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THE MODELING OF MOBILIZATION WORK PROCESS FOR EMERGENCY RESCUE BASED ON STOCHASTIC PETRI NET

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Abstract. *Emergency rescue refers to the activities and plans adopted by relevant governments for prevention, preparation of, response to and recovery from the emergency incidents with destructive power in order to protect public security. It has become an important branch of emergency management system. Effective and efficient mobilization work process plays an increasingly important role in better protecting public safety when responding to emergence incidents. This paper carries out a modeling analysis on the mobilization work process for emergency rescue based on stochastic Petri net. The model constructed in the research can not only visually display the mobilization work process, but also provide us a way to analyze the performance of the mobilization work by calculating the busy probability of place and the utilization probability of transition with the help of the isomorphic Markov chain of the stochastic Petri net model. As a result of the empirical analysis, the information for assigning, implementing and achieving the mobilization task, giving order of mobilization is much needed to pay more attention to. Meanwhile, the activities of initiating emergency recovery plan without delay, assigning the mobilization tasks reasonably, performing the mobilization tasks effectively and efficiently, evaluating and documenting the mobilization work are very important processes for improving the efficiency and effectiveness of emergency rescues.*
Keywords: Mobilization work process, Emergency rescue, Public security, Stochastic Petri net, Markov chain

1. **Introduction.** Emergency rescue usually refers to the activities and plans adopted by relevant governments for prevention, preparation of, response to and recovery from the emergency incidents with destructive power in order to protect public security. With the expanding of emergency scope, the category of emergency continues to increase, which includes not only the traditional emergency events, such as wars, but also non-traditional factors threatening public security, such as terrorism, transnational crime, weapons proliferation, and other events influencing the security of economy, information, resource, culture, public health, environment, etc. Once the emergency incident breaks out, it will produce unconventional emergency needs. Under this condition, the governments must mobilize relevant resources to meet the emergency needs according to certain mobilization work process. Therefore, it is much needed to build a mobilization work process with rapid response and effective operation for emergency rescue so as to better protect public security.

Petri net is a kind of mathematical modeling language for the description of distributed systems, which was proposed by Petri in 1962 [1,2], and has been widely used in many fields since then, especially in the field of modeling the concurrent behavior of distributed systems. For example, [3] constructed the Petri net model of logistics and distribution system; [4] studied the object-oriented modeling based on Petri net; [5] researched the model for agile production scheduling based on Petri net; [6] constructed the model for fire alarming control system based on Petri net; [7] analyzed the simulation validation method for capability requirement of weapon system based on Petri net. In the field of mobilization work process, [8] carried on a study on workflow model of emergency management based on Petri net; [9] made an analysis on the modeling of social rescue resource mobilization work process based on stochastic Petri net. All these researches provide us a clue to construct the model for mobilization work process of emergency rescue to some extent.

This paper will construct the model of mobilization work process for emergency rescue based on stochastic Petri net. It firstly introduces the methodology adopted in the paper. Then, it analyzes the mobilization work process of emergency rescue, and constructs the stochastic Petri net model of the mobilization work process. In the end, it studies the performance of the mobilization work process by calculating the busy probability of places and the utilization probability of transitions with the help of the isomorphic Markov chain of the stochastic Petri net model. The findings of this research will be helpful not only to improve the operation efficiency of the whole mobilization system for emergency rescue, but also to enhance the ability of government for dealing with the emergency incidents effectively.

2. **Stochastic Petri Net.**

2.1. **Petri net basics.** A Petri net consists of places, transitions, and arcs. Arcs run from a place to a transition or vice versa, never between places or between transitions. The places from which an arc runs to a transition are called the input places of the transition; the places to which arcs run from a transition are called the output places of the transition. Graphically, places in a Petri net may contain a discrete number of marks called tokens. Any distribution of tokens over the places will represent a configuration of the net called a marking. In a Petri net diagram, a transition may be fired if it is enabled when there are sufficient tokens in all of its input places, and if the transition is fired, it will consume the required input tokens, and create tokens in its output places.

2.2. **Mathematic expression of stochastic Petri net.** Stochastic Petri nets are a form of Petri net where the transitions are fired after a probabilistic delay determined by a random variable.

A stochastic Petri net can be expressed by a five-tuple $SPN = (P, T; F, M_0, \Lambda)$, where $N = (P, T; F)$ is a net; P is a set of states, called places, T is a set of transitions, and $P \cup T \neq \varnothing \wedge P \cap T = \varnothing$, F where $F \subseteq P \times T \cup T \times P$ is a set of flow relations called arcs between places and transitions (and between transitions and places), $\mathrm{dom}(F) \cup \mathrm{cod}(F) = S \cup T$, $\mathrm{dom}(F) = \{x|\exists y : (x, y) \in F\}$, $\mathrm{cod}(F) = \{y|\exists x : (x, y) \in F\}$; M_0 is the initial marking of the stochastic Petri net; Λ is the array of firing rates λ associated with the transitions. Here, the firing rate is a random variable, which can be a function of the current marking, that is $\lambda(M)$.

The reachable graph of a stochastic Petri net can be mapped directly to a Markov process. Each state in the reachable graph is mapped to a state in the Markov process, and the firing of a transition with firing rate λ corresponds to a Markov state transition with probability λ.

3. Modeling for Mobilization Work Process of Emergency Rescue.

3.1. The basic mobilization work process of emergency rescue. Generally, the mobilization work process for emergency rescue includes three stages, namely preparation stage, implementation stage and recovery stage, and each stage contains many activities. For simplifying the problem, we just choose implementation stage as an example. Here, we can further divide the implementation stage into two sub-stages, one of which is for the mobilization conversion, and the other of which is for the mobilization execution. In the conversion sub-stage, it is needed to identify and report the emergency firstly, and then to analyze the emergency needs and give mobilization orders. In the execution sub-stage, searching for emergency recovery plan, verifying the mobilization potential, building the mobilization alliance, assigning the mobilization tasks, executing and completing the mobilization tasks are needed, as shown in Figure 1. It is also important to note that all these activities can be further divided into some smaller sub-activities.

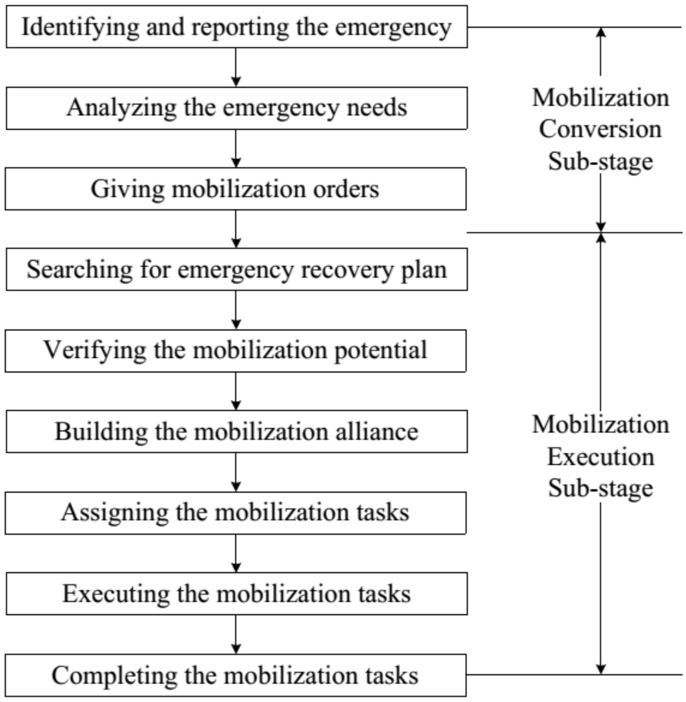

FIGURE 1. The mobilization implementation process for the emergency rescue

3.2. Case studies.

3.2.1. *Case description.* At the midnight on July 12, 2012, in the most areas of Hebei Province, especially in the northern part of Baoding municipality, Langfang municipality and Tangshan municipality, and in the southern part of Chengde municipality, it dropped extraordinary rainstorm, which resulted in most regions of Hebei Province in danger, a large number of houses collapsed; power, communication, and traffic of some areas interrupted; people's life and property seriously endangered. Under this condition, the government held an emergency meeting promptly and formed the executing institution for flood-fighting and emergency rescues. Then, the rescue, evacuation and resettlement of the victims were conducted. Meanwhile, the relief materials were dispatched and distributed, followed by the flood diversion and discharge, the donation collection and post-disaster reconstruction. Due to the weak time constraints of post disaster reconstruction and for simplifying the problem, we will only focus our attention on modeling of the mobilization work process of flood-fighting and emergency rescues.

3.2.2. *Stochastic Petri net model.* Based on the theory of stochastic Petri net and the mobilization work process for flood-fighting and emergency rescues, we can construct the simplified stochastic Petri net model of the mobilization work process for flood-fighting and emergency rescues, as shown in Figure 2. The meaning of each variable is shown in Table 1. Then, we can draw the reachable graph of the stochastic Petri net model and its isomorphic Markov chain, as shown in Figure 3 and Figure 4. Based on the execution time of each transition, the firing rate of each transition can be got, as shown in Table 2.

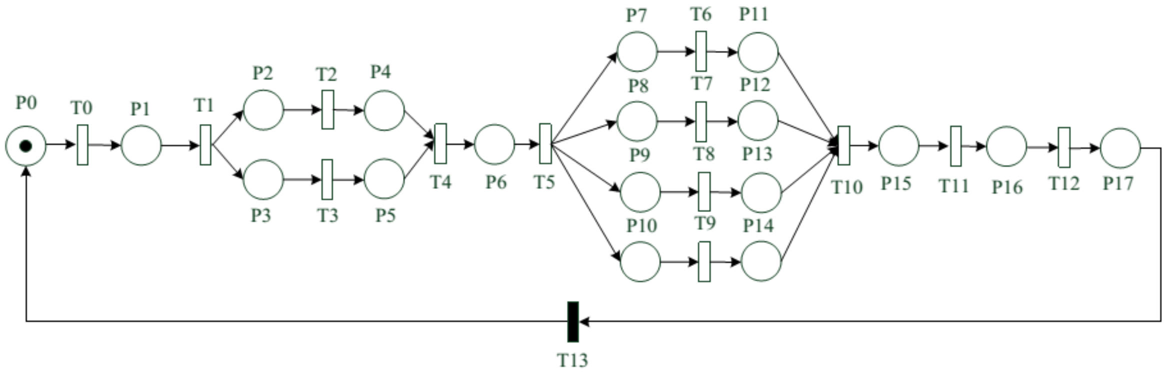

FIGURE 2. The Petri net model of the mobilization work process for the emergency rescue

TABLE 1. The meaning of each variable in the model of the mobilization work process

P	Meaning	T	Meaning
P0	State of emergency outbreak	T0	Reporting the emergency information
P1	Information of emergency	T1	Analyzing the emergency information
P2	State of reporting to provincial government	T2	Reporting to provincial government
P3	State of reporting to state flood control and drought relief headquarters	T3	Reporting to state flood control and drought relief headquarters and requesting for assistance
P4	Information gained by provincial government	T4	Giving order to flood-fighting and emergency rescue
P5	Information gained by state flood control and drought relief headquarters	T5	Initiating Hebei provincial contingency plan for flood-fighting and emergency rescue
P6	Information of instruction of flood-fighting and emergency rescues		
P7	State to construct the administration organization of mobilization alliance	T6	Constructing the administration organization of mobilization alliance for flood-fighting and emergency rescue
P8	State to construct the executive organization of mobilization alliance		
P9	State to form the mobilization tasks set	T7	Constructing the executive organization of mobilization alliance for flood-fighting and emergency rescues
P10	State to determine the priority of the mobilization tasks		
P11	State of the administration organization of mobilization alliance constructed	T8	Breaking down the mobilization tasks and forming the tasks set
P12	State of the executive organization of mobilization alliance constructed	T9	Determining the mobilization tasks priority
P13	State of the mobilization tasks set formed		
P14	State of the mobilization task priority confirmed	T10	Assigning the mobilization tasks
		T11	Executing the mobilization tasks
P15	State of the mobilization tasks assigned	T12	Evaluating and documenting the mobilization work
P16	State of the mobilization tasks completed		
P17	State of evaluating and documenting the mobilization work	T13	Assistant transition

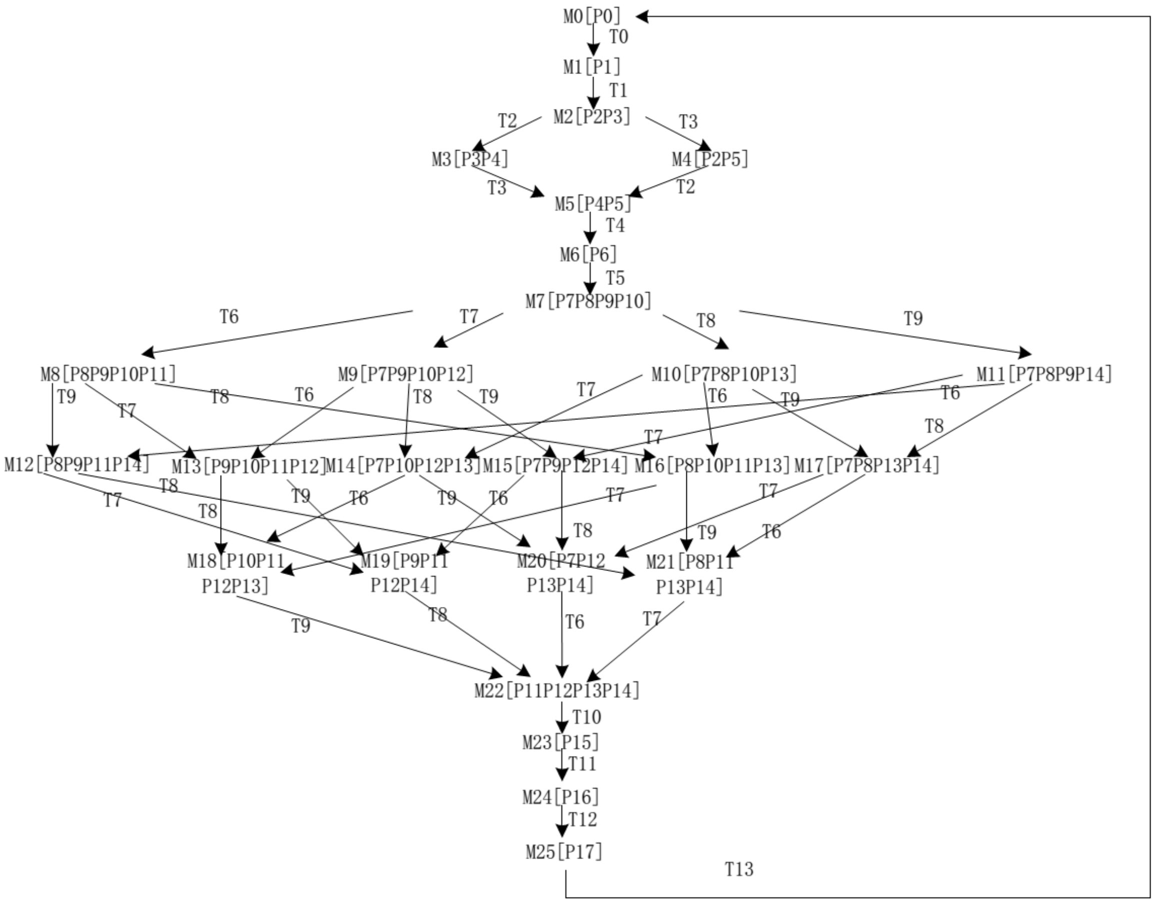

FIGURE 3. The reachable graph of the Petri net model of the mobilization work process

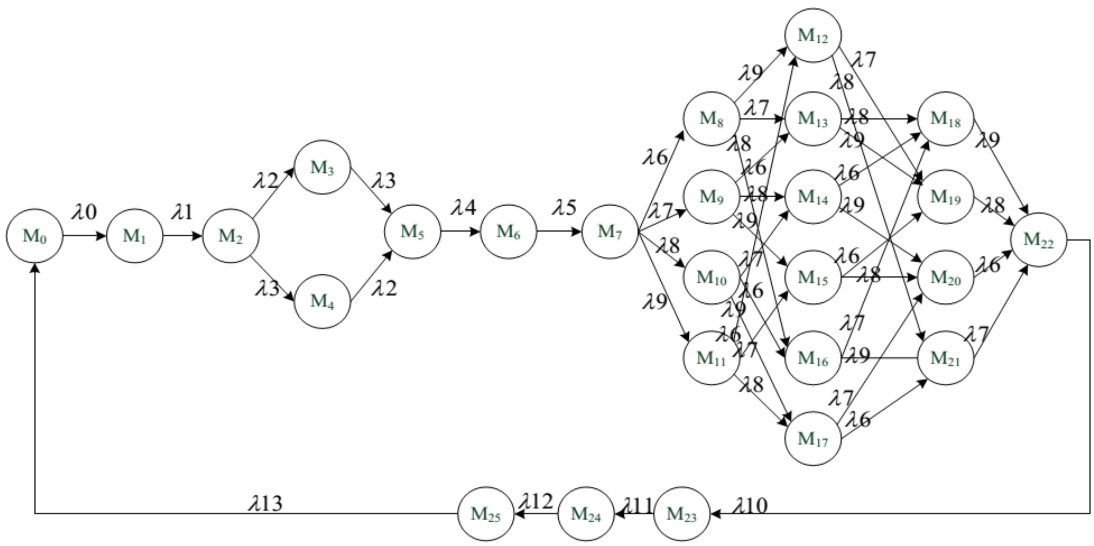

FIGURE 4. The isomorphic Markov chain of the Petri net model

TABLE 2. The average firing rate (FR) of each transition (T)

T	FR	T	FR	T	FR	T	FR	T	FR
$\lambda 0$	0.25	$\lambda 3$	1	$\lambda 6$	1	$\lambda 9$	1	$\lambda 12$	0.125
$\lambda 1$	0.5	$\lambda 4$	100000	$\lambda 7$	1	$\lambda 10$	1	$\lambda 13$	100000
$\lambda 2$	1	$\lambda 5$	1/13	$\lambda 8$	1	$\lambda 11$	0.00347		

It is easy to see that there are 26 states in the isomorphic Markov chain which are corresponding to the reachable markings of the Petri net model. We suppose the steady probability of the 26 states as $X = (x_0, x_1, x_2, \cdots, x_{25})$, and then we can get X through solving the system of linear equation $\begin{cases} XA = 0 \\ \sum_{k=0}^{25} x_k = 1 \end{cases}$. Here, $0 \leq k \leq 25$, A refers to the probability transfer matrix, which can be gained by the following formula,

$$a_{ij} = \begin{cases} \lambda_k, & \text{if } i \neq j, \text{ and there is a } t_k \in T \text{ which makes } M_i[t_k > M_j \\ 0, & \text{if } i \neq j, \text{ and there is not a } t_k \in T \text{ which makes } M_i[t_k > M_j \\ -\sum\limits_{M_i[t_k>} \lambda_k, & \text{if } i = j \end{cases}$$

Then, we can get the steady probabilities of the 26 states as shown in Table 3.

Table 3. The steady probability (SP) of the 26 states (S) of the Markov chain

S	SP	S	SP	S	SP	S	SP	S	SP	S	SP
x_0	0.06678	x_5	0.00000	x_{10}	0.00139	x_{15}	0.00139	x_{20}	0.00417	x_{25}	0.00000
x_1	0.03339	x_6	0.20868	x_{11}	0.00139	x_{16}	0.00139	x_{21}	0.00417		
x_2	0.00835	x_7	0.00417	x_{12}	0.00139	x_{17}	0.00139	x_{22}	0.01669		
x_3	0.00835	x_8	0.00139	x_{13}	0.00139	x_{18}	0.00417	x_{23}	0.48109		
x_4	0.00835	x_9	0.00139	x_{14}	0.00139	x_{19}	0.00415	x_{24}	0.13355		

3.2.3. *Busy probability of place and utilization probability of transition.* The busy probability of place refers to the probability of the place when it is in busy. If we suppose $P[s(p_i) = 1]$ as the busy probability of place p_i, then $P[s(p_i) = 1] = \sum x_j$. Here, x_j refers to the steady probabilities of all reachable markings under which place p_i has token. The utilization probability of transition Ti refers to the sum of all the steady probabilities of states in which transition Ti can be fired. Supposing $U(Ti)$ as the utilization probability of transition Ti, then $U(Ti) = \sum P[s_i]$. The busy probability of place and utilization probability of transition are shown in Table 4.

Table 4. The busy probability (BP) of place (P) and utilization probability (UP) of transition (T)

P	BP	P	BP	P	BP	T	UP	T	UP
P0	0.06678	P7	0.01669	P14	0.03478	T0	0.06678	T7	0.01669
P1	0.03339	P8	0.01669	P15	0.48109	T1	0.03339	T8	0.01669
P2	0.01669	P9	0.01669	P16	0.13355	T2	0.01669	T9	0.01669
P3	0.01669	P10	0.01669	P17	0.00000	T3	0.01669	T10	0.13912
P4	0.00835	P11	0.03478			T4	0.01669	T11	0.48109
P5	0.00835	P12	0.03478			T5	0.20868	T12	0.13355
P6	0.20868	P13	0.03478			T6	0.01669	T13	0.00000

Through the analysis of the busy probabilities of places, we can see that the values of the busy probabilities of place 15, 6 and 16 are bigger than the values of other places, which means that the states of assigning, implementing and achieving the mobilization tasks and the information for giving order of the mobilization are particular important, so we should pay more attention to these places. From the analysis of utilization probabilities of transitions, we find that the values of utilization probability of transition 11, 5, 10 and 12 are bigger than the values of other transitions, which means that these activities represented by these transitions have great effects on the execution efficiencies of this mobilization work process. That is to say, during this mobilization process, the activities of starting emergency recovery plan without delay, assigning the mobilization tasks reasonably, performing the mobilization tasks effectively and efficiently, evaluating and documenting the mobilization work are very important for further improvement of the efficiency and effectiveness of the mobilization of flood-fighting and emergency rescues.

4. **Conclusions.** The research constructs the stochastic Petri net model on the mobilization work process for emergency rescue. This model can not only visually display the mobilization work process, but also provide us a way to analyze the performance of the mobilization work by calculating the busy probability of places and the utilization probability of transitions. As can be seen from the results of the empirical analysis of the research, the states for assigning, implementing and achieving the mobilization task of flood-fighting and emergency rescues, the information of giving order of the mobilization for the flood-fighting and emergency rescues is particular important. Therefore, we should pay more attention to these units. Meanwhile, the activities of initiating emergency recovery plan without delay, assigning the mobilization tasks reasonably, performing the mobilization tasks effectively and efficiently, evaluating and documenting the mobilization work are very important for further improvement of the efficiency and effectiveness of the mobilization of flood-fighting and emergency rescues.

From the study, we can see that the stochastic Petri net is a useful mathematical modeling language for the description of distributed systems when the transitions are fired after a probabilistic delay determined by a random variable. Applying stochastic Petri net to the study of the mobilization work process for emergency rescue is a useful exploration, which has a positive meaning in improving the mobilization work process for emergency rescue. The preciseness of the stochastic Petri net model can be improved in the future research by considering such factors as conflict, concurrent and cycle. Of course, the methods and the conclusions of this paper can serve as a useful reference and supplement.

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