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RISK REDUCTION SUPPORT SYSTEM OF THE PHENOL RECOVERY PLANT

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Abstract
This paper presents process plant risk reduction support system modeling which including hazard identification, frequencies analysis, consequence analysis and hazard cost. The logic faults events tree and corresponding stochastic model were derived. The expression for remediation cost was defined. Process safety models help to build applications for loss prevention. As a case study the phenol plant for the phenol extraction by butyl-acetate was used. It purpose is to discover and locate the disturbance or faults which could lead to accidental situations. The obtained results indicate the influence of a single disturbance to registered symptoms, as well as to the safety of the whole plant. The paper illustrated management reduction support system for developing risk assessment interface and remediation cost analysis.

Keywords: fault event modeling, fault diagnosis, remediation cost

1. Introduction

Despite increased concern and safety standards, accidental situations throughout the industry occur, influencing very often large environmental damage. Regardless weather the reason for accidents is human error or technical failure, it is necessary to take an action in order to prevent them.

So many, accidents have been caused by operator's miss judgments or miss operation. There is a need to develop a system which can also suggest appropriate action to taken when a hazard occurs [1-5]. Process safety analysis begin with system idefinition. Definition includes system components, topology, input and output attributes, state variables, behavior rules and initial scenarios. Process safety analysis includes hazard identification, frequencies and probability analysis, consequence analysis and hazard cost analysis[6-7]. Hazard identification methods can be used in different ways to model part of the incident scenario leading to a possible accident[3]. A systematic cause event analysis gives the results which are summarized in the form of fault three. It follows the structure of a generic fault tree point to the release of materials, chemicals and of an event tree from this point to the release on people, the plant and the environment.

Frequency and probability analysis involves frequency values of hazards, magnitude identification of each hazard and develop of sound criteria for quantification of logic tree.

In this paper consequence modeling was developed troubleshooting system and formalizing hazard report as a learning tool and creates recommendation to correct hazard. The obtained results demonstrated successful application dispersion modeling in process risk reduction management.

2. Risk analysis of the phenol recovery plant

Phenol belongs to compound considered to be toxic in high concentrations. It can be absorbed through the skin, by inhalation, and swallowing. It occurs as a free component or as a compound in natural products, such as lignin.

Higher quantities of the phenol are formed in coking or low-temperature carbonization of wood, brown coal, or hard coal, as well as in oil cracking. It can be also synthetically produced and serves as a starting material for numerous intermediates and finished products. The major part of it is further processed into phenol-formaldehyde resins[8,9]. Processes for the phenol removal from wastewaters are extraction, steam distillation process based on the steam volatility of the phenol, adsorption on surface-active materials, such as activated carbon or ion exchanger resins, decomposition by oxidizing agents, such as hydrogen peroxide[10,11].

For extraction of the phenol from wastewaters several solvents can be used butyl-acetate, benzene, cumene, di-*izo*propylether and methyl- *izo*buthylketone.

The phenol recovery with butyl-acetate was considered as a case study. Purpose is to discover and locate the disturbances or faults which could lead to accidental situations. The considered system shown in Figure 1 is composed of numerous mutually connected units which can be classified in several group: tar-oil separator, phenol extraction, butyl-acetate recovery and phenol distillation.

3. A decision system for risk assessment analysis

Process safety analysis includes entities definition, projection, operation and diagnostics. Definition includes system components (type of units), topology (connection between units), inputs and outputs, attributes, state variables, behavior rules and initial scenarios.

Risk analysis involves hazard analysis, frequencies analysis, and consequence analysis. Hazard identification method can be used in different ways to model part of the incident scenario of possible accidents. Cause event analysis gives the results which are summarized in the form of a fault decision tree as shown in Figure 2.

The system can diagnose for causes of faults associated with state variables pressure, flow rate and temperature. The qualitative variables are described in three discrete values low, medium, high[1]. For diminishing the losses, a systematic cause-event analysis was made and the results of this was summarized in the form of fault tree. The attributes of the model are chosen to be pressure, supply, flow and resistance. Supply is described in two discrete values (present, absent).

Equipment state are described in qualitative term such as closed, open, failed, blocked and leak. The following block are considered: blockage, leakage, malfunction, or miss operation. The study of fault detection and diagnostic is concerned with designing system that can assist the human operator detecting and diagnosing equipment faults in order to present accidents.

Faults and actions should correspond to the changes in the state of equipment the following deviation in the system variables. When the leakage occurs in the Up Stream Unit-USU, the influence of leakage on USU can not be removed by closing the equipment. However, when the leakage occurs in the downstream unit DSU, the influence of leakage on DSU can be removed by closing the equipment.

Original model generates various scenarios. In the aim the completion of the qualitative simulation runs, a resultant symptom scenario matrix is formed. The interpretation and presentation means monitoring system symptoms. In the symptom decomposition phase, the relational symptom/scenario matrix is decomposed by using a projection operation to produce elementary relations. This projection operation delineates which scenarios were found to have the same symptom values in their final state.

Various scenarios of the process in Figure 1 are considered. Some of them are given in Table 1. The model characteristics for the case study includes over 50 scenarios and approximately 750 rules. Prolog programming language was chosen for the development simulation model.

This system for risk analysis is composed of several scenarios, enabling to predict the behavior of the considered plant in the case of a fault or some disturbance. As the state variables, pressure, flow, level, and temperature are defined, and their discrete values are described by appropriate attributes. In the moment when a symptom indicating a fault occurs in the system, some variables will get values different from initially defined.

The deviation indicates the disturbance, and comparison of the variable values makes identification of the faults possible, as well as its location. In this way, it is possible to identify faults leading to the accidental situations and to take an immediate response in order to prevent them.

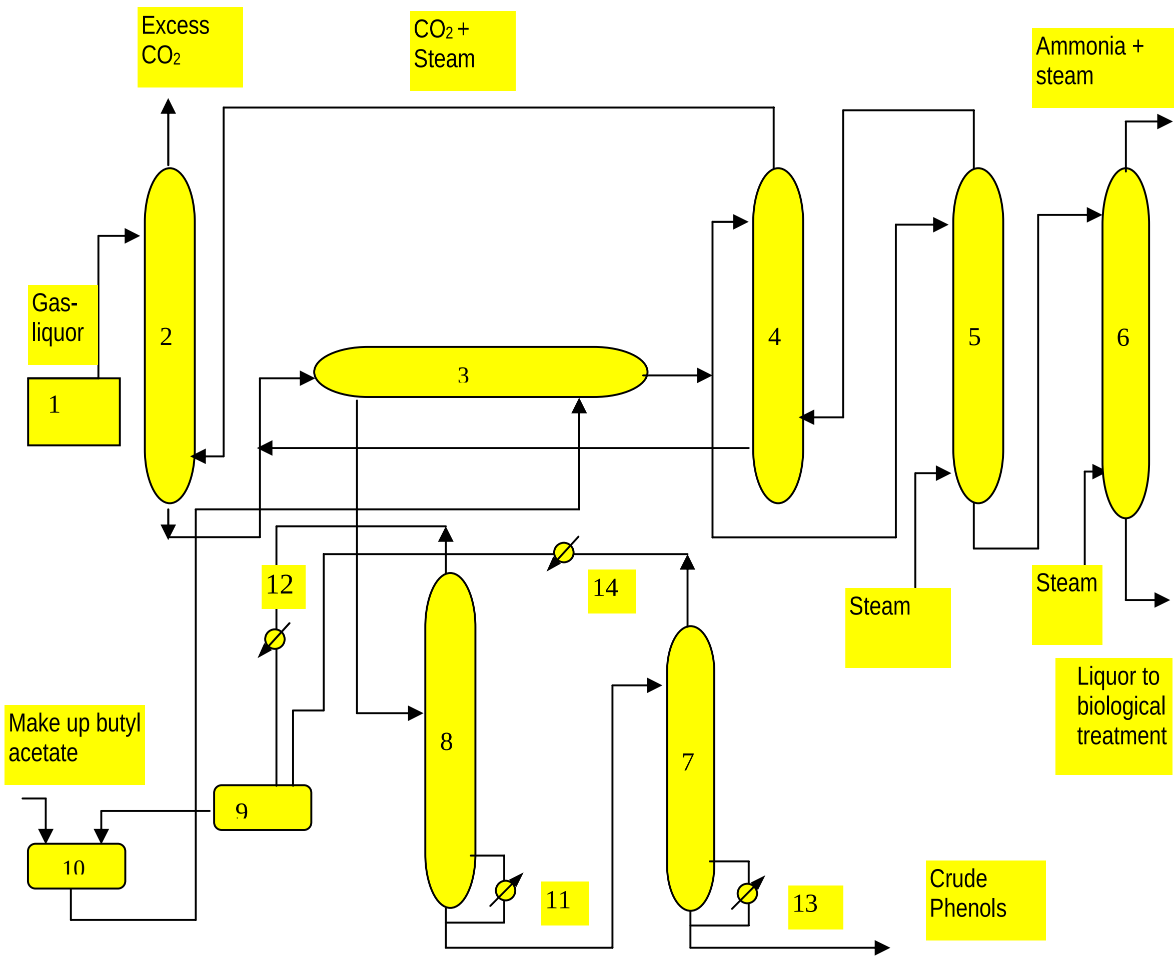

Figure 1. Phenol recovery plant. 1-Tar-oil separation; 2- Saturation tower; 3- Phenol extractor; 4- Butyl-acetate recovery tower; 5- Butyl-acetate stripping tower; 6- Ammonia stripping tower;7- Atmospheric distillation tower; 8- Vacuum distillation tower; 9- Separator drum; 10- Butyl-acetate circulating drum

Risk reduction support system

Model for risk analysis and prevention of accidental situation for phenol recovery plant is realized through development of a logical frame. Its knowledge base is composed of information streams, and database of occurred symptoms and faults at a single unit. The active logic flow operates by the use of rules in the knowledge base. The passive logic flow is the interface.

Table 1. Scenarios definition

Scenario	Changes of the state
1	Normal state
2	Tower (2) blocks
3	Tower (2) leaks
4	Phenol extractor (3) leaks
5	Phenol extractor (3) blocks
....	....
25	Tower (4) miss operation
26	Tower (5) leaks
27	Tower (6) blocks
28	Tower (6) leaks
29	Tower (5) miss operation
30	Tower (6) miss operation
....	...
39	Reboiler on the tower (11) malfunction
40	Cooler on the tower (12) malfunction
41	Tower (7) miss operation
42	Reboiler on the tower (13) malfunction
43	Cooler on the tower (14) malfunction
44	Tower (7) blocks
45	Tower (5) blocks
46	Tower (7) leaks
47	Tower (8) bocks
48	Tower (8) leaks
49	Separator drum(9) miss operation
50	Steam_absent
51	Butyl-acetate_ absent
52	Circulating drum (10) miss operation

For diagnostic purposes, scenarios are evaluated by means of monitoring system symptoms. This projection operation delineates which scenarios were found to have the same symptom values in their final state.

So many accidents have been caused by operator's miss judgments or miss operations there is need to develop a system which can also suggest appropriate action to be taken when a hazard occurs. Hazard cost analysis of the phenol recovery plant creates a resource allocation model by linking risk with the cost.

The qualitative fault tree shown in Figure 2 can be equivalent to the following system of Boolean expression equations(1).

4. The fault diagnosis model

The inductive events analysis according to faults tree in Figure 2 has given by system equations (1):

M, B and L are independent Boolean variables representing the basic events: malfunction, blockage, leakage, respectively. The cost fault assessment can be obtained from equations(1) by substituting the Boolean variables with the appropriate event frequencies linking faults with costs and using instead of the Boolean operators the probability of frequency operators. Model "what if " help to build process management applications for loss prevention.

Starting with the basic variables and their interrelations, the qualitative model of the system can be formulated successfully in the form of Boolean functions.

Table 2 shows frequencies of the basic faults events for the phenol plant from Figure 1. Inductive faults events was determined using Morgan's rule as has shown system equations(2)[6]. The system equations (1) has transformed easy into system equations (2).

Risk reduction support system is a decision support system which developing methods, tools, and techniques for developing the underlying functional aspects, solver/model management, rule management and artificial intelligence in coordinating a decision support systems functionality within its user interface.

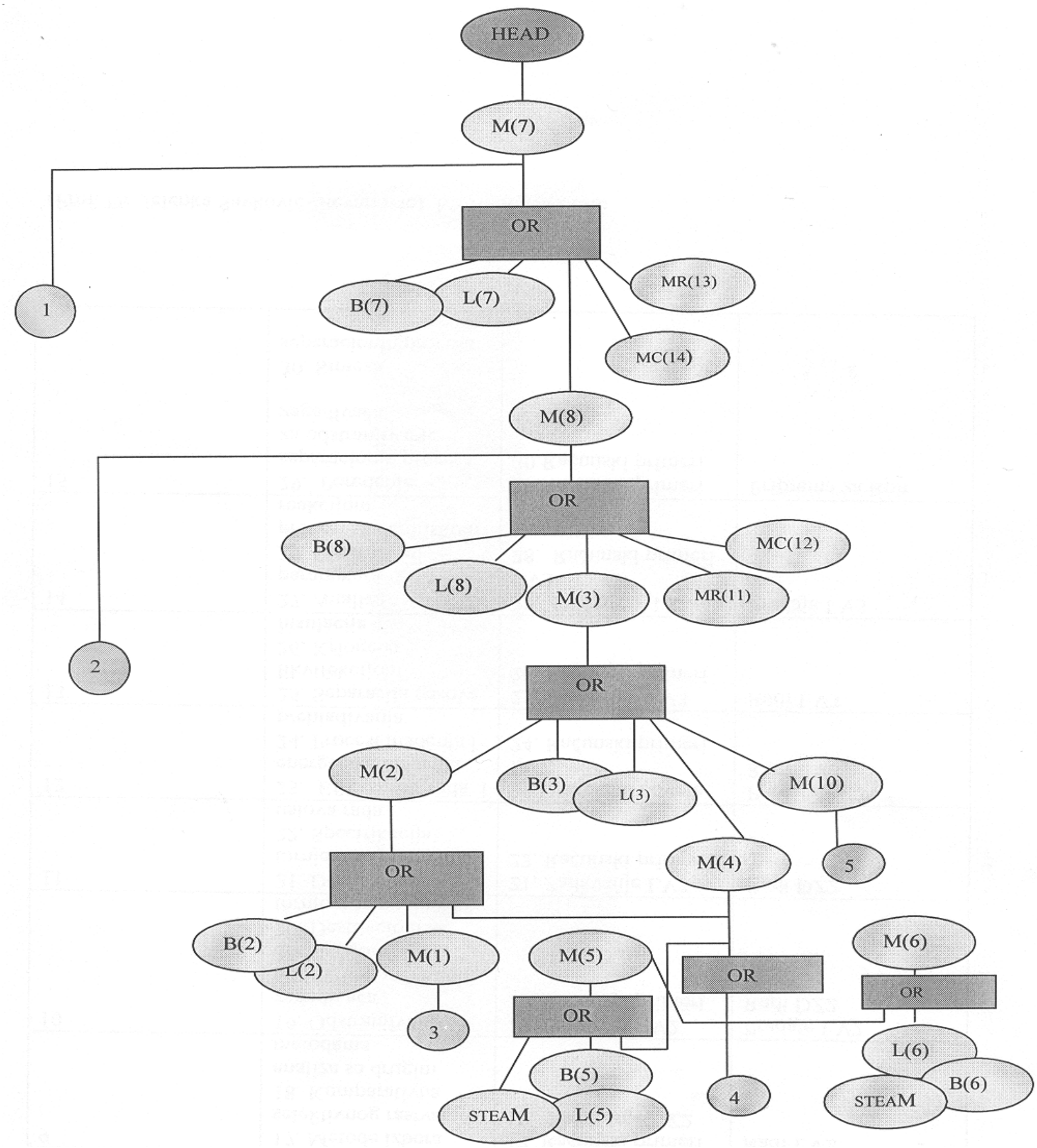

Figure 2. Risk diagnosis for the phenol recovery plant

$$HEAD = M(7)$$
$$M(7) = B(7) \cup L(7) \cup M(8) \cup M(13) \cup M(14)$$
$$M(8) = B(8) \cup L(8) \cup M(12) \cup M(11) \cup M(3)$$
$$M(3) = B(3) \cup L(3) \cup M(2) \cup M(4) \cup M(10)$$
$$M(4) = B(4) \cup L(4) \cup B(5) \cup L(5) \cup Steam\_ABSENT$$
$$M(5) = B(5) \cup L(5) \cup M(4) \cup Steam\_ABSENT$$
$$M(6) = B(6) \cup L(6) \cup M(5) \cup Steam\_ABSENT$$
$$M(9) = B(9) \cup L(9)$$
$$M(2) = B(2) \cup L(2) \cup M(1) \cup M(4)$$
$$M(1) = B(1) \cup L(1)$$
$$M(1)0 = B(10) \cup L(10) \cup M(9) \cup M(9) \cup Butylic\ Ac - ABSENT$$

Equations (1)

To make the qualitative model quantitative, the independent variables should be replaced by the relative frequencies of the events and the Boolean operators AND and OR should be replaced by the algebraic functions which producing the output frequency from the input frequencies.

$$pHEAD = 1 - pM(7)$$
$$pM(7) = 1-(1-pB(7))(1-pL(7)))(1-pM(8))(1-pM(13))(1-pM(14))$$
$$pM(8) = 1-(1-pB(8))(1-pL(8))(1-pM(12))(1-pM(11))(1-pM(3))$$
$$pM(3) = 1-(1-pB(3))(1-pL(3))(1-pM(2))(1-pM(4))(1-pM(10))$$
$$pM(4) = 1-(1-pB(4))(1-pL(4))(1-pB(5))(1-pL(5))(1-pSteam\_ABSENT)$$
$$pM(5) = 1-(1-pB(5))(1-pL(5))(1-pM(4))(1-pSteam\_ABSENT)$$
$$pM(6) = 1-(1-pB(6))(1-pL(6))(1-pM(5))(1-pSteam\_ABSENT)$$
$$pM(9) = 1-(1-pB(9))(1-pL(9))$$
$$pM(2) = 1-(1-pB(2))(1-pL(2))(1-pM(1))(1-pM(4))$$
$$pM(1) = 1-(1-pB(1))(1-pL(1))$$
$$pM(10) = 1-(1-pB(10))(1-pL(10))(1-pM(9))(1-pButylic\ Ac - ABSENT)$$

Equations (2)

The cost fault assessment was obtained by substituting the Boolean variables with the appropriate event frequencies linking faults with costs.

Table 2. Frequencies of the basic events

Event code	Middle frequency	Description
M(1)	0.0003	Tar/oil separator
M(2)	0.0003	Saturation tower
M(3)	0.0015	Phenol extractor
M(4)	0.0004	Butyl acetate recovery tower
M(5)	0.0004	Butyl acetate stripping tower
M(6)	0.0004	Ammonia stripping tower
M(7)	0.0004	Atmospheric tower
M(8)	0.0015	Vacuum distillation tower

Event code	Middle frequency	Description
M(9)	0.0003	Separation drum
M(10)	0.0003	Butyl acetate circulating drum
L(1)	0.0004	Tar/oil separator
L(2)	0.0004	Saturation tower
L(3)	0.0004	Phenol extractor
L(4)	0.0004	Butyl acetate recovery tower
L(5)	0.0004	Butyl acetate stripping tower
L(6)	0.0004	Ammonia stripping tower
L(7)	0.0004	Atmospheric tower
L(8)	0.0004	Vacuum distillation tower
L(10)	0.0004	Butyl acetate circulating drum
B(1)	0.0004	Tar/oil separator
B(2)	0.0004	Saturation tower
B(3)	0.0004	Phenol extractor
B(4)	0.0004	Butyl acetate recovery tower
B(5)	0.0004	Butyl acetate stripping tower
B(6)	0.0004	Ammonia stripping tower
B(7)	0.0004	Atmospheric tower
B(8)	0.0004	Vacuum distillation tower
B(9)	0.0004	Separation drum
B(10)	0.0004	Butyl acetate circulating drum

Fault occurring frequencies and their linking with costs are given by equations(3) and (4)

$$unit\ \ of\ \ the\ \ middle\ \ frequency = \frac{number\ \ of\ \ faults}{10^4\, hours} \qquad (3)$$

$$Cost = \frac{unit\ \ of\ \ the\ \ middle\ \ frequency}{\cos t\ \ unit} \qquad (4)$$

$$R_c = aP^b C^c \qquad (5)$$

where *P* is middle frequency of the fault and *C* is cost th fault occuring, and *a,b* and *c* are parameters.

5. Results and discussions

The developed risk reduction support system is composed of numerous scenarios, enabling to predict the behavior of the considered plant in the case of a fault or some disturbance. In the moment when a symptom indicating a fault occurs in the system, some variables will get values different from initially defined. This deviation indicates the disturbance, and comparison of the variable values makes identification of the fault possible as well as its location. Fault event analysis was developed as has shown in Figure 2 and equations.(1). The fault assessment was obtained by equations(2). Linking fault with costs are shown by equations (4) and (5), and remediation costs is given by equation(5).

6. Conclusions

The obtained results are shown successfully application logic and stochastic modeling in process plant risk analysis. This paper illustrated risk reduction system linking faults with cost damage and remediation cost. The presented risk reduction support system can be used as a supervising system during accidental situations. This system is linking qualitative and quantitative information through the networking qualitative faults events model and quantitative model. These results indicate the influence of a single disturbance to registered symptoms, as well as to the safety of the whole plant. The fault assessment and remediation costs determination methods were illustrated. The obtained results can be applied in other domains.

Symbols

a, b, c - parameters
B-blockage
C- cost
F-middle frequency
L-Leakage
M- malfunction or miss operation
P- frequency
R_c-remediation cost

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