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Medication Management Process Modeling using Coloured Petri nets

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Abstract
Medication errors are recognized as a major cause of patient safety. Physicians, pharmacists, and nurses need to a greater effort to reduce medication and medical errors. However, it is difficult to identify roles and responsibility through medication process and errors has still happened in a hospital. A major problem of medication process is an ambiguity and regulation violation. We propose a method to apply CPN (Coloured Petri nets) to a clinical setting to reduce errors and improve consensus. CPN have been used for modeling, simulation, and analysis for real-time systems. We use CPN for a medication management process, and present clinical scenarios to illustrate its application. The CPN model helps to detect weakness of the medication process and lead to improve the process through clarification. The CPN model has the potential to improve patient safety through improving understanding the clinical participants' role and responsibility in medication processes.

Keywords: Coloured Petri nets, Medication Process, Patient Safety

INTRODUCTION

Medication errors refers to all errors that occur in the medication management processes. Medication administration is an important task for health professionals and is a heavy responsibility because incorrect medication can affect patients' lives. The US Institute of Medicine (IOM) reported that 150,000 people are injured annually due to medicine misuse and there are 7000 deaths due to medication mistakes. The UK reported that medicine side effects caused 1,100 deaths annually and medication errors resulted in 200 deaths, highlighting importance and urgency of preventive measures [1].

Recently, in Korea, an evaluation of a medical institution recommended providing process-emphasized medical services that assess correct processes in nursing practices, rather than conventional structural evaluations. According to the Joint Commission Resources, medication errors account for approximately 10% of 3,548 sentinel events that caused patient deaths and severe physical and mental damages in US hospitals between 1995 and 2005 [2].

Medical practices in hospitals, including medication administration, involve various risks [3]. Therefore, mistakes in defined medical practices can have fatal consequences for patients. To avoid these consequences, defining medical processes is very important even though it is a basic activity. Ill-defined medical processes can result in a lack of understanding of the medical practices, which can lead to medical accidents. Medical processes are standardized based on such problems however, if medical processes are described in a way that is not understandable for everyone, there is still the potential for misunderstanding. A medical process description, capable of being understood by all, is required because analyses and improvements of these processes are possible when they are consistently understood.

This study investigates a method of describing medical processes that promotes consistent understanding. As a method to delineate consistent medical processes, a language that describes system operations, which was previously used in system engineering, was selected. The language defines mathematical concepts, which assist in consistent understanding and includes a state transition-based language, mathematical set based language, and mathematical logic language. Of the varied languages available, this study selected Coloured Petri Net. CPN is widely utilized in protocol verification and real-time system modeling and verification in data processing related fields [4]. However, CPN models have not been used for safety analysis in medical process.

The reasons for selecting CPN as a language to describe medical processes are as follows. First, medical processes for treating patients in a hospital include a variety of practitioners, including doctors, nurses, and pharmacists, and their relative therapeutic practices and practice outcomes. This composition of professional and practices is well matched to the method of expression in CPN. Second, CPN defines performance semantics well; therefore, simulation of prepared models is possible and understanding the medical processes defined via simulation is easily understood. Third, CPN is a modeling language in a picture form with simple grammar, which can be understood by medical professionals and system engineering professionals.

We presents description of medication processes in CPN, identification of potential problems, and modification the problems.

BACKGROUND

Medication processes and medical practice performance processes are delineated to ensure consistent medical practices across medical practitioners. Accordingly, a medical process manual is generally developed and used within the organization, and regional and national standardization is performed based on necessity. These medical processes are commonly described in a natural language, such as Korean or English, or in a flow chart as in Figure 1.

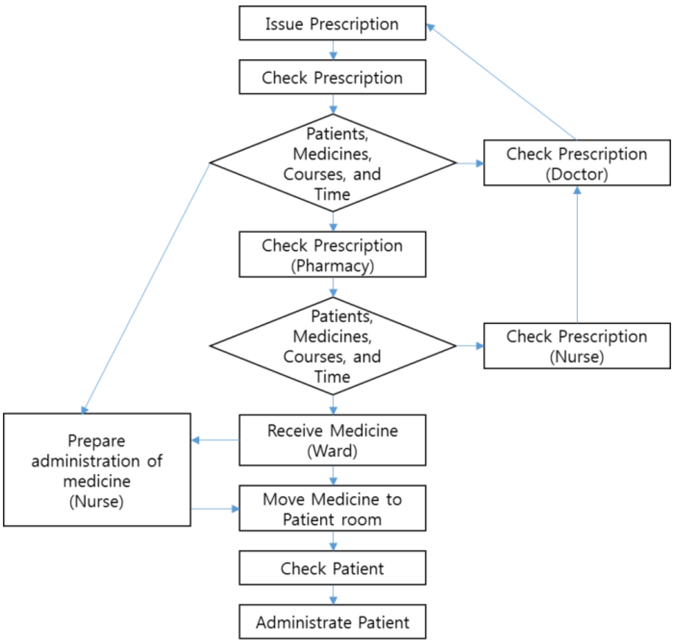

Figure 1. Medication process described as a flow chart

In general, a medication transition system includes prescription, transition, distribution, and administration. Figure 1 shows a medication process case described in a flow chart. Medial processes using flow charts seem to be easily understood, but serious limitations exist in this method.

First, medical processes can be understood incorrectly. In particular, due to the ambiguous semantics of the flow chart, it is not possible to state exactly who performs each step. As medical processes are associated with interactions between many heath care providers, it is necessary to quickly determine the health care provider in charge of each medical practice of the medical processes. An example from the flow chart in Figure 1, is ‘prescription confirmation’ after doctor prescription, but who needs to confirm the prescription is not specified.

Second, the timeliness of medical practices described in medical processes cannot be described. For instance, after prescription confirmation, patients, medicines, courses, and time are confirmed, and nurses can then prepare medication for a patient. However, a time for the prescription confirmation, medication confirmation, and actual medication is not clearly specified.

Third, description and confirmation of regulatory policies is difficult. For example, the pharmacy has a regulatory policy that prescriptions and prescribed medicines should be confirmed by two independent team of pharmacists; however, such regulations are very difficult to explain in a flow chart.

It is possible to state this information in detail with in-depth explanations, but the use of natural languages adds different ambiguities and is not an appropriate solution.

In this study, the CPN model, a type of extended Petri net, was employed as a modeling method. Petri net, first developed by C.A. Petri, can naturally express concurrency and synchronization with the advantage of visible expressions. CPN is a bipartite graph that consists of place and transition, and the state of CPN is indicated with a token [5, 6]. Each token in CPN has data types (colours), which show resources and variables; transition performance conditions are shown using guard expressions. In other words, CPN is dispersed, concurrent, and able to be expressed in graphical modeling languages of determinate or synchronized indeterminate systems. CPN expresses each process step in all possible circumstances as a graph. Basic CPN concepts used in this study follow the definition of Jensen [5].

In Petri net, not only is visible modeling possible but a variety of analysis methods are suggested, which are capable of examining achievement possibilities for which states can be shown and the boundness of the tokens that can exist finitely while performing a Petri net. In addition, there is a safety analysis method that defines accident states and removes dangerous states by automatically generating a reverse model in the Petri net model [7].

Petri net is widely utilized in the field of systems engineering; thus, its superiority as a modeling method has been verified. However, Petri net itself only provides syntax for modeling and does not provide a method or guidelines to describe medical processes; thus, there exist barriers in delineating medical processes by non Petri net professionals. To address this problem, this study select Petri net for describing medication process.

A DESCRIPTION OF MEDICATION PROCESS MODEL

This study deals with medication processes that can occur for outpatients and inpatients in a ward of university hospitals in Korea. In the hospital, medicines for all patients are prescribed via a computer system (Order Communication System) and prescriptions are transferred in real-time to the pharmacy from wards and outpatient clinics.

Medical processes are described using the CPN. The CPN itself does not provide methods for describing medical processes and, therefore, this study defined the framework of medication processes. Medication processes primarily involve collaborative relationships with other departments—the objects arriving from one department are processed and the resultant objects are transferred to the next department. In a hospital, the departments include administration, medicine, nursing, and the pharmacy; the objects correspond to those that are managed in hospitals and include patients, prescriptions, and medications. Therefore, each department assigns a role for their members based on their work, and outcomes of medical practices performed by the members are transferred to internal members or other departments.

To describe this process, a hierarchical framework was used. Medical processes consist of work transfer between departments. Therefore, the CPN model was used in the most upper level as shown in Figure 2

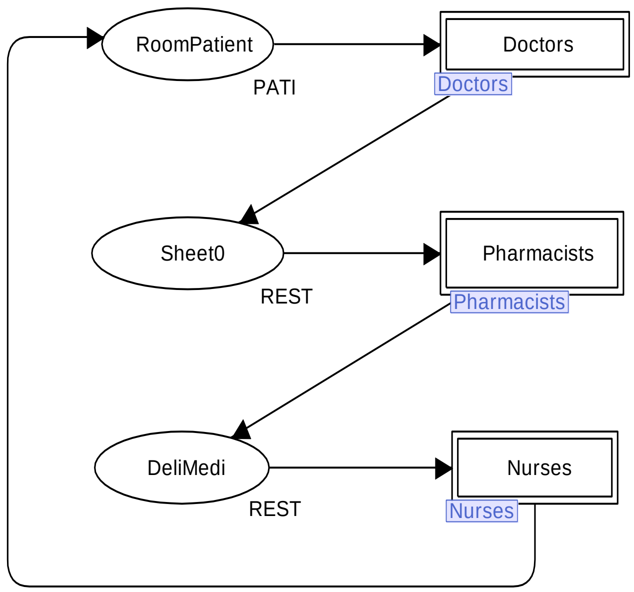

Figure 2: The top level model of medical procedures

Figure 2 describes that the medical department (Doctor) inputs patients and issues Sheet0 (the prescription), the Pharmacists receive the prescription and transfer medicines (DeliMedi), and the Nurses receive the medicines and administer these to the patients. Interaction between these departments is in the top level model are described, and interactions within the Doctors department, Pharmacists department, and Nurses department are described in lower level models.

Medical practices within each department are shown in detail again. In other words, it is expressed as medical processes in each department. The CPN subpage syntax allows hierarchical expression, which allows the medical process model to be effectively expressed. That is, there is a person in charge of each department, and that person processes the work that is entered by the department and the outcome is then transferred to next department.

Table 1 explains the CPN by comparing relevant concepts when medication process functions are modelled using a CPN support tool.

Table 1: A mapping table between Hospital activity and CPN symbol

	Hospital	Symbols in CPN
Place (oval)	Consultation preparation	Doctor
	Prescription issue after consultation	Sheet
	Patient registration	RoomPatient
	Patient waiting	Patient
	Prescription transfer	Sheet0
Transition (rectangle)	Registration behavior	Arrive
	Consultation behavior	Issue
	Prescription transfer behavior	Send

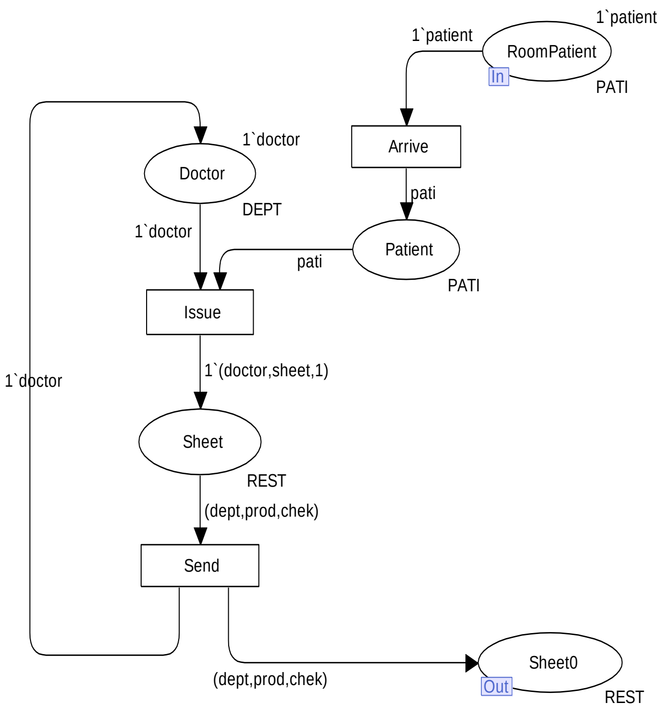

Figure 3: Consulting room model

Figure 3 shows a consulting room model. Initially, there is one doctor in a consulting room, which is described as 1`doctor in the Doctor place. The 1`doctor means one token of type Doctor and 2'doctor means two tokens. When patients arrive, the Patient place is marked as 1`patient and the doctor then consults with the patient and issues a prescription (issue transition). Once prescription is issued, one prescription is created and expressed as 1`(doctor, sheet, 1) in Sheet place. The prescription is transferred to the next department, the doctor returns to the doctor place and is available to consult the next patient.

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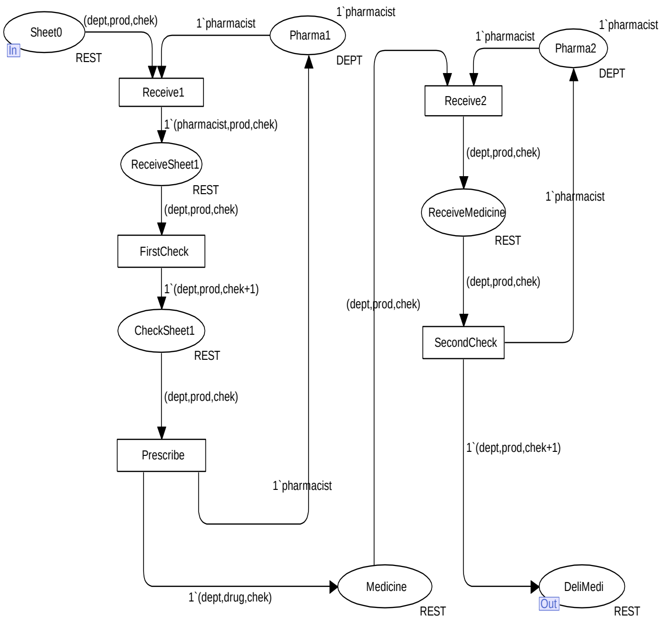

Figure 4: Pharmacy model

Figure 4 illustrates a pharmacy model. Once a prescription arrives at pharmacy, a prescription token is created at Sheet0 place. After pharmacists of Pharma1 receive and confirm the prescription (FirstCheck transition), they prescribe medicines (Prescribe transition), and prepare the medicines (Medicine place). The medicines are transferred to the pharmacists of Pharma2 to confirm and transfer to the next department. The pharmacists in the pharmacy model are divided into Pharma1 and Pharma2 to satisfy the regulatory condition that FirstCheck and SecondCheck be performed by different pharmacists.

In the nursing unit model shown in Figure 5, medicines that arrive at DeliMedi place are initially reviewed by a nurse in charge (ChiefCheck). The medicines are checked again by a general nurse (SubCheck) and then are administered to the patients (Apply). Unlike Figure 1, the CPN model (Figures 2, 3, 4, and 5) describes the confirmation processes clearly.

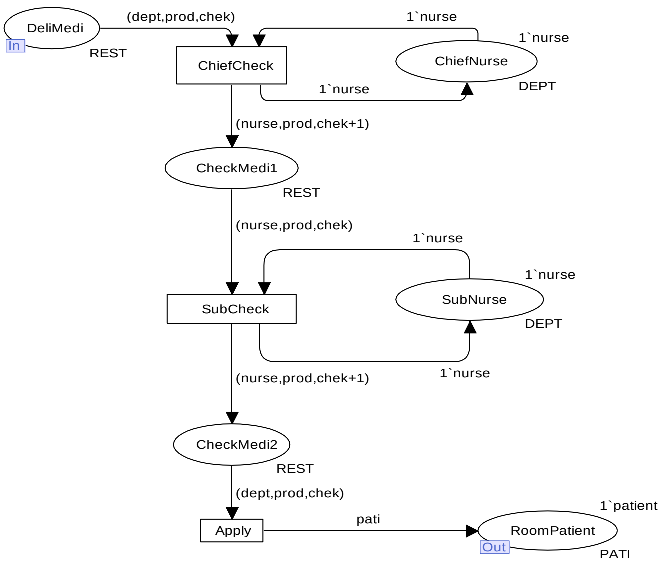

Figure 5: Nursing unit model

AN ANALYSIS OF MEDICATION PROCESS MODEL

The model described in this study is understandable and simulation is made possible by a CPN support tool. Through simulation, it is possible to confirm the current and the steps that follow. The process also allows confirmation of the correct description of the processes in the model, ensures that the model is completed correctly, and verifies that the model follows the pharmaceutical regulations of the hospital. The simulation ultimately assists in defining the standardized medical processes.

Figure 6 is an initial design of a pharmacy model. The model delineates the process of prescription (FirstCheck) after it arrives at the pharmacy; medicines are re-checked (SecondCheck) after prescription (Prescribe) followed by transferring the medicines to next department. This model seems to be correct, but does not correctly indicate that two different pharmacists should check the prescription and medication. Therefore, as shown Figure 5, prescription and medicine confirmation can be done by dividing the pharmacist group into checking prescriptions and checking prescribed medicines.

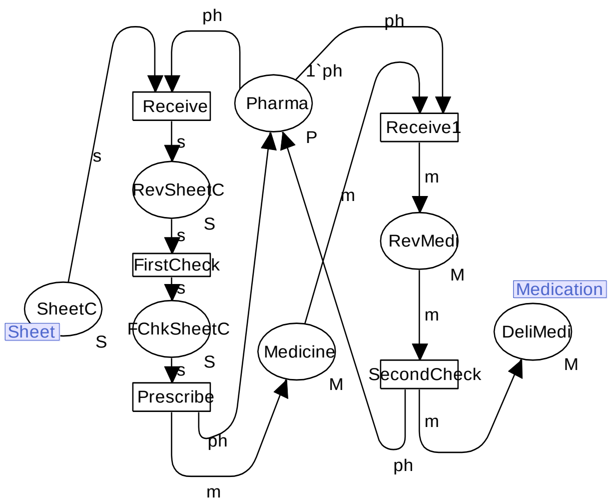

Figure 6: Pharmacy model in violation of regulations

In addition to the analysis to confirm the correct processes, statistical analyses to identify the efficiency and problems of all medical processes are possible through allocation of time for transition (for example, time to consult patients by doctors and time to prescribe medicines). The method is not explained in detail as it is outside the scope of this study.

CONCLUSION

Treating patients in a hospital is a complex medical process. In the process, a variety of practitioners perform wide range of medical practices and generate a myriad of outcomes. Complex interactions are involved in treating one patient. To aid practitioners' understating of these complex medical processes and perform those practices accurately, the processes are standardized and described in a flow chart with natural languages or explanations. However, a method based on the conventional flow chart has the limitation that individuals can misunderstand each other due to the ambiguity of the flow chart and natural language expression. Moreover, conventional methods only describe a single process and have difficulty describing a variety of processes comprehensively. Therefore, it is difficult to understand the overall medical processes and clarify responsibilities. In addition, medical processes cannot be analyzed by purpose and, thereby, a reputable method to describe medical processes is necessary.

This study modeled representative medication processes via a medical process description method using the CPN, a system modeling method utilized in system engineering. CPN is a graphical modeling method with formal semantics and its operation is defined mathematically, allowing the therapeutic processes to be described and understood in a consistent manner. Through such modeling, the various parties can have a consistent understanding of the medical processes and these processes can be described more accurately. Despite the advantages, the limitation of this method includes problems in the system model due to human errors involved in model preparation and analysis. However, the advantage of this method is the ability to find incorrect analysis using simulation, which help understand overall medical processes, eases therapeutic practices with respect to each professional's role, and clarifies where the responsibility lies. Confirming whether or not regulation violations are present in the defined medical processes is the most important element. This study defined medical processes using a mathematically defined system modeling method, CPN, and confirmed the feasibility of the methods of analysis. As more medical processes are defined and analyzed, the quality of these practices will improve. Medication process modeling performed in this study hospital is just a small part of the overall processes. Therefore, when various medical processes are modeled and analyzed in the future, medical processes in hospitals will be defined successfully without errors.

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