An Analysis of Chemical Accident Scenarios Based on Petri Nets

First A. SiFeng Jing, Second B. Gang Xiong, andThird C. Xiwei Liu, Feng Han, HongLin Zhu, *CAA*

Abstract— **For the purpose of learning lessons of chemical accident and preventing the occurrence of such event in the future, in this paper, the hierarchical object-oriented Petri nets technique is chosen to analysis the dynamic evolution of an accident scenario. The chemical accident scenarios analysis model of ethylene cracking furnace tube rupture and fire is built. And based on the model, causes are obtained and compared with the result of plant's investigation. The result reveals that the model can expound the factors that caused the accident, the relations between of them, the trajectory of accident development and the path to avoid accidents. The feasibility of this technique is verified.**

Ⅰ INTRODUCTION

As a society become increasingly wealthy, its perception of industry – and, more specifically, of the chemical process industry –gradually changes: what was once a source of work and wealth becomes a source of risk and hazard that have a negative environmental impact.

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F. A. Author is with State Key Laboratory of Intelligent Control and Management of Complex Systems, Beijing Engineering Research Center of Intelligent Systems and Technology, Institute of Automation, Chinese Academy of Sciences Beijing 100190 China (phone:010-62554288,e-mail: sifeng.jing@ ia.ac.cn).

S. B. Author is with State Key Laboratory of Intelligent Control and Management of Complex Systems, Beijing Engineering Research Center of Intelligent Systems and Technology, Institute of Automation, Chinese Academy of Sciences Beijing 100190 China(e-mail: gang.xiong@ia.ac.cn).

T. C. Author is with with State Key Laboratory of Intelligent Control and Management of Complex Systems, Beijing Engineering Research Center of Intelligent Systems and Technology, Institute of Automation, Chinese Academy of Sciences Beijing 100190 China(e-mail: xiwei.liu@ia.ac.cn).

According to Statistics, 289 chemical accidents have been handled by Ministry of Environmental Protection of the People's Republic of china only in twenty months – from January 2010 to August 2011.

This tells us it is of utmost importance to find the factors that caused the accident, to strengthen production management and thus prevent the occurrence of chemical accidents.

This articles set out a method of chemical accidents scenarios analysis, by which we can find the factors that caused the major accident, and the relations of them. This work will play a significant role in making scientific and reasonable measures for accident prevention and control strategies.

This paper is structured as follows. In Section Ⅱ, the methods of accident analysis, the development Petri Nets and its successful application in fault analysis field are briefly reviewed. In SectionⅢ, an accident rehearsal model of ethylene cracking furnace tube rupture and fire is established based on hierarchical object-oriented Petri nets. In Section Ⅳ, the accident development procedure is analyzed and lessons are obtained and Section Ⅴ concludes this article.

Ⅱ REVIEW

The usual techniques for accident scenarios analysis mainly have two categories: event trees and fault trees. However, both of these tools offer a static representation of the system, not quite suitable for the dynamic aspects of an accident sequence [1]. In order to represent the dynamic evolution of the system situation leading to an accident, in this paper Petri Nets are chosen to build accident model that reveal how the accident happened and developed.

Petri Nets are both a formal and graphical language, which is appropriate for modeling systems with concurrency. Petri Nets were firstly proposed by Carl Adam Petri—an expert from German—and developed in the early 1960s.They are a general theory of discrete parallel systems with language taken from automata theory. The ability to construct models with these properties makes Petri Nets an attractive tool for modeling operator behavior [2].Recently many applications of Petri Nets in the accident analysis showed their versatility to combine human actions, technical failures and interactions between them in order to construct the accident model. C.ZHAO, M.BHUSHAN[3]used coloured Petri Nets to successfully represent chemical processes in their work of developing a software for automated HAZOP analysis. Chao-Hua Wen and Sheue-Ling Hwang[4] used Petri Nets to construct an operator's mental model .David Vernez, Didier Buchs[5] discuss the perspectives of Petri Nets in the fields of risk analysis and accident modeling.

For the purpose of enhancing the operation cycle of petrochemical industry and reducing the accident rate, our team —team of parallel control and management—has been worked on the study and application of the Parallel System Technique on the Ethylene Long-Time Production based on ACP theory[6,7,8,9] since 2005. A lot of breakthrough were made[10,11,12,13].Currently, the Research on Emergency Recue Decision Support System based on ACP theory is being done[14].To support the research, a hierarchical object-oriented Petri Nets[15] is chosen to construct an accident model of ethylene cracking furnace tube rupture and fire. Furthermore, Dynamic process of development of the accident is systematic analyzed through the model and the path to avoid accidents is found.

Ⅲ PETRI NETS MODEL OF AN ACCIDENT CASE

1. Description of the accident scenario

At 14:35 on 26th August, 2010, the cracked gas large valve for releasing cracked gas from the BA-107 cracking furnace to following section unexpectedly closed, which caused overpressure of the cracking furnace tube, the rupture of furnace tube and ultimately fire of the furnace. The accident resulted in burns of a fireman, break down of the other three furnaces adjacent to it and production fluctuations of following-up section.

2. Petri Nets model of the accident

The model is presented in figure1. There are four subnets in the model. O_1 net represents the management of the plant; O_2 net represents behaviors of the operators under the roles of the plant rules; O_3 net represents the transfer procedure of fault; O_4 net represents the dynamic evolution of cracking furnace accidents from normal situation to fire.

In the O_1 subnet, P_{10} represents the rules and regulations for equipment management; T_{101} represents production directors pay much attention to improving the rules and regulations for equipment management; P_{101} represents the plant has complete rules and regulations for all the equipment and its accessories; T_{1012} represents the plant strictly implement all the rules and regulations; T_{102} represents production directors pay no attention to improving the rules and regulations for equipment management; P_{102} represents the plant has no complete rules and regulations for all the equipment and its accessories; T_{1022} represents the plant doesn't strictly implement all the rules and regulations; P_{11} represents the rules and regulations for techniques management; T_{111} represents production directors pay much attention to risk assessment and improving facilities for monitoring; P_{111} represents the plant has complete monitoring facilities; T_{1112} represents the plant strictly implement all the rules and regulations for techniques management; T_{112} represents production directors pay no attention to risk assessment and improving facilities for monitoring; P_{112} represents the plant has no complete monitoring facilities; T_{1112} represents the plant doesn't strictly implement all the rules and regulations for techniques management; P_{12} represents the situations of security management; T_{121} represents production directors pay much attention to improving emergency management; P_{121} represents the plant has complete plans for emergency situations; T_{1212} represents the plant often organizes specific emergency drill; T_{122} represents the plant has no complete plans for emergency situations; T_{1222} represents the plant seldom organizes specific emergency drill.

In the O_2 subnet, P_{20} represents the operators inspected production systems in accordance with rules and regulations of the plant and timely found the fault of BA-107cracking furnace; P_{21} represents the operators didn't find the fault of BA-107cracking furnace; P_{22} represents the operators found the overpressure of cracking furnace tube; P_{23} represents the operators didn't find the overpressure of cracking furnace tube; T_{2411} represents operators released abnormal information on overpressure of cracking furnace tube; T_{2412} represents operators didn't released any abnormal information on cracking furnace tube; P_{24} represents the operators found the fire of BA-107cracking furnace; P_{25} represents the operators didn't find the fire of BA-107furnace.

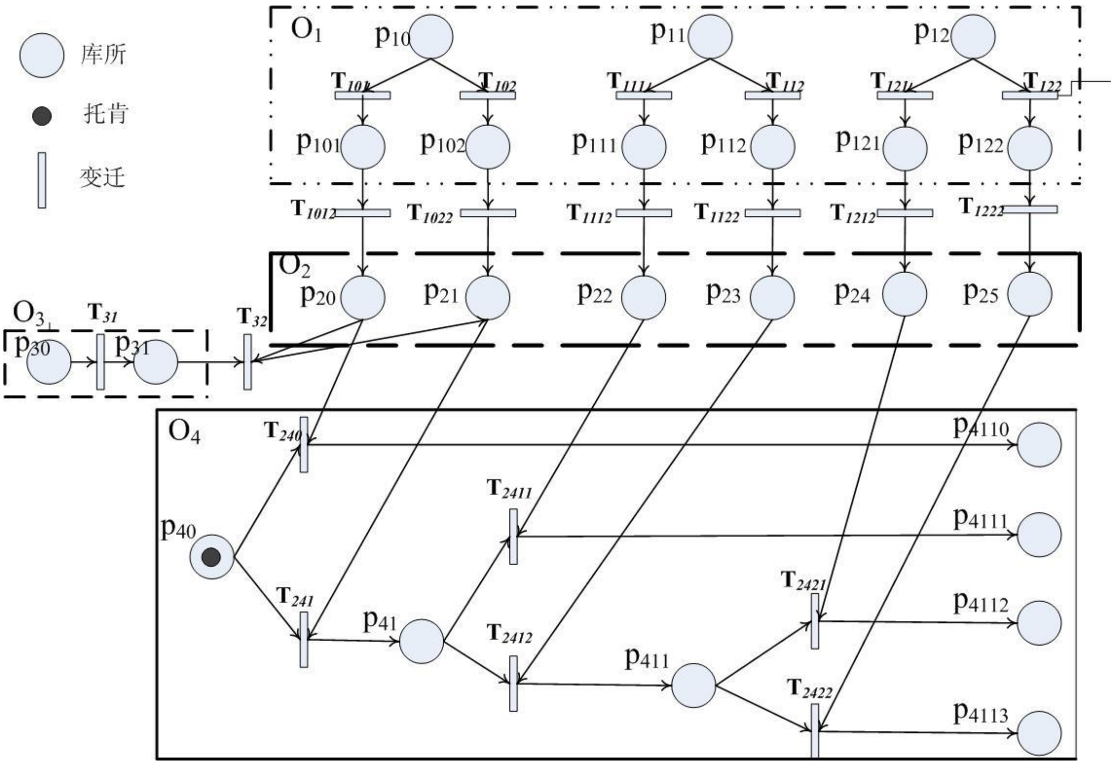

Figure1. Petri Nets model of the accident

In the O_3 subnet，P_{30} represents there is a design flaw in the power device of cracked gas large valve of BA-107 ; T_{31} represents operators open the button of cracked gas large valve of BA-107; P_{31} represents cracked gas large valve of BA-107 is closed; T_{32} represents the transit of the fault.

In the O_4 subnet，P_{40} represents the cracking furnace is normal running; T_{240} represents operators implemented the plan for abnormal situation of cracking furnace; T_{241} represents nobody implemented the plan for abnormal situation of cracking furnace; P_{4110} represents the accident is avoided; P_{41} represents the cracking furnace tube is over-pressured; T_{2411} represents measures preventing accident is taken; P_{4111} represents the accident is avoided; T_{2412} represents no measures was taken to handle the phenomena of overpressure; P_{411} represents cracking furnace tube ruptured and cracking furnace fired; T_{2421} represents scientific and reasonable emergency measures was taken; P_{4112} represents the fire was controlled and an operator was burned; T_{2421} represents unreasonable emergency measures was taken; P_{4113} represents the fire can't be controlled and caused a large number of casualties.

Ⅳ ACCIDENT CASE ANALYSIS AND MODEL VALIDATION

1. Accident case analysis

According to the model, the accident case was caused by the interaction of multiple factors.

For the purpose of making the whole accident clearly and finding the accident avoiding path for the similar abnormal situations, an analysis map was drawn in figure 2. In the map,  represents the transfer path of fault;  represents the factors that caused the accident;  represents the good measures avoiding the accident and the normal production state;  represents serious accident happened， represents serious accident was controlled;  represents uncontrollable accident.

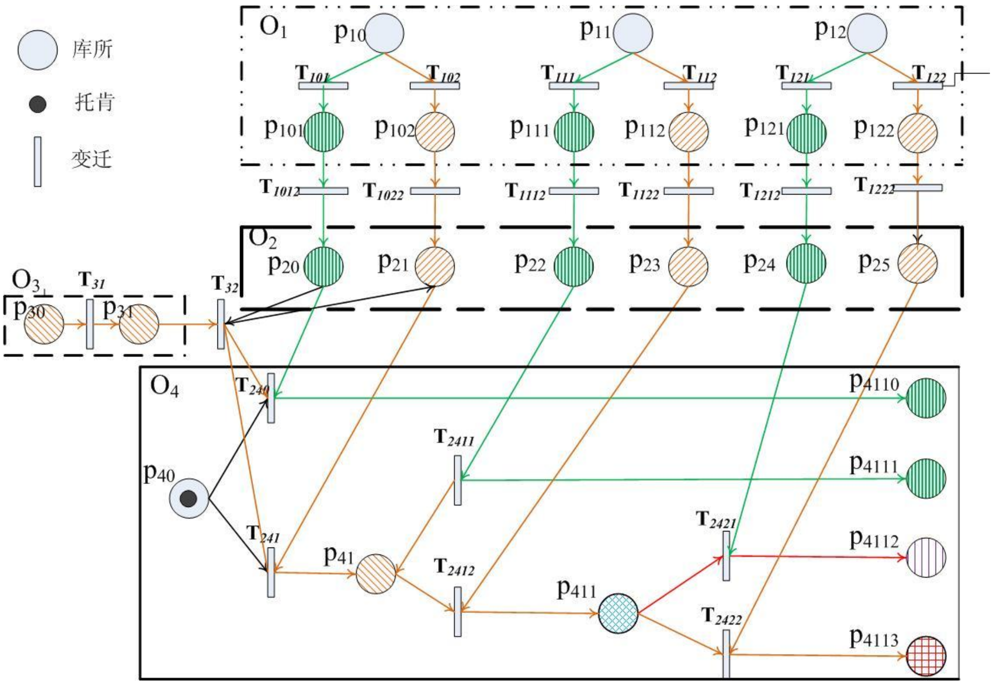

Figure2. analysis map of the accident

According to the analysis map, it is very clearly that the design flaw of power device of cracked gas large valve of BA-107 cracking furnace ----When the button of power device is turned on, the corresponding valve is closed---- is the initiation leading to the accident. As the valve fault occurs, five mainly results can be leaded under the role of different rules and regulations of the plant and behaviors of operators.

A. Complete rules and regulations for equipment management of the plant, effectively implementation of all the rules and regulations and serious and responsible behaviors of operators make the flaw timely found and the accident is avoided (P_{4110}).
B. In the case of design flaw being hardly found, pretty rules and regulations for technical management, complete monitoring facilities for process parameters and serious and responsible behaviors of operators make the phenomena of overpressure in cracking furnace tube timely found and the accident is also avoided (P_{4111}).
C. Incomplete rules and regulations and monitoring facilities coupled with irresponsible behavior of operators caused the cracking furnace fire (P_{411}).
D. Pretty measures for emergency situations of the plant make the fire be effectively controlled and resulted in small loss(P_{4112}).
E. Incomplete measures for emergency situations of the plant make the fire uncontrolled and resulted in large loss (P_{4113}).

In summary, the practices that result in P_{4110} and P_{4111} is the path to avoid the occurrence accident, which is worthy of advocacy in the actual production process; the practices that result in P_{411} and P_{4112} is the trajectory of this accident, which is the combined result of human irresponsible action and management deficiencies, should be improved in the actual production process; the practices that result in P_{4113} should be strictly prohibited.

2. Model validation

In fact, after this accident, the plant immediately launched a comprehensive investigation and found the following four causes leading to the accident.

1) Deficiencies of equipment management;
2) Irresponsible behaviors of operators ;
3) Lack of monitoring facilities for cracking furnace pressure;
4) Unskilled emergency action.

These shows that the accident lessons from Petri Nets techniques are basically consistent with the result of the plant investigations. The feasibility of Petri Net technique for accident scenarios analysis used in this article is verified.

Ⅴ CONCLUSIONS

In this paper, a hierarchical object-oriented Petri net was chosen to establish an accident scenarios analysis model. Based on the model, the dynamic evolution of the accident was presented and the accident lessons were obtained. Conclusions are drawn as follows:

1) The techniques of hierarchical object-oriented Petri net supports chemical accident scenarios analysis and the model established in this paper can detailed describe interrelationship of multiple causes, the evolution of the accident and accident avoidance path;
2) The model puts an emphasis on systemically revealing how the accident developed .

Further work is to optimise the accident scenarios analysis model and enhance the versatility of the model. The work will lay a solid foundation for the research on prediction of chemical accident consequence and accident prevention.

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