprint is given to the personnel, but a simpler way is to given a Radio-Frequency Identification (RFID) label to each personnel and any person who inters to the hospital [17]. Also The RFID reader devices can be installed in all parts of the hospital. RFID labels are actually made up of an electronic circuit and an antenna [18]. These labels are very useful because the radio waves passing through the most solid and

there is no need to place RFID reader devices. These labels can be embedded in patient's bracelets.

Some administrative facilities in the smart hospital are making medical record document for each patient that is updated in each phase of the treatment, checking the medical documents by the doctor and the patient, and real-time monitoring of drug inventory and ordering the needed medicines.

Communication facilities in the smart hospital include: communicating with doctors and hospital staff through portable communication tools, communicating between personnel wirelessly, the development of online communication platform in offices and hospitals and pharmacies and insurances, checking patients' documents via the Internet.

In any system, the protection and security is very important. In a smart hospital to access different parts is done by using authentication. Through authentication, the access to medicines can be limited.

There is also welfare facilities in a smart hospital. The System can remind the time of medicine consumption to the patients. The system constantly checks the patient's symptoms. The system can recommend to the patients the prerequisite for the initiation of treatment, such as X-ray or blood tests and etc.

The patient can access the following in his room: the possibility of viewing and controlling the environmental conditions by the patient (temperature, lighting, music, etc.), The possibility of informing nursing staff via touch screen placed in patient's room for clinical services, The possibility of watching TV and medical training programs, The possibility of automatic alarming of food and drug consumption schedule.

Proper operation of the operating room equipment on one side and standard conditions of a surgery on the other hand makes it possible to have environmental sustainability and the performance of the devices in the operating room. Making the operating room smart reduces human mistakes rate and guarantees the quality of environment and finally improve the quality of services provided in the operating room. The advantages of smart operating rooms are: smart control of environmental conditions (temperature, pressure, humidity, gases and radiation, etc.), Control of equipment and devices in the operating room, Time management and notifications and warnings, smart control of patient's conditions.

In short, smart hospital facilities are stated in the table 1.

TABLE I. FACILITIES OF A SMART HOSPITAL

Smart hospital facilities
Provide any information about the characteristics of the patient, the patient's condition and his illness
control the situation of the bed, lights and lighting, ventilation and heating and cooling systems, curtains, etc.
Provide the necessary medical tips and guidelines
Communicate between various staffs of the hospital in special time.
Provide Public information with medical advices
Saving time and energy
Declaring the patient's request, such as pain or a problem, the end of serum or drugs, need to bathroom or WC, coming the nurse or crew, etc.
Possibility of informing nurse staff via touch screen.
Possibility of watching TV and medical training programs
Possibility of automatic alarming of food and drug consumption schedule

The benefits achieved from all of the facilities described above, are shown in Table 2.

TABLE II. BENEFITS OF A SMART HOSPITAL

Smart hospital benefits
Improve patient care
Optimize processes of hospital
Reduce operating costs
Help to avoid harmful faults
Prevent the loss of hospital equipment
Prevent consumption of counterfeit drugs
Better revenue by offering special treatment services
Saving costs and energy

IV. PETRI NET DESIGN

Petri Nets have been proven to be convenient for modeling concurrent and asynchronous activities as well as for detecting deadlocks [5]. A Petri Net is a graph include places, transitions and arcs. It's a powerful tool for modeling and analysis of asynchronous, concurrent systems and queuing networks. Also, Timed Petri Nets [15] are utilized for performance evaluation, and Colored Petri Nets [16] have been useful for modeling complex systems processing several different jobs.

In this Section, Petri Net design for a smart hospital is described. First, a general scenario is proposed then an integrated Petri Net model is shown in Figure 6. The details of the Petri Net model as controllable parameters and choice variables are also stated.

A. Scenario

In this subsection, a general scenario is mentioned from beginning to end of entering patient to the smart hospital and discharging. It is a general scenario and the details of each step is ignored.

The patient can go to the hospital himself that in this case transferred to the emergency department. It is possible that the patient transferred to the emergency department via ambulance. In an emergency department, empty bed capacity, the capacity of admitting and emergency department capacity are constantly checked. Upon arrival to the emergency department the patient's EMR is called and the type of patient's treatment is decided. If the diagnosis is given to outpatient treatment, the patient is treated in the emergency department. At this time, the patient's EMR is checked again. If the patient is recovered his discharging is decided and ultimately patient's EHR is updated. Figure 2 shows Petri Net model of outpatient treatment staff in the emergency department.

If the condition of patient is such that he needs to be hospitalized or surgery, it is decided and transferred to the relevant staff. If the patient needs to surgery, first capacity of operating room is checked, then the hospitalization in the public staff or intensive care is decided. In all phases of the surgery, the doctors participate in decision-making related to

the patient directly or indirectly. Figure 3 shows Petri Net model of the surgery phases.

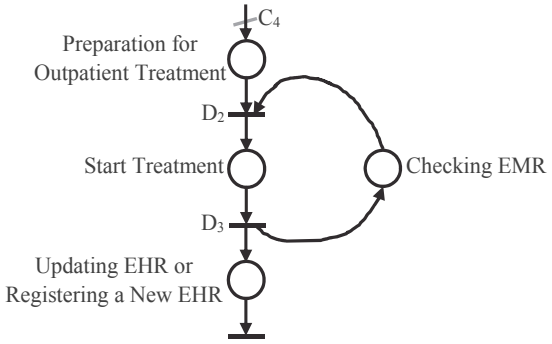

Fig. 2. Petri Net model of outpatient treatment staff

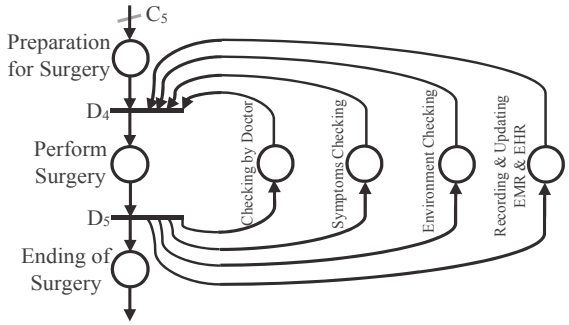

Fig. 3. Petri Net model of the surgery phases

In the admission phase or after the surgery, patient is transferred to the intensive care or the public staff based on the decision of the system and doctors. If decision-making about the patient, is so that the intensive care is needed, at first the capacity of intensive care is checked, then the hospitalization in this staff is done. At this phase the patient is under strict supervision of doctors and smart system. In the case of recovering the patient is transferred to the public staff according to the decision of doctors and smart system. Figure 4 shows Petri Net model of the intensive care.

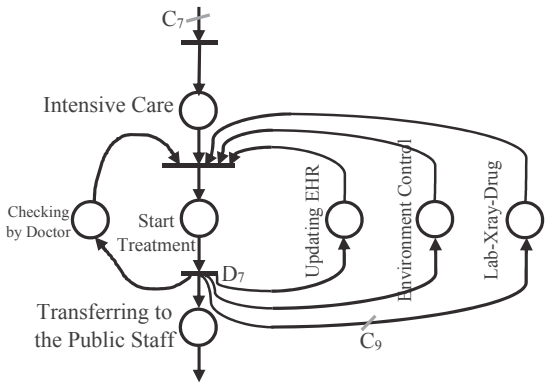

Fig. 4. Petri Net model of the intensive care

The patient with any condition is transferred to the public staff, finally. In this staff the treatment is continued and the patient's information is controlled by doctors and smart system. The conditions are under control in this phase by smart system. Finally, by decision-making, the patient can be discharged. Figure 5 shows Petri Net model of public staff.

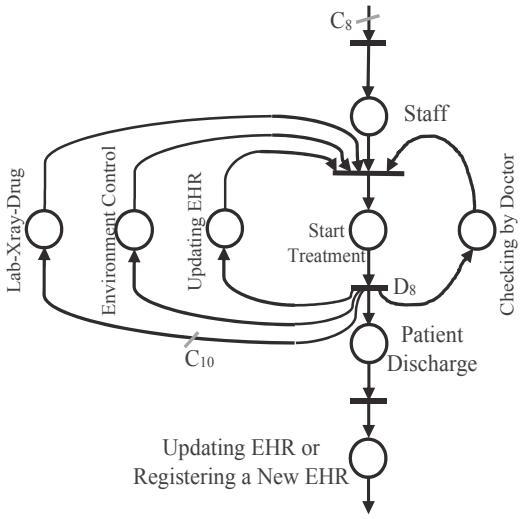

Fig. 5. Petri Net model of public staff

The mentioned scenarios is a simple and routine scenario in the hospital. At different phases, different capacities are checked by the smart system, constantly. Doctors receive and observe the patient's information, regularly. The smart system can help to the doctor for decision-making according to the patient's symptoms and therefore can act as an assistant for the doctor.

B. Controllable Parameters

The design and operation of a smart hospital require giving solutions to some freedom degrees of the system, in order to define a specific configuration for the patient handle process. These freedom degrees can be represented in a Petri Net model of the smart hospital by means of freedom degrees or controllable parameters, which, in the case of an alternatives aggregation Petri Net, are called undefined parameters [5]. Some of the most significant controllable parameters, which can be considered and specified for the design and operation of a smart hospital, are presented in the following:

C_1. The capacity of emergency department.

C_2. The number of empty beds.

C_3. The capacity of admission.

C_4. The capacity of outpatient treatment staff.

C_5. The capacity of operating room.

C_6. The number of empty beds for hospitalization.

C_7. The capacity of Intensive care.

C_8. The capacity of public staff.

C_9. The number of available laboratories.

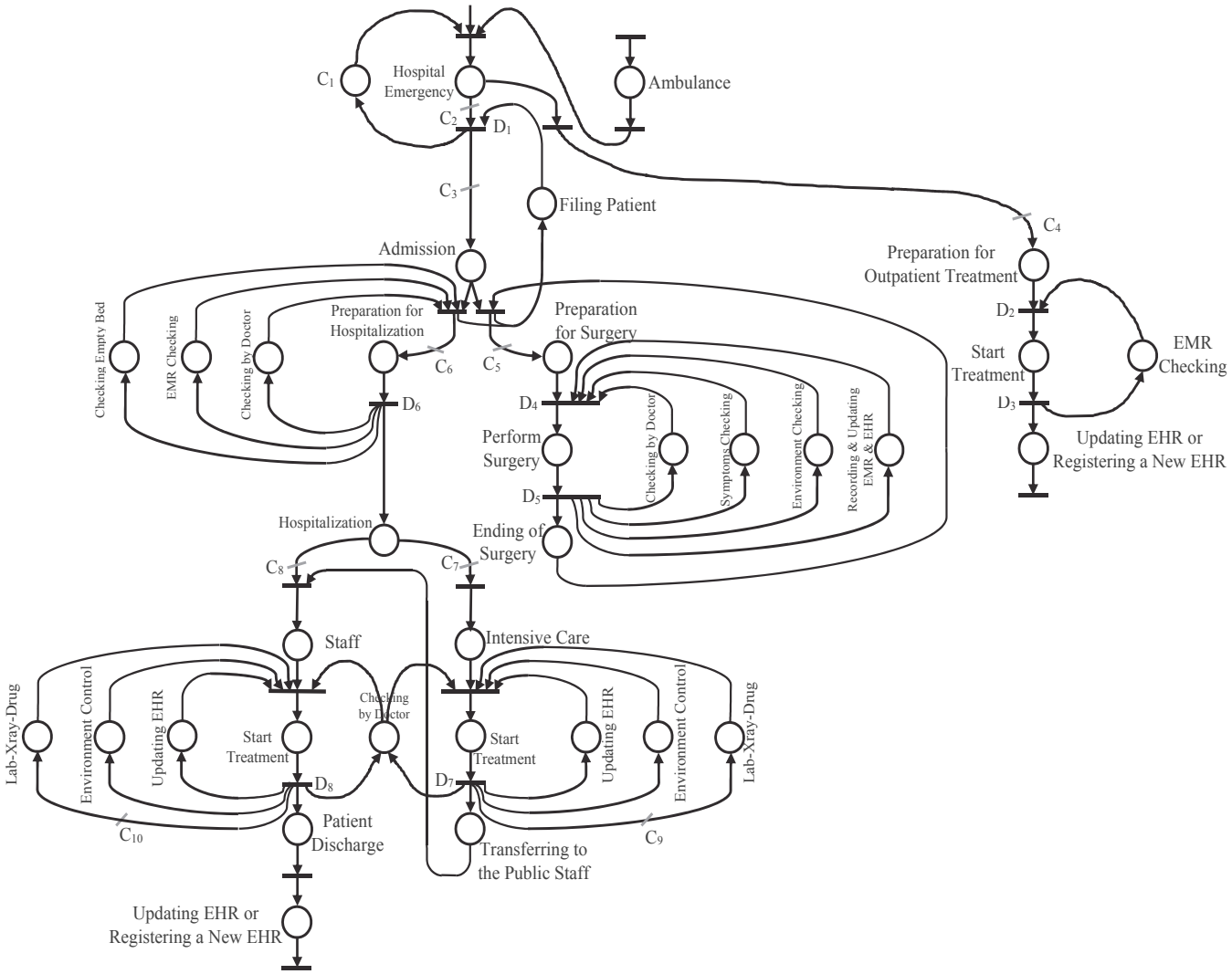

Fig. 6. Petri Net model for all phases integrated with more details

C_{10}. The number of available laboratories.

The controllable parameters of the model, represented in the previous list, are to be chosen among the values of a set associated to every parameter.

C. Decisions and Choice Variables

In Figure 6, all the processes by which decisions are made by the smart system with the help of doctor is displayed with the letter "D". Decision-making processes are mentioned at the following list:

D_1. Decision-making processes about the type of treatment or admission.

D_2. Decision-making processes about the type of outpatient treatment.

D_3. Decision-making processes about discharging the patient.

D_4. Decision-making processes about the type of surgery.

D_5. Decision-making processes about the completion of the surgery.

D_6. Decision-making processes about the hospitalization process.

D_7. Decision-making processes about the transferring from intensive care to the public staff.

D_8. Decision-making processes about discharging of patient from hospital.

Sometimes, the patient's condition can be found according to the patient's symptoms. In this case D_1 decides on the type of admission. If treatment is an outpatient basis, D_2 decides on the type of treatment and D_3 decides on the time of discharging. D_4 and D_5 decide on the type surgery during the surgery. D_6 decides on the type of hospitalization. If the patient is hospitalized in the intensive care, D_7 decides on the

transferring of the patient to the public staff. After completion of the treatment and the patient's recovering, D_8 makes decision about discharging from hospital.

V. CONCLUSIONS

In this paper features of a smart hospital are proposed and ideas for making smart of different staffs of a hospital are stated. Then a simple smart hospital is modeled by Petri Nets. As it is seen, a model of a smart hospital can be developed, using the paradigm of the Petri Nets, with the purpose of developing a DSS for the design and operation of such a facility. This model is an initial model, and the purpose of the initial model is using an efficient well-known official language to describe discrete event system, such as hospital system and their particular implementation of the alternatives aggregation Petri Nets. Also the reducing of the size of the model is possible by removing redundant information between different alternative structural configurations of the system. In addition, the development of an efficient DSS is the achievements of this paper by using a single-stage optimization with simulation.

The performance results in a simulated laboratory environment are very satisfactory. By applying several hypothetical scenario to the system, a decision making is done well. The results are appropriate from the perspective of the authors, but a certain criterion cannot be considered for it. To get more realistic results of the performance of the proposed basic model, a real hospital environment with all smart devices and tools that are mentioned in this paper, is needed. According to the model, testing were impossible in a real environment for the authors, but the results were hopeful in a simple laboratory environment. A suggestion as future works is that the simple model proposed in this paper can be developed and tested in a real environment.

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