Application of Petri Nets in Dynamic Process Modeling of Chemical Emergency Management

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***Abstract*—Chemical emergency response process is a dynamic complex process. To improve the effectiveness of emergency management, Petri nets are applied to model dynamic process of chemical emergency response process in this paper. A dynamic process model of emergency management is built based on hybrid Petri nets and hierarchical object-oriented Petri nets. The result reveals that the model can indicated the properties of Continuity, timeliness, interactive and multiple possibilities of emergency response process.**

Keywords—dynamic process modeling;chemical emergency management;hybrid Petri nets; hierarchical object-oriented Petri nets

I. INTRODUCTION

An emergency is generally an unexpected event which does or could harm people, environment, resources, property, or institutions. Chemical accidents occurring during operations may result in substantial consequences both inside and outside the premises of an installation. The initiating event of a major accident in such a system is a failure, which may, and usually does, lead to more failures and ,finally to uncontrollable hazardous events. Many approaches have been proposed for l emergency management. In general the job of emergency management is to provide decision supports for responding to catastrophic events and reducing their magnitude and their social impacts to more acceptable levels. Another part of emergency management is planning.

Emergencies are unpredictable in their occurrence and the sequence of events during an emergency are uncertain and the end results may be different every time. Emergency management process is a dynamic complex process. In general, it is studied as a complex system.

There are as yet no effective, widely accepted methods for complex system issues due to the dynamics, uncertainty, and multiplicity of it. The ACP (Artificial Systems, Computational Experiments, Parallel Execution, ACP) approach [1, 2, 3, 4] was proposed for simulation, analysis, and control of complex systems. The approach is widely applied to solve complex system issues in many industries, such as petrochemical industry, traffic field, and information security field. Some remarkable progresses [5, 6, 7] in the petrochemical industry were made. ACP based 3D emergency drill system [8] was designed and developed to enhance emergency management skills of an emergency response personnel.

S.P.Kourniotis and C.T.Kiranoudis[9] reviews the approaches and proposes a systemic approach to effective chemical emergency. Prasad Bammidi and Kevin L.Moore[10] presents an systems approach for emergency management system(EMS), which view EMS from the perspective of system science, as a discrete-event dynamical system (DEDS) and gives a Petri net model of some aspects of the EMS. Madjid Tavana[11]use Petri nets for dynamic process modeling of the EMS at a nuclear power plant

In this paper, much attention has been given to approaches for modeling, analysis, and design of emergency planning and response systems. In next section, an overview of chemical emergency response process is followed and Petri nets are reviewed. Section 3 proposed a Petri net model for dynamic process modeling and section 4 presents discussions and conclusions.

II. REVIEW

Chemical emergency response process is a dynamic complex process which is a continuous interaction system of humans, event and environment. The process not only includes discrete events, such as alarming, fault detection, personnel scheduling, resource scheduling, technical parameters adjustment, but also includes continuous events, such as fault detection process, technical parameters adjustment process. So, it can be pointed out that chemical emergency response process can be viewed as a hybrid system.

Fault detection process is a complex accident analysis process. Intuitively, accidents are perceived as the result of a single cause or, at best, of a few determining factors. As the development of accident theories, accident analysis methods have evolved to a branched events chain and finally to a

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multilinear events sequence from the linear chain of events based on the domino theory.

The well-known fault-tree analysis (FTA) or event-tree analysis (ETA) methods are associated to the branched chain of events model, while the Hazard and Operability study (HAZOP) method considers accident sequences even less complex. It must be stressed that, due to their elementary theoretical background, these methods encounter some limitations when used to handle complex systems. The limited use of classical methods is discussed by David Vernez and Didier Buchs[12].They presented that the Petri Nets (PNs) should be able to overcome these limitations.

Defined by C.A. Petri in 1962, Petri nets are mathematical tools that allow dynamic simulation of parallel and concurrent systems with time constraints. Designed originally for the computer-engineering field, Petri nets are now used for dynamic systems specification, description and verification in a wide range of applications. Dynamic systems modeling through Petri nets have encountered a large success and several new developments have been made since Dr. Petri's early work. Some of these developments such as hierarchical nets, object-oriented Petri nets, Stochastic Petri Nets (SPN), Coloured Petri Nets (CPN) and hybrid Petri nets are of utmost interest for simulation of complex systems.

Many systems are naturally hybrid. A hybrid system can model using hybrid Petri nets. A hybrid Petri net can be obtained if one part is discrete and another part is continuous. Rene David and Hassane Alla[13] make a survey of their team's work about hybrid Petri nets (definition, properties, and modeling) and illustrated their work by many examples.

Jang-Eui Hong and Doo-Hwan Bae[14] propose a hierarchical object-oriented Petri net (HOONet). They pointed that HOONet supports a wide range of object oriented features including abstract, encapsulated and modularized objects, object interaction by message passing, inheritance, and polymorphism. HOONet also supports a variety of modeling and analysis mechanisms such as incremental modeling of evolving systems, unfolding the HOONet to lower level Petri net, and incremental reachability analysis for HOONet models. In their work, usefulness of HOONet is demonstrated by applying it to modeling and analysis with an example.

Due to the dynamics and complexity of chemical emergency response process, hybrid PNs and hierarchical object-oriented Petri nets (HOONet) is applied to model a dynamic emergency management process in a nuclear power plant.

III. CASE STUDY

Madjid Tavana[10] use decision tree and ordinary place-transition PNs respectively to model the emergency management system at the Khaskovo nuclear power plant in Eastern Europe. PNs are evidently better than decision tree in modeling sequential execution, prioritization, and concurrency of emergency management process. However, only the static properties of the system are presented in Madjid Tanana's work.

Emergency procedure described at the Khaskovo nuclear power plant as follow [10]. The ESOs respond to various types of emergencies. If there are no general anomalies or alarms, the ESO continues to supply power to the grid. Upon an anomaly or alarm, the ESO is expected to check the core temperature. The core temperature must remain at the normal level of 213°F. If the core temperature inspection shows normal levels, the ESO resets and restarts the system monitor loop. However, if the core temperature exceeds 213°F, the ESO activates the primary cooling water pumps. If the primary cooling water pumps start successfully, the ESO resets and restarts the system monitor loop. However, if the primary cooling water pumps fail to start, the ESO activates the backup pumps. If the backup pumps start successfully, the ESO resets and restarts the system monitor loop. If the backup pumps fail to start, the ESO initiates the evacuation process, as a core breech is imminent. The process of reset and restart of the system monitor loop involves the following procedures. After every reset and restart of the system, the ESO verifies the core temperature. If the core temperature verification shows normal levels of 213°F or less, the ESO resets and restarts the system monitor loop. If the core temperature is greater that 213°F, the ESO checks the fire alarm. IF the fire alarm is not activated, the ESO verifies the core temperature again. IF the fire alarm is activated, the ESO dispatches the fire department. If the fire department can keep the temperature at 213°F or less, the ESO resets and restarts the system monitor loop. If the core temperature is increased beyond the normal levels of 213°F, the ESO checks the core water level. If the core water level is normal, the ESO resets and restarts the system monitor loop. However, if the core water level is low, the ESO is expected to activate the makeup water pumps. If the makeup water pumps start successfully, the ESO resets and restarts the system monitor loop. However, if the makeup water pumps fail to start, the ESO must activate the backup makeup water pumps. If the backup makeup water pumps start successfully, the ESO resets and restarts the system monitor loop. If the backup makeup water pumps fail to start, the ESO initiates the evacuation process.

In this paper, a dynamic process model of emergency management system at the Khaskovo nuclear power plant is built based on hybrid PNs and HOOPN. Fig.4 and table IV depict the dynamic process of Khaskovo' s emergency management. Three emergency handling measures are modeling by three subnets shown by Figure 1, Figure 2 and Figure 3.

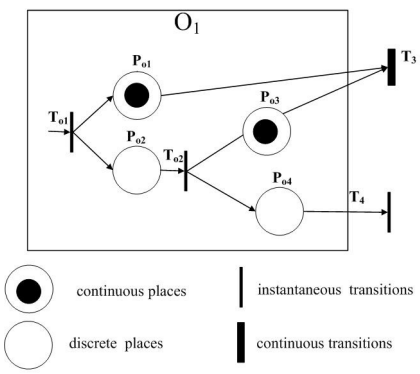

Fig.1 Petri nets for cooling process

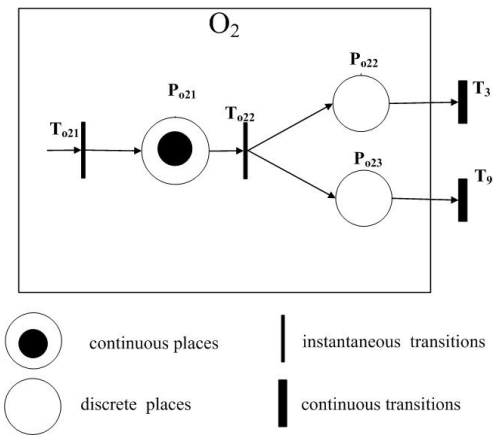

Fig.2 Petri nets for extinguishing the fire

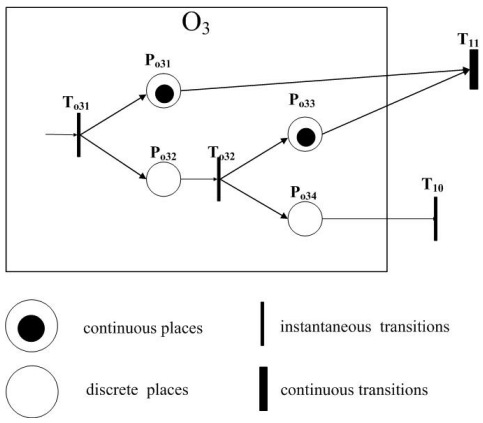

Fig.3 Petri nets for filling water

TABLE Ⅰ Notations of Places and Transitions for Fig1

Places	Transitions
P_{o1} system with activate primary cooling water pumps	T_{o1} activate primary cooling water pumps
P_{o2} system with failed primary cooling water pumps	T_{o2} activate backup cooling water pumps
P_{o3} system with working backup cooling water pumps	T_3 reset and restart the system monitor loop when the primary cooling pump is running
P_{o3} system with failed backup cooling water pumps	T_4 initiate the evacuation when the core temperature>213°F after running the primary cooling pump

TABLE Ⅱ Notations of Places and Transitions for Fig2

Places	Transitions
P_{o21} the fire department is disposing fire alarm	T_{o21} dispatches the fire department
P_{o22} the core temperature<=213° F after the fire department disposal for fire alarm	T_{o22} the core temperature verification
P_{o23} the core temperature>13F after the fire department disposal for fire alarm	T_3 reset and restart the system monitor loop when the primary cooling pump is running
	T_9 the core water level verification

TABLE Ⅲ Notations of Places and Transitions for Fig3

Places	Transitions
P_{o31} makeup water pumps start	T_{o31} activate makeup water pumps
P_{o32} makeup water pumps fail	T_{o32} activate backup makeup water pumps
P_{o33} backup makeup water pumps start	T_{10} initiate the evacuation when backup makeup water pump fail
P_{o34} backup makeup water pumps fail	T_{11} reset and restart the system monitor loop when the makeup water pump is running

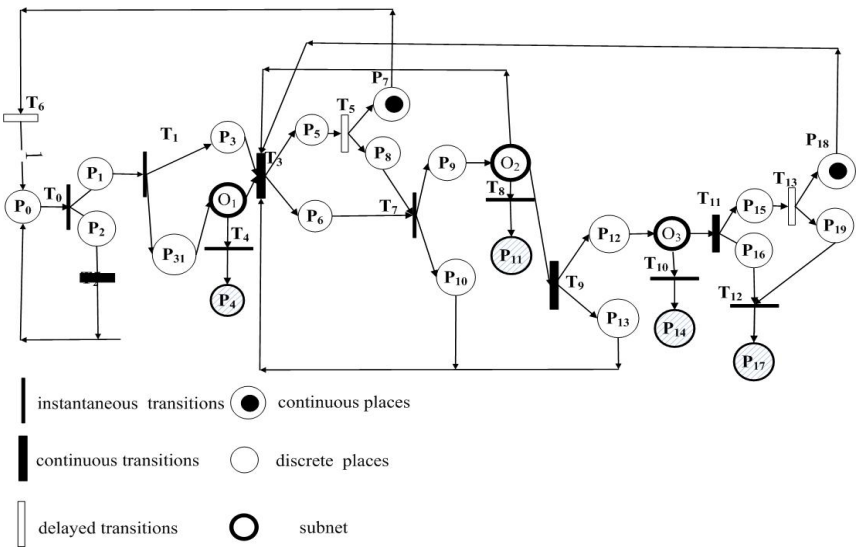

Fig.4 Dynamic process model of Khaskovo's emergency management

TABLE Ⅳ Notations of Places and Transitions for Fig4

Places	Transitions
P_0 idle system	T_0 anomaly verification
P_1 anomalies in supply power system	T_1 the core temperature verification
P_2 no anomalies in supply power system	T_2 supply power
P_3 temperature<=213°F	T_3 reset and restart the system monitor loop when the primary cooling pump is running
P_{31} temperature>213°F	
O_1 subnet for cooling process	T_4 initiate the evacuation when P_6
P_4 emergency for high T	T_5 the core temperature verification after △T of P_5
P_5 the core temperature<=213°F after running the primary cooling pump	T_6 supply power when P_7 is unchanged
P_6 the core temperature>213°F after running the primary cooling pump	T_7 fire alarm verification
P_7 the core temperature<=213°F after △T of P_5	T_8 initiate the evacuation when the fire is uncontrolled
P_8 the core temperature>213°F after △T of P_5	T_9 the core water level verification
P_9 system with active fire alarm	T_{10} initiate the evacuation when backup makeup water pump fail
P_{10} system with inactive fire alarm	T_{11} reset and restart the system monitor loop when the makeup water pump is running
O_2 subnet for extinguishing the fire	T_{12} initiate the evacuation when P_{15}
P_{11} emergency for fire	T_{13} the core temperature verification after△T of P_{15}
P_{12} low core water level	
P_{13} normal core water level	
O_3 subnet for filling water	
P_{14} emergency for low core water level	
P_{15} the core temperature<=213°F after running the makeup water pump	
P_{16} the core temperature>213°F after running the makeup water pump	
P_{18} the core temperature<=213°F after △T of P_{15}	
P_{19} the core temperature>213°F after △T of P_{15}	

IV. DISCUSSIONS AND CONCLUSIONS

1. *Discussions*

The model shown in figure.1 has four advantages in simulating emergency management procedure. Firstly, it describes the dynamic emergency handling process by using continuous places and continuous transitions. Continuous places Po1 and Po3 means the cooling pumps is running until Continuous places P7 (the core temperature remains at normal level of 213°F or less). Continuous transitions T3 has been implementing until P2. Secondly, timeliness of emergency handling process is taken on by instantaneous transition. Take subnet O1 for example: 1) once P31, To1 must be perform immediately, 2) once Po1, To1 must be perform immediately, and 3) once Po4, T4 must be perform immediately. Otherwise, timing is delayed and the event will uncontrollable. Thirdly, delayed transitions can indicate interaction between system and environment after emergency response operations. T5 is performed after △T of P5 and T6 is performed when P7 is constant in a △T period. It is worth mentioning that △T is a parameters obtained by detailed technical process. Finally, the model describes the interactions among subnets. Almost all the possible dynamic paths of encountered in emergency handling are displayed in the model. It provides decision supports for emergency response personnel. For example, P0- T0- P1- T1- P3- T3- P5- T5- P7- T6- P0 is one of possible path.

2. *Conclusions*

The model proposed in this paper can indicated the properties of emergency management dynamic process. The properties include Continuity, timeliness, interactive and multiple possibilities. The next work is that to apply the method of dynamic simulation for nuclear power plant to chemical emergency management in practice, and then to develop a computational experiments platform for chemical response planning evaluation.

REFERENCES

[1] F.Y. Wang, J.S. Lansing. From Artificial Life to Artificial Societies—New Methods for Studies of Complex Social Systems. Complex systems and complexity science, vol.1, no.1, pp.33-41, January 2004.

[2] F.Y. Wang. Parallel system methods for management and control of complex Systems. Control and Decision, vol.19, no.5, pp.485-489, May 2004.

[3] F.Y. Wang. Computational Experiments for Behavior Analysis and Decision Evaluation of Complex Systems. Journal of system simulation, vol.16, no.5, pp.893-897, May 2004.

[4] F.Y. Wang. Computational Theory and Method on Complex System. China Basic Science. Science Frontier. May 2004.

[5] C.J. Cheng, F.Cui, L.F.Lee. Parallel Management Systems for ComplexProductions: Methods and Applications. Complex Systems and Complexity Science, vol.7, no.1, pp.24-32, September 2010.

[6] G. Xiong, F.Y. Wang, M.Yu. Parallel Evaluation Method to Improve Long Period Ethylene Production Management. Control Engineering of China, vol.17, no.3, pp.401-406, May 2010.

[7] Z. Shen, F.Y. Wang and C. J. Cheng. A fuzzy model on how the management affects a worker's State, 2010 IEEE International Conference on Service Operations and Logistics, and Informatics, Qingdao, Shandong, China . July,2010.

[8] S.F. Jing, C.J. Cheng, and G. Xiong, "ACP based 3D emergency drills system for Petrochemical Enterprises," in proceedings of 2012 World Congress on Intelligent Control and Automation,Beijing, China, pp. 4126-4131, July 2012.

[9] S.P. Kourniotis , C.T. Kiranoudis and N.C.Markatos, "A systemic approach to effective chemical emergency management," Safety Science. vol. 38, pp. 49-61, 2001.

[10] P. Bammidi , K. L.Moore, "Emergency Management Systems: A Systems Approach," Proceedings of the IEEE International conference on systems,man, and cybernetics. vol. 2, pp. 1565-1570, 1994.

[11] M. Tavana, "Dynamic process modelling using Petri nets with applications to nuclear power plant emergency management," Int.J. Simulation and process Modelling. vol. 4, No.2, pp. 130-1138, 2008.

[12] D. Vernez , D. Buchs, and G. Pierrehumbert, "Perspectives in the use of coloured Petri nets for risk analysis and accident modelling," Safety Science. vol. 41, pp. 445-463, 2003.

[13] R. David , H. Alla, "On Hybrid Petri Nets," Discrete Event Dynamic Systems: Theory and Applications, vol.11, pp. 9–40, 2001.

[14] J.E. Hong, D.H. Bae, "Software modeling and analysis using a hierarchical object-oriented Petri net," Information Sciences, vol.130, pp.133–164, 2000.