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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.

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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”.

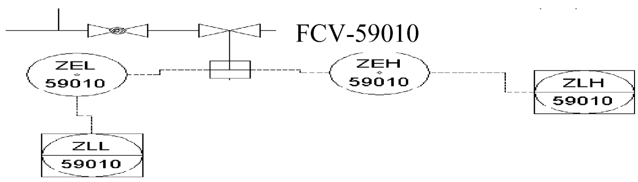

Figure 1. A simple instrument loop

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".

Instrument List

Loop	Item Tag	Item Type	Associated Deviation	Process Item	Response
59010	ZEH-59010	high level alarm	L+ , L0	test1001PU34-PU	isIndicator , isAlarm
59010	ZLH-59010	high level alarm	L+ , L0	test1001PU34-PU	isIndicator , isAlarm
59010	ZEL-59010	low level alarm	L- , L0	test1001PU34-PU	isAlarm
59010	ZLL-59010	low level alarm	L- , L0	test1001PU34-PU	isAlarm
59010	FCV-59010	cv body		test1001PU34-PU	isControl

Figure 2. Instrument List

Process Item List   Highlight in SP

Process Item Tag	Process Item Type	Instrument Tag	Instrument Name	Associated Deviation	Response
test1001PU34-PU	Primary Piping	ZEH-59010	high level alarm	L+ , L0	isIndicator , isAlarm
test1001PU34-PU	Primary Piping	ZLH-59010	high level alarm	L+ , L0	isIndicator , isAlarm
test1001PU34-PU	Primary Piping	ZEL-59010	low level alarm	L- , L0	isAlarm
test1001PU34-PU	Primary Piping	ZLL-59010	low level alarm	L- , L0	isAlarm
test1001PU34-PU	Primary Piping	FCV-59010	cv body		isControl

Figure 3. Process Item List

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 controlInstrumentTag='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.

	A	B	C	D	E	F	G	H	I	J	K
1	FIGURE SAFETY ANALYSIS FUNCTION EVALUATION CHART (SAFE)										
2						SHUTDOWN OIFUNCTION PERFORMED	open input control device:cv-body	close input control device:cv-body	open input control device:cv-body	open input control device:cv-body	
3							FCV-59010	FCV-59010	PCV-51001	XCV-51004	
4	PROCESS COMPONENT										
5	IDENTIFICATION	SERVICE	DEVICE IDENT	CAUSE COMMENT	CAUSE						
6	test1001PU34-PU	Primary Piping	ZEH-59010	Primary-Piping high level	level alarm high			X			
7			ZLH-59010	Primary-Piping high level	level alarm high			X			
8			ZEL-59010	Primary-Piping low level	level alarm low		X				
9			ZLL-59010	Primary-Piping low level	level alarm low		X				
10											

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.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
1	FIGURE SAFETY ANALYSIS FUNCTION EVALUATION CHART (SAFE)																								
2						FUNCTION PERFORMED	stop/close input control device :Generic-Centrifugal-pump	stop/close input control device :cv-body	stop/close input control device :cv-body	stop/close output control device: cv-body	stop/close input control device :cv-body	stop/close input control device :Generic-Centrifugal-pump	stop/close input control device :cv-body	stop/close output control device: cv-body	stop in-line control pump: Generic-Centrifugal-pump	open in-line control device:cv-body	stop in-line control pump: Generic-Centrifugal-pump	open in-line control device:cv-body	close input/ouput control device:cv-body	close input/ouput control device:cv-body	close input/ouput control device:cv-body	close input/ouput control device:Generic-Centrifugal-pump	close input/ouput control device:cv-body	close input/ouput control device:Generic-Centrifugal-pump	close input/ouput control device:cv-body
3						SHUTI	P-002	V-004	V-003	V-005	V-001	P-001	V-002	V-003	P-002	V-004	P-001	V-002	V-003	V-005	V-004	P-002	V-001	P-001	V-002
4	PROCESS COMPONENT																								
5	IDENTIFI	SERVICE	DEVICE IDENT	CAUSE COMMENT	CAUSE																				
6	B-1340	Blanketed Fixed Roof	LIS-201	Blanketed-Fixed-Roof	level alarm high						X	X	X												
7				Blanketed-Fixed-Roof	level alarm low									X											
8				Blanketed-Fixed-Roof	level-indicator error														X				X	X	X
9	B-1347	Blanketed Fixed Roof	LIS-202	Blanketed-Fixed-Roof	level alarm high		X	X	X																
10				Blanketed-Fixed-Roof	level alarm low					X															
11				Blanketed-Fixed-Roof	level-indicator error														X	X	X	X			
12	P-001	Generic Centrifugal pump	LIS-201																						
13		not attached to this proces	V-002	protecting pump:Gene	cv-body closed												X								
14		not attached to this proces	P-001	protecting pump:Gene	Generic-Centrifugal-pump started													X							
15	P-002	Generic Centrifugal pump	LIS-202																						
16		not attached to this proces	V-004	protecting pump:Gene	cv-body closed										X										
17		not attached to this proces	P-002	protecting pump:Gene	Generic-Centrifugal-pump started											X									

WholeResult / CauseEffectOnly

Figure 6 Cause & Effect Table in Excel for an extended P&ID based on Drath et al (2006)

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).

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