Development of Hazard Identification system based on SDG Models

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Abstract

There are many kinds of hazards in chemical plants. In order to operate safely chemical plants, it is important to assess the risk in chemical plants. Hazard and Operability Study (HAZOP) is one of the specific methods of process risk. HAZOP is widely used in the risk assessment to identify hazard. An automatic analysis system is developed to perform HAZOP effectively. In this study, semi-automatic analysis system was developed by using the Signed Directed Graph (SDG). SDG shows deviation of the propagation in equipment. Analysis is performed based on the propagation of deviation. Therefore equipment is added to the system in accordance with the rules. Our developed hazard identification system is applied to one chemical process. And the future works for this study are explained.

Keywords: hazard identification; Hazard and Operability Study; Signed Directed Graph;

1. Introduction

In recent years, chemical plants are increased scale and complexity by improvement of the technology. So, the safety management is important to companies and society. Chemical plants have many hazards that are caused by materials, system configurations and equipment characteristics. If an accident occurs, there is a possibility of a serious impact on employees, local residents in the community. Therefore, it is more important to perform of the "risk assessment" which is assumed possible accidents and causes beforehand in industrial facilities and calculated the risk based on frequency of the accident and size of the damage when the accident occurred [1].

A variety of evaluation index is used to perform a risk assessment. Therefore, various evaluation methods are proposed in order to estimate each item as systematic and effectively. However, it is need to discuss several experts familiar with the behavior of equipment, operating conditions and the characteristics of the material. And much time, labor and cost are...
necessary. Furthermore, variability of evaluation results is expected by the subjectivity of the analysts. The many research institutions develop computer system to support the implementation of each evaluation method in order to solve these problems. For example, A. Meel et al. [2] developed the system used in the risk assessment to create a statistical model based on the accident database and Maryam Kalantarnia et al. [3] developed dynamic risk assessment approach based on Bayesian inference.

2. Purpose and Approach

It is important to ensure the safety in industrial facilities, and hazards in the facility must be identified during the design phase of the facility. Hazard and Operability Study (HAZOP) is a technique that has been created for the purpose of identification of hazards[4]. It has the feature that it is highly exhaustive systematic analysis compared to the other methods with the same purpose. However, the research and development of the HAZOP analysis system by the automatic processing of the computer are demanded because it requires a lot of time and labor to perform.

Various techniques are developed in each research institution in order to systematize the method the experts perform the HAZOP. For example, C. Zhao et al. [5] developed PHASuite. PHASuite models HAZOP analysis carries it out by replacing knowledge to ontology-based information and using a knowledge base and colored Petri net. K.Kawamura et al. [6] developed. HazopNavi assumes a cause and performs HAZOP analysis in conjunction with intelligent CAD system called Dynamic Flow Diagram. Dynamic Flow Diagram is CAD system to clarify the operation, behavior and the structure of the chemical process.

The System developed by various research institutions is divided into generic HAZOP analysis system and non-generic HAZOP analysis system. The generic HAZOP analysis system means that its reasoning logic can be applied to different chemical processes. For example, there are HAZID developed by S.A. McCoy et al. [7], ExpHAZOP+ developed by Shiby Rahman et al. [8] and D-higraphs HAZOP developed by Manuel Rodríguez et al. [9]. The non-generic HAZOP analysis means that its reasoning logic is chemical process specific or chemical plant specific. For example, C. Jeerawongsuntorn et al. [10] developed HAZOP application for continuous biodiesel production. Z. Švandová et al. [11] developed HAZOP using dynamic simulation. The generic HAZOP analysis system can analyze a variety of chemical process. But the generic HAZOP analysis system can’t identify the inherent danger that exists in each chemical process. On the other hand, the non-generic HAZOP analysis system can identify the inherent danger that exists in the specific chemical process. But the non-generic HAZOP analysis system can analyze only one chemical process. These show that the coexistence of generic HAZOP analysis and non-generic HAZOP analysis is difficult.

The final objective of our research is the development of the HAZOP analysis system that includes both generic HAZOP analysis and non-generic HAZOP analysis. As the first, the generic HAZOP analysis system was developed in this study. The analysis model along the thought of the fault propagation is defined based on the logical thought procedure of an expert performing HAZOP analysis. Specifically, propagation path is built beforehand by modeling how the deviation is propagated each piece of equipment. And the deviation assumed the pipe is propagated along the propagation path. The developed system selects hazard from a database prepared beforehand by the function of equipment and the deviation. In this way, the system semi-automatically identifies the hazard of the chemical plant.
3. Purpose and Approach

HAZOP analysis is a technique to identify hazard by using ‘deviation’ from the design intent. Deviation is combined a ‘guide word’ and a ‘process parameter’. Guide word is a keyword used in analysis. Process parameters are flow, pressure, temperature and etc. In analysis, deviation is applied the pipe that is a part of process and propagated next equipment. Fault propagation is process that deviation is propagated. Fault propagation is used to identify hazards and assess safety measures in HAZOP.

HAZOP analysis system analyzes the fault propagation among each equipment in the chemical plant. This system requires to format the information about chemical plant available on the analysis system and to build a framework to use. Therefore, the equipment and process information are modeled for the analysis of HAZOP in the HAZOP analysis system. So, SDG(Signed Directed Graph) model indicates fault propagation within the equipment is built and stored in the database. The system analyzes the fault propagation by building a framework for the integration database and combining these models.

3.1 SDG model

SDG technique is applied to indicate qualitatively the relationship between cause and consequence in the developed system. The basic model of SDG is shown in Fig.1.

![Figure 1. The basic model of SDG](image)

"A" and "B" in Fig.1 are called a node and express the vertices of the graph. This node contains a process parameter such a temperature, flow, pressure, level and composition. The node has qualitative values such as "0" "+" "+", each qualitative value expresses steady state, more steady state and less steady state. The arrow is called an arc and means association of "A" and "B". It expresses that "B" is affected by "A" in Fig.1. Sign (A-B) is expressed by two qualitative expression of "+" "+". When the Sign (A-B) is "+", the process parameter "B" has a positive correlation with respect to "A". When the Sign (A-B) is "+", the process parameter "B" has a negative correlation with respect to "A". In other words the state of node "B" is decided by a state of node "A" and the state of the arc. In the case of cause analysis, the system analysis by reversing the direction of the arc. SDG model is defined as the set of process parameters to be considered in the analysis by SDG. The developed system considers the case to be propagated to the different parameters for the deviation of the original by modeling the relationship between cause and consequence as using SDG.

3.2 Equipment model

Equipment model expresses the modeled information about equipment constituting a plant. This model is consisted of SDG model to model the functions to be performed inside the equipment from input to output. And the model has a single path that is connected to each of SDG model. Characterized function of equipment such as tanks and valves is expressed by equipment model. If the deviation is propagated, the shift and the propagation of the deviation are defined by each of the internal function of the equipment. The shift in the deviation before and after the equipment is represented by combining SDG model as shown in Fig.2. Multi-
input multi-output equipment model in Fig.2 has four SDG models according to a number of input and output. And, four propagation paths are built in this model.

![Figure 2. The example of SDG model in the equipment model](image)

3.3 Fault propagation analysis

(1) Framework of Fault Propagation. The framework of fault propagation analysis is built as the plant model using the equipment model. The plant model is composed of a group of equipments that are passed with the same fluid. The propagation path expressed by SDG model is connected to the next equipment and then the next group. Therefore, whole plant propagation path is configured. Therefore, the developed system propagates deviation throughout the plant at the time of analysis in order to identify the hazard. These are shown fig.3.

![Figure 3. Framework of Fault Propagation](image)
(2) Cause and Consequence Analysis. In cause and consequence analysis, the developed system selects a deviation from the steady state in the pipe that is connected between the equipments. In cause analysis, the deviation is propagated to the upstream side along the propagation path of SDG model. In consequence analysis, the deviation is propagated to the downstream side deviation along the propagation path of SDG model. The flow deviation is applied between equipment B and equipment C in Fig.4. The deviation is propagated to downstream in the path of the arrow pointing to the right, and to upstream in the path of the arrow pointing to the left.

In this example, the developed system propagates Flow-More and Pressure-More to equipment B, and Level-More and Pressure-More to equipment A at cause analysis. The developed system propagates Flow-More and Temperature-More to equipment C, Flow-More and Temperature-More to equipment D, and Level-More and Temperature-More to equipment E at consequence analysis. The analysis results of cause and consequence are selected from the database referring to the internal function of equipment, the kind of the deviation that propagated and a direction of analysis. This analysis is performed repeatedly until the end of the group. An example of the results is shown in Table 1. Causes and consequences are not a one-to-one correspondence. A number of analysis results of the equipment depend on the database. The developed system can select more causes and consequences analysis results by propagating the deviation and checking up the database.
4. Case Study

The proposed method has been applied to several process plants. The developed system is applied to a part of the process to produce ethylene.

4.1 Analysis object process

Acetylene is supplied from the previous process and boosted by the compressor (see Fig.5). The range of the analysis object is as far as acetylene which has been heated in the heat exchanger enters the reactor. The range is equipment No.1-11 shown in Fig.5. There are main equipment includes a compressor (No.1), six valves (No.2, 4, 7-10), a tube shell heat exchanger (No.5), a reactor (No.11). In addition, a flow is divided into two with equipment No.3, and a flow is put together with one with equipment No. 6. Then, the deviation that is temperature rise is assumed in the pipe that is between the No.10 and No.6.

![Figure 5. Part of the drawing of the ethylene production process](image)

4.2 Propagation path and SDG model of equipment

Fig.6 shows combined SDG model for each piece of equipment to build the propagation path. All equipment except the heat exchanger is expressed by the left SDG model in Fig.6. The heat exchanger has four paths. There are four types of paths, from inlet tube side to outlet tube side (No.4 → No.5), from inlet shell side to outlet shell side (No.8→No.9), from inlet tube side to outlet shell side (No.4→No.9), from inlet shell side to outlet tube side (No.8 → No.5). The heat exchanger has four SDG models because it is multi-input multi-output equipment. Two kinds of paths from inlet tube side to outlet tube side and from inlet shell side...
to outlet tube side are used in cause analysis. Then the two SDG models which are surrounded by broken line in Fig.6 are used for cause analysis. The developed system builds the propagation path. Consequence analysis propagates from equipment No.10 to equipment No.11. However, cause analysis divides the propagation in two lines from equipment No.6 to equipment No.5 and from equipment No.6 to equipment No.7. Furthermore, cause analysis divides the propagation in two lines from equipment No.5 to equipment No.6 and from equipment No.5 to equipment No.8 because equipment No.5 is a heat exchanger. Cause analysis propagates to the left of the deviation as shown in Fig.7. In this case study, equipment No.1 is propagated Temperature-More, equipment No.8 is propagated Flow-More, Temperature-More and Pressure-More in cause analysis. Equipment No.11 is propagated Temperature-More in consequence analysis. Of course, the deviation is propagated even to the end equipment and the analysis is performed by the kind of deviation and the function of equipment. If the propagation of the deviation is ensured, leakage of analysis is prevented by enhancing the corresponding database.

![Figure 6. SDG model for each equipment](image)

![Figure 7. Propagation of the deviation along the propagation path](image)

4.3 Consideration

Analysis result screen by the developed system is shown in Fig.8. Cause list shows seven analysis results. Two analysis results are the cause of Temperature-More in equipment No.5. Another analysis result is the cause of Flow-More in equipment No.8. The other analysis results show that the deviation of Flow-More is propagated from upstream of equipment No.1,
and the deviations of Flow-More, Temperature-More and Pressure-More are propagated from upstream of equipment No.8. Consequence list shows four analysis results. Three analysis results are the consequence of Temperature-More in equipment No.11. Another analysis result shows that the deviation of Temperature-More is propagated to downstream of equipment No.11.

In the case study, the number of cause and consequence results was less than the number of equipment that consisted of the process. It is necessary that the resulting information is stored to the database and the deviation is propagated to the equipment in order for developed system to select the result. Therefore analysis result shows cause as a result of propagation from upstream of the equipment and consequence as a result of the propagation to downstream of the equipment, the developed system shows the deviation to be analyzed is propagated to the end of the range. The developed system can contribute to identify the hazards by user enhances the database.

**Figure 8.** Analysis result screen

### 5. Conclusions and Future Work

This paper proposed a method to build a propagation path between equipment inside and equipment. We modeled the behavior of the equipment by SDG model in order to realize the system propagation analysis of an abnormality in the HAZOP analysis. Thereby, the system was developed in order to perform semi-automated analysis that is selected the deviation at the beginning of the analysis.
However, the developed system selects all cause and consequence that satisfies the condition. Analysis result of the developed system are included the results that are duplicate results and should be left out on purpose by HAZOP analysts in comparison with HAZOP which a conventional person performs.

In this situation we may overlook which analysis result is important. We think that it is necessary to sift out the results of the analysis of the system in the same thought process when people selected, and deviation dose not propagate to the end by the action of the instrumentation equipment at the time of analysis.

Our future direction is to develop the non-generic HAZOP analysis system. And we will integrate the generic HAZOP analysis system with non-generic HAZOP analysis system. We need to classify the common points and non-common points of each chemical plant for the development of non-generic HAZOP analysis system. It means that non-common points are characteristics of each chemical plant. Individual analysis logic and model are required to identify the potential hazards that exist in the characteristics. We integrate the two developed systems. Then, we analyze the general part of the chemical plant by generic HAZOP analysis part, the characteristic part of each chemical plant by non-generic HAZOP analysis part. We want to contribute to the safety of chemical plants by developing the system using several types of analysis.

References
