A MODEL TO DESCRIBE THE HOSPITAL DRUG DISTRIBUTION SYSTEM VIA FIRST ORDER HYBRID PETRI NETS

Mariagrazia Dotoli[(a1)], Maria Pia Fanti[(a2)], Agostino Marcello Mangini[(a3)], Walter Ukovich[(b4)]

[(a)]Dipartimento di Elettrotecnica ed Elettronica, Polytechnic of Bari (Italy)
[(b)] Dipartimento di Elettrotecnica, Elettronica e Informatica, University of Trieste (Italy)

[(1)]dotoli@deemail.poliba.it, [(2)]fanti@deemail.poliba.it, [(3)]mangini@deemail.poliba.it, [(4)]walter.ukovich@deei.units.it

ABSTRACT

The paper proposes a model for simulation and performance evaluation of the hospital drug distribution system, a key process for the effectiveness and efficiency of the hospital offered services. In particular, we propose a modeling technique employing the first order hybrid Petri nets formalism, i.e., Petri nets making use of first order fluid approximation. The presented model is able to effectively describe the typical doctors and nurses daily operations and may be employed for staffing performance evaluation and optimization. A simulation of the drug distribution system of a department of an Italian hospital is performed in the well-known MATLAB environment to enlighten the potential of the proposed model.

Keywords: hospital drug distribution system, modeling, hybrid Petri nets, performance evaluation.

1. INTRODUCTION

The growing costs in the healthcare industry and the increasing demand for patient satisfaction force hospitals to improve their performance and effectiveness. The main tasks of a hospital can be synthesized in two objectives: i) *service quality* i.e., the effectiveness of the offered services; ii) *efficiency* as the reduction of the costs of drugs and staff, as well as the reduction of patient waiting times. The application of suitable management strategies in order to organize and coordinate the flow of people, drugs and information can be a key feature to reach such objectives of quality and efficiency.

In the related literature different approaches are investigated to improve the hospital processes and organization. For instance, Qi, G. Xu, Huo and X. Xu (2006) study the hospital management by applying industrial engineering strategies. Moreover, Kumar and Shim (2007) modify the business processes in an emergency department in order to minimize the patient waiting times. Furthermore, medical informatics systems and Internet related technologies are proposed and investigated in the literature (S.S. Choi, M.K. Choi, Song and Son 2005, Loh and Lee 2005). Usually, simulation is employed as a tool for verification and validation of the presented solution for the improvement of quality and efficiency. Typically, simulation is either carried out by way of a simulation software (Gunal and Pidd 2007, Kumar and Shim 2007), or by Petri Net (PN) models (S.S. Choi, M.K. Choi, Song and Son 2005, Xiong, Zhou and Manikopoulos 1994). However, the mentioned contributions in the related literature share the limitation that the solutions to improve the hospital management and organization are based on heuristic strategies.

This paper proposes a model to describe and optimize the drug distribution system in hospitals. Indeed, among the hospital processes and workflows, the drug prescription and distribution have a basic and key importance to improve service quality and efficiency (Taxis, Dean and Barber 1999). More precisely, the proposed model describes the drug distribution system starting from the prescription of medications by the doctor to the drug administering to the patient.

The presented model is based on First Order Hybrid Petri Nets (FOHPNs) (Balduzzi, Giua and Menga 2000) that are a hybrid PN formalism able to describe both the continuous and discrete dynamics of the system. Continuous places hold fluid, whereas discrete places contain a non-negative integer number of tokens and transitions, which are either discrete or continuous. FOHPNs present several key features. Fluid approximations provide an aggregated formulation to deal with complex systems, thus reducing the dimension of the state space so that the simulation can be efficiently performed. Moreover, the design parameters in fluid models are continuous; hence, there is the possibility of using gradient information to speed up optimization. In other words, the model allows us to define optimization problems of polynomial complexity in order to select suitable parameters that optimize appropriate performance indices.

The objectives of the proposed model are twofold. First, it describes the operations of doctors prescribing drugs and of nurses recording prescriptions and distributing drugs. Hence, the obtained model is suitable for describing the dynamics of drug distribution in hospital wards in order to analyze and simulate the system. Second, the fluid model allows us to optimize the number of doctors and of nurses that should be present in each work-shift to obtain satisfactory performance indices and service quality.

The obtained results are the starting study for the application to the hospital drug distribution system of innovative Information and Communication Technologies (ICT) tools as well as of recently developed electronics and informatics tools, in order to improve the system management.

The paper is organized as follows. Section 2 reports some basic definitions about the structure and dynamics of FOHPNs. Section 3 presents the description of the considered drug distribution system and the proposed FOHPN model. Moreover, Section 4 reports the simulation data and discusses the results obtained by the numerical simulation. Finally, Section 5 reports the conclusions.

2. FIRST ORDER HYBRID PETRI NETS

2.1. Net Structure and Marking

A FOHPN (Balduzzi, Giua and Menga 2000) is a bipartite digraph described by the six-tuple $PN=(P, T, \boldsymbol{Pre}, \boldsymbol{Post}, \Delta, F)$. The set of places $P=P_d \cup P_c$ is partitioned into a set of discrete places P_d (represented by circles) and a set of continuous places (represented by double circles). The set of transitions $T=T_d \cup T_c$ is partitioned into a set of discrete transitions T_d and a set of continuous transitions T_c (represented by double boxes). Moreover, the set of discrete transitions $T_d=T_I \cup T_S \cup T_D$ is partitioned into a set of immediate transitions T_I (represented by bars), a set of stochastic transitions T_S (represented by boxes) and a set of deterministic timed transitions T_D (represented by black boxes). We also denote $T_t=T_S \cup T_D$, indicating the set of timed transitions.

The matrices ***Pre*** and ***Post*** are the $|P| \times |T|$ pre-incidence and the post-incidence matrix, respectively. Note that $|A|$ denotes the cardinality of set A. Such matrices specify the net digraph arcs and are defined as follows: $\boldsymbol{Pre}, \boldsymbol{Post} : \begin{cases} P_c \times T \to \mathbb{R}^+ \\ P_d \times T \to \mathbb{N} \end{cases}$. We require that for all $t \in T_c$ and for all $p \in P_d$ it holds $\boldsymbol{Pre}(p,t)=\boldsymbol{Post}(p,t)$ (*well-formed nets*).

Function $\Delta : T_t \to \mathbb{R}^+$ specifies the timing of timed transitions. In particular, each $t_j \in T_S$ is associated with the average firing delay $\Delta(t_j)=\delta_j = 1/\lambda_j$, where λ_j is the average transition firing rate. Each $t_j \in T_D$ is associated with the constant firing delay $\Delta(t_j)=\delta_j$. Moreover, F: $T_c \to \mathbb{R}^+ \times \mathbb{R}_\infty^+$ specifies the firing speeds associated to continuous transitions, where $\mathbb{R}_\infty^+ = \mathbb{R}^+ \cup \{+\infty\}$. For any $t_j \in T_c$ we let $F(t_j)=(V_{mj}, V_{Mj})$, with $V_{mj} \le V_{Mj}$, where V_{mj} is the minimum firing speed and V_{Mj} the maximum firing speed of the continuous transition.

Given a FOHPN and a transition $t \in T$, we define sets $\bullet t=\{p \in P: Pre(p,t)>0\}$, $t\bullet=\{p \in P: Post(p,t)>0\}$ (pre-set and post-set of t). The corresponding restrictions to continuous or discrete places are ${}^{(d)}t=\bullet t \cap P_d$ or ${}^{(c)}t=\bullet t \cap P_c$. Similar notations may be used for pre-sets and post-sets of places. The net incidence matrix is $\boldsymbol{C}(p,t)=\boldsymbol{Post}(p,t)-\boldsymbol{Pre}(p,t)$. The restriction of $\boldsymbol{C}$ to P_X and T_X (with X,Y $\in$ {c, d}) is $\boldsymbol{C}_{XY}$.

A marking $\mathbf{m} : \begin{cases} P_d \to \mathbb{N} \\ P_c \to \mathbb{R}^+ \end{cases}$ is a function assigning each discrete place a non-negative number of tokens (represented by black dots) and each continuous place a fluid volume; m_i denotes the marking of place p_i. The value of a marking at time τ is $\mathbf{m}(\tau)$.

The restrictions of $\mathbf{m}$ to P_d and P_c are $\mathbf{m}^d$ and $\mathbf{m}^c$. A FOHPN system $\langle PN, \mathbf{m}(\tau_0) \rangle$ is a FOHPN with initial marking $\mathbf{m}(\tau_0)$. The firings of continuous and discrete transitions are as follows: 1) a discrete transition $t \in T_d$ is enabled at $\mathbf{m}$ if for all $p_i \in \bullet t$, $m_i \ge \boldsymbol{Pre}(p_i,t)$; 2) a continuous transition $t \in T_c$ is enabled at $\mathbf{m}$ if for all $p_i \in {}^{(d)}t$, $m_i \ge \boldsymbol{Pre}(p_i,t)$. Moreover, an enabled transition $t \in T_c$ is said strongly enabled at $\mathbf{m}$ if for all $p_i \in {}^{(c)}t$, $m_i>0$; $t \in T_c$ is weakly enabled at $\mathbf{m}$ if for some $p_i \in {}^{(c)}t$, $m_i=0$. In addition, if $\langle PN, \mathbf{m} \rangle$ is a FOHPN system and $t_j \in T_c$, then its Instantaneous Firing Speed (IFS) is indicated by v_j and it holds: 1) if t_j is not enabled then $v_j=0$; 2) if t_j is strongly enabled, it may fire with any IFS $v_j \in [V_{mj}, V_{Mj}]$; 3) if t_j is weakly enabled, it may fire with any $v_j \in [V_{mj}, V_j]$, where $V_j \le V_{Mj}$ depends on the amount of fluid entering the empty input continuous place of t_j. In fact, t_j cannot remove more fluid from any empty input continuous place p^* than the quantity entered in p^* by other transitions.

We denote by $\boldsymbol{v}(\tau)=[v_1(\tau)\ v_2(\tau) \ldots v_{|Tc|}(\tau)]^T$ the IFS vector at time τ. Any admissible IFS vector $\boldsymbol{v}$ at $\mathbf{m}$ is a feasible solution of the following linear set:

$$\begin{aligned} V_{Mj} - v_j \ge 0 \qquad & \forall t_j \in T_\varepsilon(\mathbf{m}) \\ v_j - V_{mj} \ge 0 \qquad & \forall t_j \in T_\varepsilon(\mathbf{m}) \\ v_j = 0 \qquad & \forall t_j \in T_\upsilon(\mathbf{m}) \\ \sum_{t_j \in T_\varepsilon} C(p, t_j) v_j \ge 0 \quad & \forall p \in P_\varepsilon(\mathbf{m}) \end{aligned} \tag{1}$$

where $T_\varepsilon(\mathbf{m}) \subset T_c$ ($T_\upsilon(\mathbf{m}) \subset T_c$) is the subset of continuous transitions that are enabled (not enabled) at $\mathbf{m}$ and $P_\varepsilon(\mathbf{m}) = \{p_i \in P_c \mid m_i = 0\}$ is the subset of empty continuous places. The set of all solutions of (1) is denoted $S(PN, \mathbf{m})$.

2.2. Net Dynamics

The net dynamics combines time-driven and event-driven dynamics. *Macro events* occur when: i) a discrete transition fires or the enabling/disabling of a continuous transition takes place; ii) a continuous place becomes empty. The time-driven evolution of the marking of a place $p_i \in P_c$ is:

$$\dot{m}_i(\tau) = \sum_{t_j \in T_C} C(p_i, t_j) v_j(\tau) \,. \tag{2}$$

If τ_k and τ_{k+1} are the occurrence times of two subsequent macro-events, we assume that within the time interval $[\tau_k, \tau_{k+1})$ (macro period) the IFS vector $v(\tau_k)$ is constant. Then the continuous behavior of a FOHPN for $\tau \in [\tau_k, \tau_{k+1})$ is as follows:

$$\begin{aligned} \mathbf{m^c}(\tau) &= \mathbf{m^c}(\tau_k) + \boldsymbol{C}_{\mathbf{cc}} \mathbf{v}(\tau_k)(\tau - \tau_k) \\ \mathbf{m^d}(\tau) &= \mathbf{m^d}(\tau_k). \end{aligned} \tag{3}$$

The net evolution at the occurrence of a macro-event is:

$$\begin{aligned} \mathbf{m^c}(\tau_k) &= \mathbf{m^c}(\tau_k^{\,-}) + \boldsymbol{C}_{\mathbf{cd}} \boldsymbol{\sigma}(\tau_k) \\ \mathbf{m^d}(\tau_k) &= \mathbf{m^d}(\tau_k^{\,-}) + \boldsymbol{C}_{\mathbf{dd}} \boldsymbol{\sigma}(\tau_k), \end{aligned} \tag{4}$$

where $\boldsymbol{\sigma}(\tau_k)$ is the firing count vector associated to the firing of the discrete transition t_j.

3. DRUG DISTRIBUTION SYSTEM MODEL

3.1. System Description

The paper focuses on the drug distribution system of an Italian hospital department during each day of the week. Moreover, at this stage we assume that the work organization does not employ the modern ICT tools, a typical situation in most Italian hospitals.

The model input is represented by the patients that the doctors have to examine every day of the week. We assume that the number of patients is different each day. The system dynamics is as follows. Doctors visit patients daily and prescribe them drugs on a daily basis. Hence, the charge nurse records the prescribed medication on a book. Successively, nurses distribute and administer the different kinds of drugs. If the medications are stored in the department buffer storage, they are ready for administering. If this is not the case, medicines have to be ordered to the hospital pharmacy. Figure 1 shows a simplified scheme of the considered drug distribution system.

3.2. FOHPN Model

The FOHPN depicted in Figure 2 models the drug distribution to the patients present in the considered department each day of the week according to the scheme in Figure 1.

Every day, a certain number of patients is examined. The value of such an average number depends on the current day following a characteristic curve and is modelled by the weights b_j with j=1,…,7.

Accordingly, the stochastic transitions $t_j \in T_S$ with j=8,…,14 model the patient arrivals (we assume the hour as the time unit), while the timed discrete transitions $t_i \in T_D$, with i=1,…,7 and associated firing delay $\Delta(t_i) = \delta_i$ =24 h, represent the change of the day.

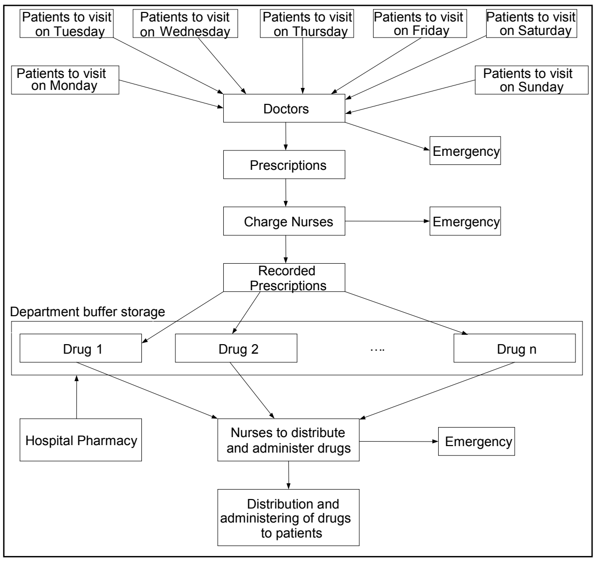

Figure 1: The scheme of the drug distribution system.

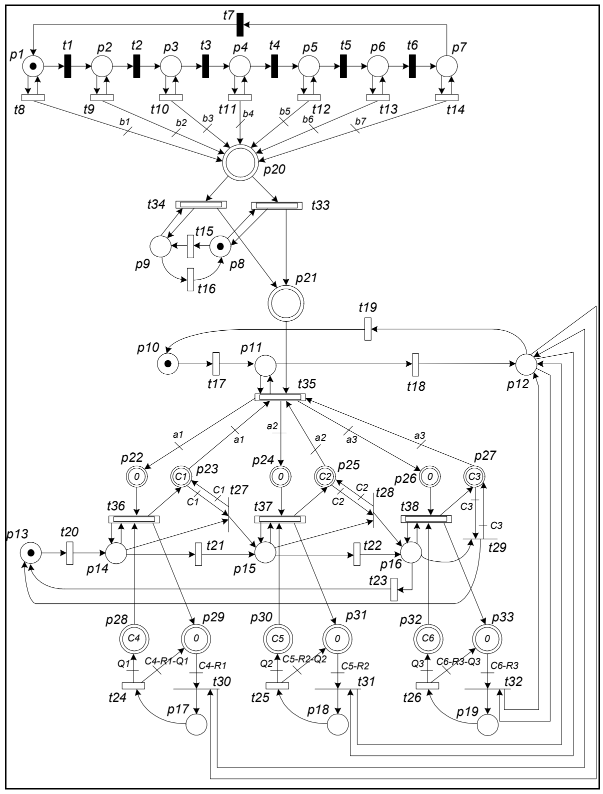

Figure 2: The FOHPN model of the considered drug distribution system.

Marking m_{20} represents the number of patients to be visited by the doctors. Place p_{20} enables two transitions t_{33}, $t_{34} \in T_c$ that model the works of the doctors in two alternative situations: t_{33} is enabled if the doctor has to do his rounds in the ward (p_8 is marked), whereas t_{34} is enabled if the doctor has to make an emergency visit (p_9 is marked). Consequently, the firing speed of transition t_{33} has to be assumed greater than that of t_{34}. After the patient examination, the doctor prescribes the drugs. Accordingly, the fluid content of the continuous place p_{21} represents the doctor prescriptions.

The charge nurse answers the emergency calls in the ward (place p_{10} marked), records the prescribed drugs on a book (place p_{11} marked and the corresponding transition t_{35} that represents the recording action enabled) and checks that the ward stockroom contains all the necessary drugs verifying the sell-by date (place p_{12} marked). Accordingly, the stochastic transitions t_{17}, t_{18} and t_{19} model the change of activity of the charge nurse.

The recorded prescriptions can correspond to different ways of administering medications. In Figure 2 we consider three main types of drugs administering: oral (place p_{22}), intravenous (place p_{24}), intramuscular (place p_{26}). Weights a_1, a_2 and a_3 represent the corresponding average number of oral, intravenous and intramuscular administerings present in a prescription.

When the charge nurse checks the ward stockroom, if the required drugs are not available or are inferior in number to a certain threshold R_i with i=1,…,3 (the marking m_{29}, m_{31}, m_{33} exceeds the value C_4-R_1, C_5-R_2, C_6-R_3, with C_i with i=4,5,6 representing the capacity of the stockroom of oral, intravenous and intramuscular drugs, respectively), the charge nurse requests the medicines (t_{30}, t_{31}, t_{32}) to the hospital pharmacy. Hence, the workers provide the ward with the required drugs by the transitions t_{24}, t_{25} and t_{26} in the quantities Q_1, Q_2 and Q_3 for each type of medication, respectively. Note that the fictious capacities C_i with i=1,2,3 are included to avoid that the continuous transitions t_{36}, t_{37} and t_{38} are enabled even when no administering is required.

The last stage of the drug distribution system in the FOHPN model is represented by the nurses that administer the prescribed drugs following the indications of the record book (transitions t_{36}, t_{37}, t_{38}). Similar to the doctors and charge nurse, we consider also for the nurses the possibility that they have to satisfy an emergency call in the ward (place p_{13} marked).

Finally, the continuous places p_{23}, p_{25}, p_{27} represent the capacity of the medication buffers p_{22}, p_{24} and p_{26} and are necessary together with the instantaneous transitions t_{27}, t_{28} and t_{29} to shift to a different type of drug to administer if no prescription is present in the record book for the currently considered type of drug.

4. DRUG DISTRIBUTION SYSTEM SIMULATION

4.1. Simulation Specification

The dynamics of the FOHPN in Figure 2 is analyzed via simulation using the data in Tables 1 to 3 and the initial marking in the Figure. In the tables variables d, c and n represent respectively the number of doctors, charge nurses and nurses available in the department. The data of the simulated drug distribution system are obtained from interviews made to administration and medical staff of a typical department of an Italian hospital.

Table 1: Continuous transitions firing speed [hours] and description

Transition	$[V_{min}, V_{max}]$	Description
t_{33}	$[0, 3d]$	Patient examination under normal conditions
t_{34}	$[0, 2.1d]$	Patient examination under emergency
t_{35}	$[0, 12c]$	Prescription recording
t_{36}	$[0, 12n]$	Recording of administering of oral drug
t_{37}	$[0, 6n]$	Recording of administering of intravenous drug
t_{38}	$[0, 4n]$	Recording of administering of intramuscular drug

Table 2: Discrete transitions firing delay [hours] and description.

Transition	Average firing delay	Description
t_1, t_2, t_3, t_4, t_5, t_6, t_7	8	Work-shift duration on each day
t_8, t_9, t_{10}, t_{11}, t_{12}, t_{13}, t_{14}	1	Waiting time before examinations
t_{15}	7	Waiting time before an emergency
t_{16}	1	Time spent for emergency by a doctor
t_{17}	1	Time spent answering emergency calls by charge nurse
t_{18}	7	Time spent recording prescribed drugs by charge nurse
t_{19}	2	Time spent verifying stockroom levels by charge nurse
t_{20}	2	Time spent answering emergency calls by nurse
t_{21}	2	Time spent administering oral drug by nurse
t_{22}	2	Time spent administering intravenous drug by nurse
t_{23}	2	Time spent administering intramuscular drug by nurse
t_{24}	2	Time to replenish the inventory stocks of oral drug
t_{25}	2	Time to replenish the inventory stocks of intravenous drug
t_{26}	2	Time to replenish the inventory stocks of intramuscular drug
t_1, t_2, t_3, t_4, t_5, t_6, t_7	8	Work-shift duration on each day

Table 3: Weights, capacities, reorder levels and fixed order quantities [units].

a_1	a_2	a_3	b_1	b_2	b_3	b_4	b_5	b_6	b_7		
2	2	1	110	90	70	105	80	60	50		
C_1	C_2	C_3	C_4	C_5	C_6	Q_1	Q_2	Q_3	R_1	R_2	R_3
10^5	10^5	10^5	2000	1200	800	1400	800	600	20	20	20

In order to analyze the system behavior, the following performance indices are selected:

i) the average patient number visited per day;

ii) the average prescription number per day.

The simulations are performed in the MATLAB environment (The Mathworks 2006), an efficient software that allows us to model FOHPN systems with a large number of places and transitions. Such a matrix-based software appears particularly appropriate for simulating the dynamics of FOHPNs based on the matrix formulation of the marking update. Moreover, MATLAB is able to integrate modeling and simulation of hybrid systems with the execution of control and optimization algorithms.

We consider a simulation run of 112 time units, so that the total run time equals 2 weeks if we associate one time unit to one hour and 1 day to every 8 hours work-shift.

The simulation study is performed choosing the IFS vector of the continuous transitions $t_{33},\ldots,t_{38}$ in the FOHPN in Figure 2, representing the work rates of the doctors and nurses staff. At each macro-period the IFS vector $\boldsymbol{v}$ has to satisfy the constraint set (1) and has to maximize the sum of all flow rates:

$$\max\ (\mathbf{1}^{T}\cdot\boldsymbol{v}),\ \text{s.t. } \boldsymbol{v}\in S(PN,\boldsymbol{m}). \tag{5}$$

In other words, such an operative condition allows us to estimate the maximum level of performance of the FOHPN system model, evaluated in terms of flows of patients, prescriptions and drugs to administer. By the knowledge of such rates it is possible to determine the optimal personnel dimension during each work-shift to obtain satisfactory performance indices and adequate service quality.

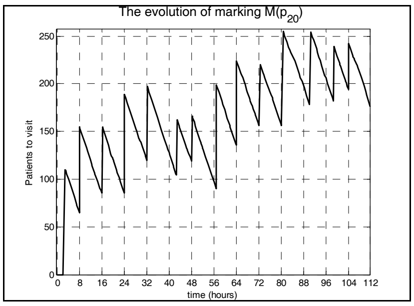

Figure 3: Patients waiting for examination (scenario 1: d=3, c=1, n=5).

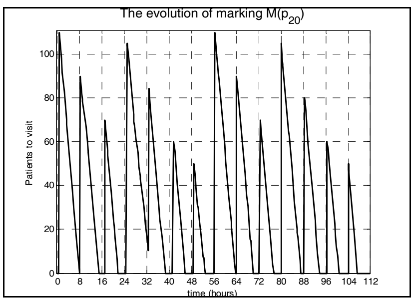

Figure 4: Patients waiting for examination (scenario 2: d=5, c=1, n=5).

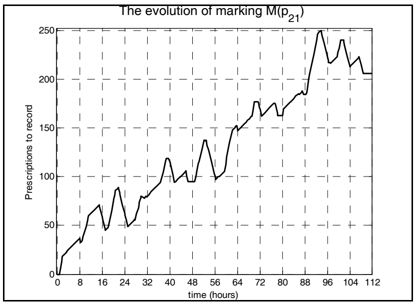

Figure 5: Prescriptions to record (scenario 2: d=5, c=1, n=5).

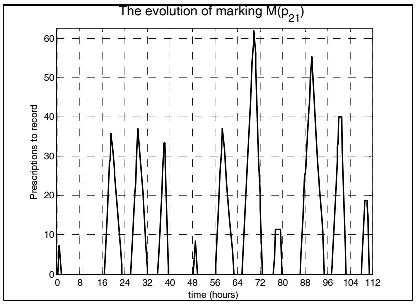

Figure 6: Prescriptions to record (scenario 3: d=5, c=2, n=5).

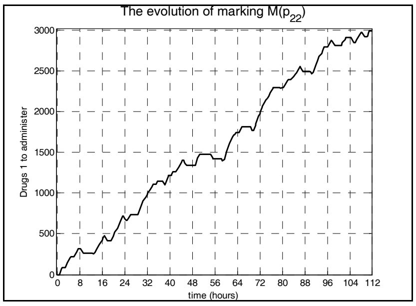

Figure 7: Oral administering to make (scenario 3: d=5, c=2, n=5).

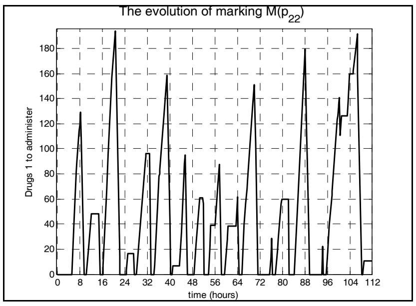

Figure 8: Oral administering to make (scenario 4: d=5, c=2, n=12).

4.2. Simulation Results

The simulations are performed for 4 scenarios, in which the staff dimensions d, c and n are varied.

In scenario 1 we assume d=3, c=1, n=5 and obtain a marking m_{20}, represented in Figure 3, that clearly corresponds to a situation in which the number of available doctors is insufficient to visit all patients. Indeed, the patient visits are not all performed in the established day.

In a second scenario, we increase *d*=5 and leave variables *c* and *n* unchanged with respect to scenario 1. Figure 4 shows that the number of patients to be yet examined at the end of each day (i.e., after each 8 hour work-shift) equals zero, i.e., every patient is visited in the predefined day. The only exception is registered at the end of the fourth day of the run time, when an emergency is present (note the variation of the rate of visits in the graph), but the patient surplus is coped with the next day. Hence, overall the number of doctors *d* is sufficient to deal with the average expected daily patient flow. However, marking m_{21}, represented in Figure 4, indicates that the only available charge nurse cannot record all prescriptions, so that the waiting prescriptions tend to increase indefinitely.

Hence, we consider a third scenario, with *d*=5, *c*=2 and *n* unchanged with respect to scenarios 1 and 2. Figure 5 visibly shows that the number of prescriptions still to be recorded at the end of each day is zero, i.e., overall the number of charge nurses *c* is now sufficient to cope with the average expected daily prescription flow. However, marking m_{22}, represented in Figure 7, shows that the available nurses are insufficient to administer the oral drugs (and the same can be shown to happen to the less frequently administered oral drugs), so that the waiting administerings tend to increase indefinitely.

A fourth and final scenario with *d*=5, *c*=2 and *n*=12 corresponds to a staff dimension such that all average daily flows of patients, prescriptions and administerings can be coped with by the department personnel. As an example, Figure 8 shows that with this configuration the (frequent) oral administering can be managed, except for an emergency that takes place in the second last day of the considered run-time and is coped with the next day.

5. CONCLUSION

To cope with the growing needs for service and quality in healthcare, we present a model for simulation and performance evaluation of the hospital drug distribution system. The proposed modeling technique employs the first order hybrid Petri nets formalism, i.e., Petri nets making use of first order fluid approximation. A simulation based on a hospital case study shows the effectiveness of the model in describing the system dynamics and in optimizing the hospital staff dimension to maximize the system performance, measured in terms of daily patients, prescriptions and drugs flows.

6. REFERENCES

Balduzzi, F., Giua, A., Menga, G., 2000. Modelling and Control with First Order Hybrid Petri Nets. *IEEE Transactions on Robotics and Automation*, 4 (16), 382-399.

Choi, S. S., Choi, M.K., Song, W.J., Son, S.H., 2005. Ubiquitous RFID Healthcare Systems Analysis on PhysioNet Grid Portal Services Using Petri Nets. *Proceedings of IEEE ICICS*, 1254-1258.

Gunal, M.M., Pidd, M., 2007. Interconnected DES Models of Emergency, Outpatient and Inpatient Departments of a Hospital. *Proceedings of the 2007 Winter Simulation Conference*, 1461- 1465.

Kumar, A., Shim S.J., 2007. Eliminating Emergency Department Wait by BPR Implementation. *Proceedings of the 2007 IEEE IEEM,* 1679-1683.

Loh, P.K.K., Lee, A., 2005. Medical Informatics System with Wireless Sensor Network-Enabled for Hospitals. *Proceeding of IEEE ISSNIP 2005,* 265-270.

Qi, E., Xu, G., Huo, Y, Xu, X., 2006. Study of Hospital Management Based on Hospitalization Process Improvement. *Proceedings of the IEEE IEEM,* 74-78.

The Mathworks, 2006. *MATLAB Release Notes for Release 14*. Natick, MA: The Mathworks.

Taxis, K., Dean, B., Barber, N., 1999. Hospital Drug Distribution Systems in the UK and Germany – a Study of Medication Errors. *Pharmacy World & Science*, 21 (1), 25-30.

Xiong, H.H., Zhou, M.C., Manikopoulos, C.N., 1994. Modeling and Performance Analysis of Medical Services Systems Using Petri Nets. *Proc. IEEE International Conference on Systems, Man and Cybernetics,* 2339-2342.

Mariagrazia Dotoli is since 1999 Assistant Professor in Systems and Control Engineering at the Department of Electrical and Electronic Engineering of Politecnico di Bari. Dr. Dotoli is the Associate Editor of the Mediterranean J. of Measurement and Control, of the Int. J. of Automation and Control and of the Int. J. of Systems Signal Control and Engineering Application.

Maria Pia Fanti is an Associate Professor of Systems and Control Engineering at the Department of Electrical and Electronic Engineering of Politecnico di Bari. Prof. Fanti is Associate Editor of IEEE Trans. on Systems, Man, and Cybernetics- Part A, IEEE Trans. on Automation Science and Engineering, the Mediterranean J of Measurement and Control, the Int. J. of Automation and Control, Enterprise Information Systems. She is Chair of the Central & South Italy Systems Man and Cybernetics IEEE Chapter.

Agostino Marcello Mangini is a Ph.D. student in Electrical Engineering at Politecnico di Bari and was a visiting scholar at the Zaragoza University. He was in the program committee of the 2007 IEEE International Conference on Systems, Man, and Cybernetics.

Walter Ukovich is Full Professor of Operations Research and director of the Department of Electrical Engineering, Electronics and Computer Science of the University of Trieste. His main research interests are in optimization, logistics and production planning and control. He has authored or co-authored over one hundred scientific papers on several scientific journals.