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Citation: An, H. ... et al., 2009. Automated cause and effect analysis for process plants. IN: Chemical Engineering Transactions XVII: Proceedings of the 9th International Conference on Chemical and Process Engineering (ICHeaP-9), Rome, Italy, pp. 1281 - 1286.

Additional Information:

• This is a conference paper. It was presented at ICheaP-9, the ninth International Conference on Chemical & Process Engineering 10-13 May 2009, Rome, Italy. The definitive version is available at: http://dx.doi.org/10.3303/CET0917214

Metadata Record: https://dspace.lboro.ac.uk/2134/11413

Version: Published

Publisher: © AIDIC Servizi S.r.l.

Please cite the published version.
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Automated Cause & Effect Analysis for Process Plants


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Cause & Effect (C&E) analysis for process plants is one of the tasks associated with Process Control Engineering (PCE). With the availability of electronic Piping and Instrumentation Diagrams (P&IDs), a Computer-Aided tool is developed to carry out the analysis automatically by encoding knowledge related to PCE in rules so that they can be applied to a given set of P&IDs to produce the corresponding C&E Diagrams. This paper describes how this is achieved. A rule-based system and an instrument checker are developed. They are used to generate the results and the results are displayed in a format that complies with ISO 10418 (ISO, 2003).

1. Introduction

Safety Analysis Function Evaluation chart (SAFE), or Cause & Effect (C&E) Table, is one of the established cause and effect analysis techniques stated in ISO 10418 (ISO, 2003) that can be applied to identify unfavorable safety-related outcome and the design of protective measures. A computer-aided tool that can produce the C&E analysis result automatically is developed and integrated with Intergraph’s Engineering Enterprise Suite through Smart Plant Process Safety (SPPS). SPPS is a knowledge-based system that automates the process of HAZard and Operability Study (HAZOP). It is developed by Hazid Technologies Ltd., UK. The C&E tool consists of an Instrument Checker, a general purpose knowledge based rule engine and a tool that outputs the results for displaying using Microsoft Excel. The layout of the table complies with ISO 10418 (ISO, 2003).

This paper describes the above components of the system. An example is used to illustrate the working of the system and a comparison between results of this tool and that of the tool described by Drath et al (2006) is given.

2. Instrument Checker

Given a P&ID, the Instrument Checker is a tool that identifies the instrument loops and their connections with the process items. The output of this tool is used as input to the rule-based system.

Please cite this article as: An H., Chung P., McDonald J. and Madden J., (2009). Automated cause & effect analysis for process plants, Chemical Engineering Transactions, 17, 1281-1286 DOI: 10.3303/CET0917214
The tool first identifies all the instruments in the process plant. For each instrument, it traces the upstream and downstream connections of each branch line until a process item is found. Given a process item, a list of instruments that are connected to it is kept. Similarly, given an instrument, a list of process items that are connected to it is kept.

Consider the P&ID shown in figure 1, which is a very small part taken from a much larger plant. The following instruments are identified:

- two high level alarms – “ZEH-59010” and “ZLH-59010”;
- two low level alarms – “ZEL-59010” and “ZLL-59010”;
- one control valve – “FCV-59010”.

![Diagram](image)

*Figure 1. A simple instrument loop*

Figure 2 shows the instruments, their connections with process items, related deviations and responses. Figure 3 shows all the instruments in the loop are attached to the same process item “test1001PU34-PU”.

### 3. Rule-based System

A rule-based system is built to analyze process events and the corresponding process responses. CLIPS (C Language Integrated Production System) is chosen as the development tool as it supports rule-based, object-oriented and procedure programming methods (Riley, 2008). A rule-based system in CLIPS consists of three components: a set of facts, a set of rules and the inference engine that controls the overall execution by matching the rules against the facts to infer new information (Giarratano & Riley, 1994).

#### 3.1 Facts about process items, instruments and connectivity

The output from the Instrument Check is converted into CLIPS facts as input for the rule-based system. Here are some example facts:

- (equipment pipe test1001PU34-PU 1-in-2-out)
- (device high-level-alarm ZEH-59010)
- (flow-connection FCV-59010 out test1001PU34-PU)
- (signal-connection ZEH-59010 FCV-59010)
The first fact states that “test1001PU34-PU” is a 1-in-2-out pipe of the class “equipment”. The second fact states that “ZEH-59010” is a high level alarm of the class “device”. The third fact states that the out flow of “FCV-59010” is connected to “test1001PU34-PU”. The fourth fact states that there is a signal connection between “ZEH-59010” and “FCV-59010”.

**Figure 2. Instrument List**

<table>
<thead>
<tr>
<th>Loop</th>
<th>Item Tag</th>
<th>Item Type</th>
<th>Associated Deviation</th>
<th>Process Item</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>59010</td>
<td>ZEH-59010</td>
<td>high level alarm</td>
<td>L- , L0</td>
<td>test1001PU34-PU</td>
<td>isAlarm</td>
</tr>
<tr>
<td>59010</td>
<td>ZEL-59010</td>
<td>high level alarm</td>
<td>L- , L0</td>
<td>test1001PU34-PU</td>
<td>isAlarm</td>
</tr>
<tr>
<td>59010</td>
<td>ZEH-59010</td>
<td>low level alarm</td>
<td>L- , L0</td>
<td>test1001PU34-PU</td>
<td>isAlarm</td>
</tr>
<tr>
<td>59010</td>
<td>FCV-59010</td>
<td>cv body</td>
<td>L- , L0</td>
<td>test1001PU34-PU</td>
<td>isControl</td>
</tr>
</tbody>
</table>

**Figure 3. Process Item List**

<table>
<thead>
<tr>
<th>Process Item Tag</th>
<th>Process Item Type</th>
<th>Instrument Tag</th>
<th>Instrument Name</th>
<th>Associated Deviation</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>test1001PU34-PU</td>
<td>Primary Piping</td>
<td>ZEH-59010</td>
<td>high level alarm</td>
<td>L- , L0</td>
<td>isAlarm</td>
</tr>
<tr>
<td>test1001PU34-PU</td>
<td>Primary Piping</td>
<td>ZEL-59010</td>
<td>high level alarm</td>
<td>L- , L0</td>
<td>isAlarm</td>
</tr>
<tr>
<td>test1001PU34-PU</td>
<td>Primary Piping</td>
<td>ZEL-59010</td>
<td>low level alarm</td>
<td>L- , L0</td>
<td>isAlarm</td>
</tr>
<tr>
<td>test1001PU34-PU</td>
<td>Primary Piping</td>
<td>FCV-59010</td>
<td>cv body</td>
<td>L- , L0</td>
<td>isControl</td>
</tr>
</tbody>
</table>

### 3.2 The reasoning rules

The reasoning rules are extracted from ISO 10418 (ISO, 2003). The following is an example rule and the rule is coded in CLIPS format in the system.

**IF**

there is a level indicator or a high level alarm

**AND**

there is a vessel

**AND**

there is a control device which is either a control valve or a control pump

**AND**

the control device is connected to the vessel

**AND**

there is a signal connection between the level indicator or alarm to the control device or the vessel

**THEN**

conclude that the control device will be triggered when the level of the vessel reaches a high level.
3.3 The reasoning process
A rule is activated when all the conditions specified are satisfied by the facts contained in the system. When a rule is fired the action(s) specified will be taken. Normally the action is to call a function to write some output in the result file in XML format. Part of the output is shown in Figure 4.

```
<cause_effect>
<cause_comment processitemTag="test1001PU34-PU">Primary-Piping high level</cause_comment>
<cause instrumentTag="ZEH-59010">level alarm high</cause>
<effect controlInstrmntTag="FCV-59010">close input control device</effect>
</cause_effect>
```

Figure 4 Output in XML format.

4. Displaying the C&E Result table
After the rule-based system in CLIPS engine has generated the results in the XML format a Parser is called to parse the XML result and convert it into a Comma-Separated Values (CSV) text file. An engineer can open the CSV file with Excel, and the C&E table will be presented in the format specified in ISO 10418 (ISO, 2003).

Part of the Cause & Effect table is shown in figure 6. A cross is placed in a cell to indicate the cause and effect link between a process component, sensor instrument and control device. Figure 5 shows that process component “test1001PU34-PU” has four instrument devices attached to it (“ZEH-59010”, “ZLH-59010”, “ZEL-59010”, “ZLL-59010”). If the high level alarm “ZEH-59010” or “ZLH-59010” goes off then the input control valve FCV-59010 will be closed. If the low level alarm “ZEL-59010” or “ZLL-59010” goes off then the input control valve FCV-59010 will be opened.

```
<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>FIGURE SAFETY ANALYSIS FUNCTION EVALUATION CHART</td>
<td>SAFE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>PROCESS COMPONENT</td>
<td>SERVICE</td>
<td>DEVICE IDENT</td>
<td>CAUSE COMMENT</td>
<td>CAUSE</td>
</tr>
<tr>
<td>3</td>
<td>test1001PU34-PU</td>
<td>Primary-Piping</td>
<td>ZEH-59010</td>
<td>Primary-Piping high level</td>
<td>level alarm high</td>
</tr>
<tr>
<td>4</td>
<td>ZLH-59010</td>
<td>Primary-Piping high level</td>
<td>level alarm high</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>ZEL-59010</td>
<td>Primary-Piping low level</td>
<td>level alarm low</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>ZLL-59010</td>
<td>Primary-Piping low level</td>
<td>level alarm low</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>
```

Figure 5 Part of the result table
5. Comparison with related work

The knowledge-based system reported in Drath et al (2006) is also designed and implemented to automate the generation of Cause & Effect Table. Their paper uses an interlock example to illustrate their work. In order to carry out a comparison, the authors have produced and extended a P&ID from their example and applied the cause effect analysis tool reported here to that plant. The result is shown in figure 6.

Comparing with the result reported in Drath et al (2006), the result produced by our system has two additional features:

- The result table provides a comprehensive list of process components and their attached devices. The user also has the option of viewing only components that have cause and effect links that apply to them.
- The table provides more detailed classification of function performed.

![Figure 6 Cause & Effect Table in Excel for an extended P&ID based on Drath et al (2006)](image-url)
6. Conclusion

Carrying out safety analysis is important to prevent accidents and help in the design of control and protective systems for process plants. Control and sensor devices and their related control actions can be presented in a SAFT chart to help with the analysis process. A SAFT chart is also called a Cause & Effect (C&E) Table as it reflects information about process events and their corresponding safe guards.

An automated C&E analysis tool is introduced in this paper. Its components, working principles and data processing methods are described. The system consists of an Instrument Checker which prepares the data for analysis by identifying all the instruments and their attached process items and the process items and their attached instruments. A general purpose rule engine is used to build the knowledge-based system. The output from the rule engine is converted into C&E table in Excel and the layout of the table is compatible with ISO 10418 (ISO, 2003).

Acknowledgements

The research reported in this paper is supported by an EngD (Engineering Doctorate) studentship funded by the Engineering and Physical Sciences Research Council (EPSRC) and Hazid Technologies Ltd. The studentship is administrated by the CICE at Loughborough University.

Reference


