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Quantitative analysis of the evacuation system by means of Generalized Stochastic Petri nets*

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Abstract

The aim of this article is to perform a quantitative analysis of the evacuation system by using Generalized Stochastic Petri nets and capturing all the properties and characteristics related to its dynamics.

Keywords: modeling, Petri nets, properties verification, quantitative analysis

1 Introduction

To check properties of distributed systems various methods can be used. Petri nets is one of the methods which demonstrated good results. For a more accurate modeling it is required to define a configuration of the system, intended to work in a certain context. It should correspond to certain performance restrictions. Performance restrictions aim to ensure functional characteristics in the current context related to response time. In particular, this study is focused on quantitative investigations related to dynamics of the modeled system.

Social disaster can lead to other accidents and catastrophes and it may be necessary to keep human health and in some cases, human life, and for these it will be opportune to evacuate successfully inhabitants.

The formalism of Petri net can be applied in the both theoretical and practical ways. In order to surprise as close as possible modeled real systems, the classical Petri net has been extended with the notion of time [1], [3]. Petri nets are a powerful modeling technique because

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they can be used to model complex systems and to verify if the modeled systems satisfy some criteria.

In order to perform a case study of extended evacuation system we used analysis modules of PIPE [2] and obtained properties and characteristics of them.

In this way the formal method like Petri nets becomes an important tool for detecting, monitoring, modelling and mitigating social disasters [5], [6] caused by actions of different nature.

The paper is organized as follows. First, existing approaches related to modelling disaster and emergency management activities will be presented. Section 2 deals with the requirements of modeling using Generalized Stochastic Petri nets. In Section 3 the proposed model for the evacuation of people in case of disaster will be introduced, including a case study. In Section 4 quantitative analysis is presented with the obtained results. The paper finalizes with conclusions.

2 Generalized Stochastic Petri Nets

We will use the Generalized Stochastic Petri Nets (GSPN) [4] to perform quantitative analysis, because they can capture aspects of production in time of actions and immediately produce some actions. They are characterized by two types of transitions:

1. *Stochastic transitions*: associated with an exponentially distributed firing delay;

2. *Immediate transitions*: associated with a null firing delay.

Formally, a GSPN can be defined as follows: GSPN = $(P; T; \Pi; I; O; H; M_0; W)$, where

- P is a set of places;

- T is a set of transitions, $P \bigcap T = \emptyset$;

- $I; O; H : T \rightarrow N(N = P \bigcup T)$, are the input, output and inhibition functions;

- $M_0 : P \rightarrow N$ is the initial marking;
- $\Pi : T \rightarrow N$ is the priority function that associates the lower priorities to timed transitions and higher priorities to immediate transitions.
- $W : T \rightarrow R$ is a function that associates a real value to the transitions, $w(t)$ is:
  - a (possibly marking dependent) rate of a negative exponential distribution specifying the firing delay, when transition t is a timed transition (represented by a hollow rectangle).
  - a (possibly marking dependent) firing weight, when transition t is immediate (represented by a filled rectangle).

When a new marking is reached, if only timed transitions are enabled, this marking is called *tangible*; if at least one immediate transition is enabled, the marking is called *vanishing*.

The selection the transition of which will fire is based on the priorities and weights. First, the set of transitions with the highest priority is found and if it contains more than one enabled transition, the selection is based on the rates or weights of the transitions according to the expression:

$$P(t) = \frac{w(t)}{\sum_{t\prime \in E(M)} w(t\prime)}, \tag{1}$$

where $E(M)$ is the set of transitions enabled at marking M, i.e. the set of enabled transitions with the highest priority.

3 Evacuation system

Suppose that there is a building as it is specified in Fig. 1. $M1 - M8$ are the rooms, $M11 - M81$ are the doors. Petri Net of this building is given in Fig. 2.

Rooms are modeled using places $R1 - R8$, doors are modeled using places $D11 - D81$, movements from the rooms to the doors are

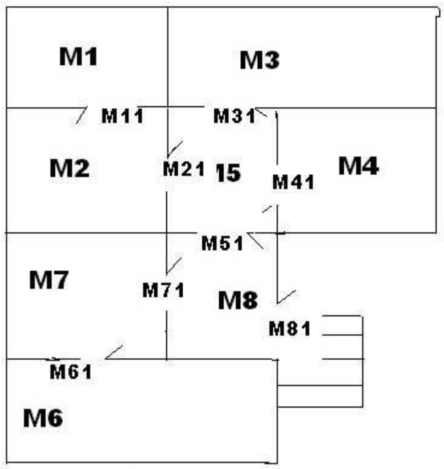

Figure 1. Building plan

modeled by timed transitions $t_0 - t_7$, movements from the doors into the rooms are modeled by immediate transitions $t_8 - t_{14}$. Each inhabitant is modeled by one token, respectively. People are accumulated in the places. The transfer function is used, which takes into account the time spent in the queue (moving time of a human in the room) and the density and flow rate. The initial marking is $M_0 = (1, 1, 0, 0, 0, 0, 1, 0, 3, 0, 2, 0, 1, 0, 0, 0)$.

4 Quantitative analysis

After the simulation we obtained the results from which it is observed the exponential growth of the number of tangible states (Table 1).

The average number of tokens (people) was also obtained (Fig. 3). The number of people from the initial state is constant.

The net is bounded, has a finite set of states (1124 states) which lead to a finite number of steps necessary for evacuation. Also it is safe, transitions do not influence each other, each place works independently

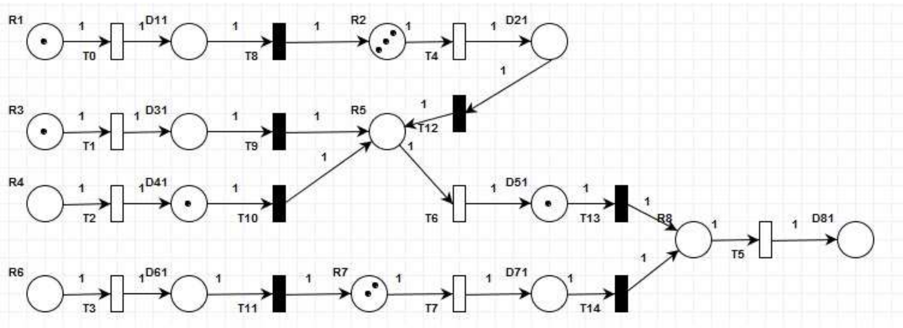

Figure 2. GSPN which models the building from Fig. 1

Table 1. Tangible states

Nr	Number of people in rooms	Number of tangible states	Number of arcs in reachability graph
1	4	241	364
2	9	1124	2389
3	15	1888	3086

Petri net simulation results

Place	Average number of tokens	95% confidence interval (+/-)
R1	0.35	0.2147
R3	0.1	0.21825
R4	0	0
R6	0	0
D11	0.025	0
D31	0.025	0
D41	0	0.024
D61	0	0
R2	0.475	0.93823
R5	2.375	1.35811
R7	0.55	0.45015
D21	0.1	0
D51	0.175	0.024
D71	0.05	0
R8	3.325	1.37582
D81	1.45	1.04339

Figure 3. Average number of tokens in places

Throughput of Timed Transitions

Transition	Throughput
T0	0.28205
T1	0.07692
T2	0.28205
T3	0.28205
T4	0.28205
T5	0.35897
T6	0.35897
T7	0.07692

Figure 4. Throughput of timed transitions

P-Invariants

D11	D21	D31	D41	D51	D61	D71	D81	R1	R2	R3	R4	R5	R6	R7	R8
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

The net is covered by positive P-Invariants, therefore it is bounded.

P-Invariant equations

M(D11) + M(D21) + M(D31) + M(D41) + M(D51) + M(D61) + M(D71) + M(D81) + M(R1) + M(R2) + M(R3) + M(R4) + M(R5) + M(R6) + M(R7) + M(R8) = 9

Figure 5. P invariants

of one another. It is conservative (Fig. 5), the number of people is constant, new people do not appear, all 9 people from the initial state have been accumulated in the last place $D81$.

5 Conclusion

In this study, a method of Generalized Stochastic Petri Nets was proposed for modeling and simulation of system that represents emergency evacuation of people in case of social disaster. This method allows checking such properties as boundedness, conservativeness, deadlock, safeness.

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