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The Study on the Development of Hazard Evaluation Expert System

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Abstracts Inherently safe plants are maintained through the systematic identification of potential hazards, and various hazard evaluation methods have been developed. Recently, much effort is given into the development of automated hazard evaluation system by introducing the expert system. An automated system will help to obtain consistency and to make the result more reliable.

HAZOP study is one of the most systematic and logical evaluation procedure. However, it has disadvantages: experts should participate at the same time, the detailed study requires much man-hour, and the results depend on the expertise of the experts. Therefore, the automation of hazard evaluation is necessary to reduce the required time and to get the consistent evaluation results.

In this study, HAxSYM, an expert system to automate HAZOP study, is developed. The case studies are performed to validate the effectiveness of the developed system, and the results are compared to the results of traditional method.

Keywords HAZOP study, hazard evaluation, expert system, automation, chemical process

1. INTRODUCTION

To ensure the safety of chemical plants, correct and systematic data accumulation, analysis and innovations should be performed throughout the plants lifetime -- design, manufacturing, construction, operation, maintenance, and process upgrade, etc. The inherently safe plants are maintained through the systematic identification and mitigation of potential hazards, and various hazard evaluation methods have been developed and used for this purpose.

The attention to safety is increased, and the hazard evaluation is legalized to be applied to the design and operation of the plants. HAZOP (Hazard and Operability) study, which is one of the most frequently applied hazard evaluation methods, is also acknowledged as one of the most systematic and logical methods in the chemical process industry.

However, HAZOP study has disadvantages. The experts should participate at the same time, the detailed study requires much man-hour, and the results depend on the expertise of the participating experts so that the consistency of the results is difficult to maintain from one study session to the next. Therefore, the automation of hazard evaluation is necessary to reduce the required time and to get the consistent evaluation results.

2. Hazard Evaluation Procedures

Hazard evaluation procedures are used to identify and evaluate potential hazards and to mitigate the effects in the chemical plant/process. Currently twelve methods are widely used: safety review, checklist, relative ranking, PHA, what-if, what-if/checklist, HAZOP study, FMEA, fault tree analysis, event tree analysis, cause-consequence analysis, and human reliability analysis.

Safety review, checklist analysis, relative ranking, PHA, what-if analysis are effective when applied to assess hazards of large process or complex plants in broad view. By applying these methods before the actual construction, additional cost for improvement of the safety may be reduced.

What-if/checklist analysis, HAZOP study, and FMEA are effective while analyzing general hazards at the design stage or during routine operations. The results may be used as the basis of more detailed analysis.

Fault tree analysis, event tree analysis, cause-consequence analysis, human reliability analysis should be reserved for the case of very detailed analysis of specific hazards under consideration; these methods require the personnel trained in appropriate knowledge and technique, and take very long time and efforts with respect to other more generalized methods.

The explanation of the HAZOP study and failure mode and effect analysis follows.

2.1. HAZOP study

HAZOP study started in the ICI to identify hazards in processes. HAZOP study was originally used for the application to evaluate the new designs and/or novel technologies. However, HAZOP study can be applied to every step in the processes' life time. This method is based on the principle that various experts who have various background and expertise can identify more hazards through creative and systematic brainstorming together than individual expert analyzes the process and then incorporates the results from individual efforts.

HAZOP study is carried out through evaluating effects and their seriousness of deviations from original design intention. Experts with expertise on various areas study P&ID and, if needed, operation procedure. Although one person can analyze hazards using the same methodology with HAZOP study, hazard analysis which is done in this way is not HAZOP study; the requirement for the HAZOP study is participancy of many experts. Therefore, the biggest difference of other hazard analyses and HAZOP study is in the number of participants.

In HAZOP study, a "study node", particular step in a process/procedure, is concentrated for the analysis. In each node, deviations derived using pre-determined guide words are inspected. Guide words are used to search for the every possible deviations in process parameters.

Usually HAZOP study requires much time to finish as the analysis procedure is carried out in sequence; after all the deviations in one study node are considered, the next node is analyzed.

Each guide word is applied to the relevant process parameters, produces related deviations, and analyzed on study nodes. The following is an example of the generation of deviations from normal condition made by combination of guide words and process parameters.

Guide Words	Parameter	Deviation
NO	+ FLOW	= NO FLOW
MORE	+ PRESSURE	= HIGH PRESSURE
AS WELL AS	+ ONE PHASE	= TWO PHASE
OTHER THAN	+ OPERATION	= MAINTENANCE

The causes and the consequences of the generated deviations are then found out throught the brainstorming of the experts.

2.2. FMEA(Failure Modes and Effects Analysis)

Failure Modes and Effects Analysis (FMEA) is the method to evaluate the equipment failures and their effects to the process. The analysis results may be used to decide the part to modify for the enhancement of system design. During the analysis, the members explain the effects from the possible equipment failures, and limit the failures only to the hardware failures; therefore, this method is straightforward, and easy to apply.

Each failure in equipment is considered independent of other failures in the system. The usual procedure for FMEA is as following.

Firstly, the problem for the analysis is defined. Then the analysis is performed, and the result is documented. Scope of the analysis and the conditions for the analysis are included in the definition stage. The problem definition also includes the level of the analysis and the definitions of boundary conditions. Detailed problem definition is necessary for the detailed and effective analysis.

The advantages of FMEA are; easy to apply at the equipment level, easy for laymen to comprehend, less analysis time than other analysis methods, and fast to find hazardous single failure. However, the disadvantages are; important interactions may not be found as only one equipment is processed for the analysis, all the failures are due to the hardware failures, and the results are not detailed enough to be quantitatively used. By adding the criticality to the results of FMEA, FMECA(failure modes, effects and criticality analysis) may be performed.

The analysis procedures of HAZOP study and FMEA are systematic, and this systematicity makes the automation of these analysis methods easier. The repetitive use and the hierarchical structure of process equipment are also the strong points in the automation.

3. Expert System

3.1. Expert System

Expert system is a programme to solve the problems of a specific domain by using the domain knowledge; that is, an expert system extracts information by restructuring expertise of experts, and, based on this information, provides solution of problems in a specific domain through the inference mechanism.

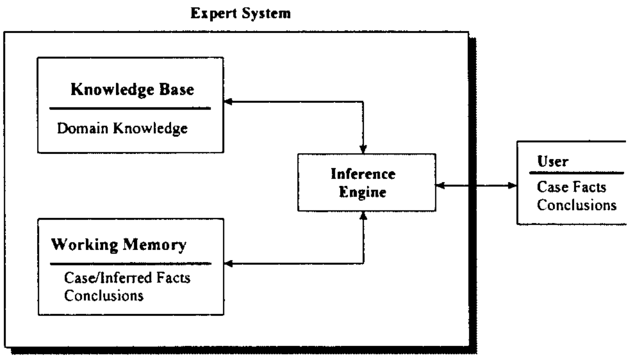

Fig. 1. Expert System Problem Solving

3.2. Knowledge Representation for the Automation of Hazard Evaluation

Performance of an expert system depends largely on the quality of knowledge contained in the system; as the quality of knowledge of an expert system gets better, so does the performance of the expert system. Better domain knowledge necessitated better methodology in knowledge representation. Most commonly used methods are: procedural method, rule-based method, logic-based method, semantic network, and frame.

Modeling of chemical process units can be classified into two category; qualitative and quantitative. Quantitative modeling is used for the flowsheeting, while qualitative modeling is mainly used for other applications such as fault diagnosis. Modeling procedure is tedious and is difficult to the neophytes; in case of qualitative modeling, governing equations in differential form is required.

HAZOP study and FMEA proceed by applying appropriate guidewords to process parameters and analyzing the resulting deviations and their cause and effects. It is not necessary to use differential equations for this kind of purpose, and is rather useful to simplify the representation for uses' understanding and expansion of knowledge base.

4. Framework of HAxSYM

4.1. Development of the Framework

The evaluation step is; the cases of equipment failure are considered, and then the effects to other process units and process material streams are considered. This relationship between the cause and the consequence is determined as the direct result of the FMEA, and this is used as the basic data while searching the knowledge base. FMEA method treats all the failures in a process as hardware failures; therefore, appropriate process knowledge including other failure causes and effects, such as misoperation, should be included. The search result of the knowledge base is facilitated for the HAZOP study with the cause-consequence relationship.

Causes may be classified into the three categories: equipment failure, human error, and external event. These causes are classified into '1st cause' and '2nd cause' according to the severity; the consequences are also divided into '1st consequence' and '2nd consequence.'

After finding out the 1st consequences from the causes, safeguard are taken into the consideration, recommendations are given, and the 2nd consequences are given later.

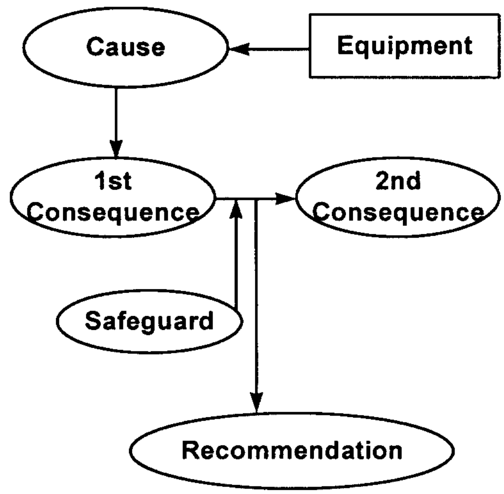

Fig. 2. Inference Flow

4.2. Implementation of HAxSYM

The chemical process is consist of 'equipment' and 'stream'. Equipment is the basic unit such as valve, pump, etc., and stream is the flow between equipment. Equipment and stream objects are frame-structured.

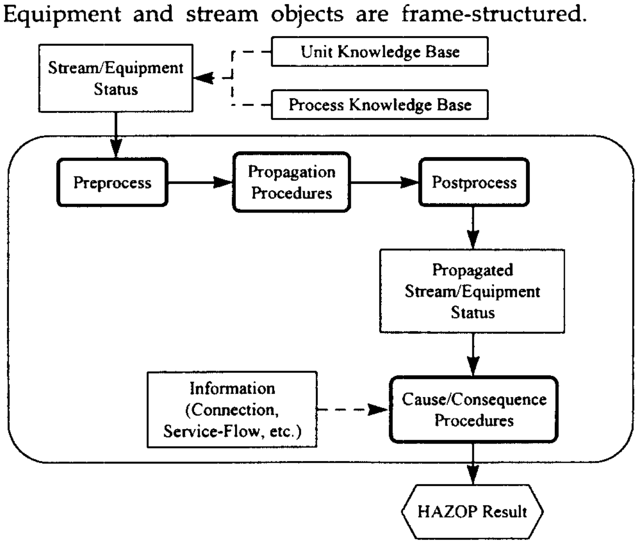

Fig. 3. Structure of HAxSYM

The procedures for the hazard analysis are divided into three groups: propagation procedures, causes and

Table 1. Example of Analysis Results of HAxSYM

NODE 1 : Column Overhead			HAZOP STUDY RESULTS Depentanizer Unit as a Case Study 2 by HAxSYM			
ITEM	DEVIATION		1st CAUSE	2nd CAUSE	1st CONSEQUENCE	2nd CONSEQUENCE
	parameter	guide word				
				impeller fault		
				rotation fault		
C-201						
E-204			shell leak	corrosion		
				gasket failure		
E-202	flow	more				
D-201	level	high			overflow	
C-201	flow	more				
D-201	pressure	less	leak in drum			
P-202			suction plugged	valve pinched	loss of NPSH	
				line plugged	cavitation	
					overheat	
					damage to the pump	
					less feed to destined equipment	
C-201						
E-204						
D-201	pressure	more	outlet line blocked	control valve fail closed		
P-202			discharge line blocked	control valve fail closed	increased to pump shut off press	pump damage
C-201						
E-204						

consequences procedures, and general procedures. Propagation procedures represent the effects of the changes in operation modes or equipment failures. Causes and consequence procedures contain the knowledge on the causes and consequences of the equipment failures. General procedures activates the propagation procedures, and causes and consequence procedures.

The system was implemented using expert system tool, G2.

5. Case Studies

The developed system is applied to the three processes to validate its usefulness, and the results are compared to those from the traditional experience-based HAZOP study.

The results show that the HAxSYM gives more causes and consequences than the traditional HAZOP study. However, human HAZOP study considers the process-specific knowledge and other deviations in cases such as maintenance.

6. Conclusions

The framework for the automation of HAZOP study was developed and implemented. The comparison with the traditional HAZOP study shows that the hazard analysis may be automated.

The selective filtering of the results should be further studied to reduce and/or eliminate the need for the examination by experts. Also quantitative information should be incorporated to enhance the quality of the analysis results.

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