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Cognitive Reliability Analysis of the Process Plant

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Abstract

A cognitive model which includes qualitative and quantitative information processing was derived in this paper. Process safety analysis which including qualitative fault event identification, relative frequencies and event probability function as well as consequence analysis was provided. As a case study, the successful application of cognitive modeling is made to process reliability analysis. For accidents detection the cognitive model forecasted the future behaviour of the system and than compared this with the actual situation. The obtained results illustrated a useful estimation of the system behaviour during abnormal situation. This paper is the first report in the literature showing the information flux unit.

Keywords: Information flux, cognitive modeling, fault event analysis, frequency

1. Introduction

Methods for analyzing system safety and the synthesis for the construction of fault Tolerant system are of elementary importance for equipment in the chemical industries. Process safety analysis begins with plant, materials and environmental definition. It includes system components, topology, input and output attributes, state variables, behavior rules and initial scenarios. The control features are qualitative variables description and logic rules for manipulating variables values between systematic states.

The goal of process cognitive reliability analysis is to capture the benefits of common sense reasoning about process malfunction as displayed in human behavior (Savkovic-Stevanovic, 2004 (a), 2004 (b), 2004 (c)). The study of fault detection and diagnosis is concerned with designing that can assist the human operator is detecting and diagnosing equipment faults in order to present accidents (Savkovic-Stevanovic, 1992 and 1994). As case study the ammonia production plant was used. Industrial activities related to ammonia production and processing. The considered system is composed of numerous mutually connected process units: scrubbers, converters, pumps, compressors, coolers, heaters, tank storage and streams.

2. Frequencies and Probability Analysys

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Frequency and probability analysis involve frequency values of hazards, magnitude identification of each hazard and development a sound criteria for quantification of logic reliability tree.

All hazard, major and minor need to involve. The relationship between hazard and risk must be defined. Consequences modeling develops troubleshooting system formalizing as a learning tool and creates recommendation to tolerant system building. Method for reliability analysis was worked out based on logic algebra and probability theory. A number of methods for safety analysis were worked out based on the classical results of Boolean algebra, probability theory and fuzzy logic algebra.

The fault event of a system are in the first instance generally formulated in an if-then form. This can be immediately reformulated using the operators AND, OR NOT in Boolean form, if one can assume that the primary events have only two states existence and non-existence.

Starting with the basic variables and their interrelations, the qualitative event model of the system can be formulated successively in the form of Boolean functions. To make the qualitative model quantitative, the independent variables should be replaced by relative frequencies of the events pi , Boolean operators AND and OR should be replaced by the algebraic functions (operators) AND(p1 , p2, pn) and OR (p1 , p2 , pn) producing the output frequency py from the input frequencies p1 , p2 , pn .

The following faults are considered: blockage, leakage, malfunction or miss-operation. The study of fault detection and diagnostic is concerned with designing that can assist the human operator detecting and diagnosing equipment faults in order to prevent accidents system.

The qualitative fault tree and corresponding qualitative model was derived for ammonia plant system Eqs(1). This system represents qualitative events model expressed by logic algebra. M, B, and L are independent logic variables representing the basic events malfunction, blockage and leakage, respectively. Frequencies of the basic events are defined in Table 1. Frequencies of induced events are derived based on frequencies of the basic events. The reliability model was derived by substituting for the logic variables the appropriate event frequencies and using instead of the logic operators (Boolean or fuzzy) the probability frequency operators as shows system Eqs(3).

3. Description of the Case Study

As a case study production of the ammonia has been chosen (Figure 1). The plant consists of a ammonia converter, ammonia storage tank, centrifugal circulator, nitrogen wash tower, four scrubbers, exchanger liquid N2/O2, shift converter, two dryers, one gas -fired preheated, gas generator, two chiller coolers and two coolers as well as four reciprocating compressors.

Also, the system can diagnose for causes of faults associated with state variables pressures, flow rates and temperatures. The qualitative variables are described in three discrete values low, medium and high. Equipment states are also described inqualitative term such as closed, open, failed, blocked and leak. The following faults are considered: blockage, leakage, malfunction or miss operation.

4. The Ammonia Plant Reliability Analysys

The system topology or component interconnections are defined by the process connections of the working process model. The level of aggregation is defined by themodular component interconnections which define propagation paths of attributes within the system. C++ programming language was chosen for the development simulation model.
The qualitative event model is given by expression (1). The quantitative reliability model is derived according expression (3). The system equations can be easy solved for all unknown frequencies using the values of the frequencies of the basic events given in Table 1.The crisp values of the basic frequencies figuring in Table 1 should be considered as the best estimated. The unit of the middle frequency of the basic events in the number if faults per 104 hours.
For the fuzzy analysis of the event tree, the Boolean operators were replaced by the fuzzy frequency operators ORF (...) and ANF(. ...) . The fuzzy reliability model is given by expression (2).

The qualitative model event equations:

HEAD = AST
AST = B(AST) ∪ L(AST) ∪ M(C1) ∪ M(C2) ∪ AC
AC = B(AC) ∪ L(AC) ∪ M(CM4)
M(C2) = AC ∪ M(P) ∪ M(CM4)
M(CM4)= CM3 ∪ N2T
N2T = L(N2T) ∪ B(N2T) ∪ M(DR2) ∪ M(CC2) ∪ SC4 ∪ SC3
SC4 = L(SC4) ∪ B(SC4) ∪ SC3
SC3 = L(SC3) ∪ B(SC3) ∪ SCON
SCON = L(SCON) ∪ B(SCON) ∪ S(STEAM) ∪ SC2
SC2 = L(SC2) ∪ B(SC2) ∪ S(CAUS) ∪ M(G) ∪ M(PH) ∪ CM2)
CM2 =M(CM2) ∪ S(NAT.GAS)
CM3 = M(CM3) ∪ EXC
EXC = L(EXC) ∪ B(EXC) ∪ $M(CM_E)$ ∪ ET ∪ DR1
ET = L(ET) ∪ B(ET)
DR1 = M(DR1) ∪ M(CC1) ∪ M(CM1) ∪ SC1
SC1 = L(SC1) ∪ B(SC1) ∪ S(AIR) ∪ S (CAUSTIC) (1)

The corresponding fuzzy reliability model:

HEAD = AST
AST = ORF(B(AST), L(AST), M(C1), M(C2), AC)
AC = ORF(B(AC), L(AC), M(CM4))
M(C2) = ORF(AC, M(P), M(CM4))
M(CM4)=ORF(CM3, N2T)
N2T = ORF(L(N2T), B(N2T), M(DR2), M(CC2), SC4, SC3)
SC4 = ORF(L(SC4) ,B(SC4), SC3)
SC3 = ORF(L(SC3), B(SC3), SCON)
SCON = ORF(L(SCON), B(SCON), S(STEAM), SC2)

SC2 = ORF(L(SC2), B(SC2), S(CAUS), M(G), M(PH), CM2

CM2 =ORF(M(CM2), S(NATGAS))

CM3 = ORF(M(CM3), EXC)

EXC = ORF(L(EXC), B(EXC), M(CM_E), ET, DR1)

ET = ORF(L(ET), B(ET))

DR1 = ORF(M(DR1), M(CC1), M(CM1), SC1)

SC1 = ORF(L(SC1), B(SC1), S(AIR), S(CAUSTIC)) (2)

The quantitative reliabiliy model:

pHEAD = 1-pAST

pAST = 1-(1-pB(AST)) (1-p L(AST))(1-pM(C1))(1- pM(C2)) (1- pAC)

pAC = 1-(1- pB(AC))(1-pL(AC)) (1-pM(CM4))

pM(C2) = 1-(1-pAC) (1-pM(P)) (1-pM(CM

pM(CM4)= 1-(1-pCM3)(1-p N2T)

pN2T = 1-(1-pL(N2T)),(1-p B(N2T))(1-p M(DR2)) (1-pM(CC2))(1-p SC4) (1-pSC3)

pSC4 =1-(1-pL(SC4)) (1-pB(SC4)) (1-pSC3)

pSC3 = 1-(1-pL(SC3)) (1-pB(SC3)) (1-pSCON)

pSCON = 1-(1-pL(SCON))(1-pB(SCON))(1-p S(STEAM) (1-pSC2)

pSC2 = 1-(1-pL(SC2))(1-p B(SC2)) (1-pS(CAUS))(1-p M(G)) (1-pM(PH)) (1-pCM2)

pCM2 =1-(1-pM(CM2))(1-p S(NAT.GAS))

pCM3 = 1-(1-pM(CM3))(1-p EXC)

pEXC =1-(1-p L(EXC)) (1-pB(EXC))(1-p M(CM_E)) (1-pET)(1-p DR1)

pET = 1-(1-p L(ET))(p B(ET))

pDR1 = 1-(1-p M(DR1)) (1-pM(CC1))(1-pM(CM1))(1-pSC1)

pSC1 =1-(1-p L(SC1)) (1-pB(SC1))(1-pS(AIR))(1-pS (CAUSTIC)) (3)

Table 1. Frequencies of the basic events

Event code	Middle frequency	Description
M(PH)	0.0003	Malfunction of a preheater
M(CC)	0.0002	Malfunction of a chiller cooler
M(C)	0.0002	Malfunction of a cooler
M(DR)	0.0003	Malfunction of a dryer
M(P)	0.0004	Malfunction of a pump
M(CM)	0.0004	Malfunction of a compressor
M(G)	0.0005	Malfunction of a gas generator
	0.0015	Air supply
S(CAUSTIC)	0.0014	Caustic supply
S(N.GAS)	0.0015	Natural gas supply
S(STEAM)	0.0009	Steam supply
LAST	0.0019	Leakage of the ammonia tank
BAST	0.0009	Blockage of the ammonia tank
LAC	0.0006	Leackage of the ammonia converter

BAC	0.0011	Blockage of the ammonia converter
LN2T	0.0009	Leackage of the nitrogen tower
BN2T	0.0005	Blockage of the nitogen tower
LSC	0.0009	Leackage of a scrubber
BSC	0.0005	Blockage of a scrubber
LSCON	0.0009	Leackage of the shift converter
BCON	0.0006	Blockage of the shift converter
LET	0.0011	Leackage of the expander tower
BET	0.0009	Blockage of the expander tower
LEXC	0.0011	Leackage of a exchanger
BEXC	0.0009	Blockage of a exchanger

5. The Cognitive Model

The quality of a structural relationship is determined through entropy of the state transition matrix, which determines its forecasting power over a single step (Savkovic-Stevanovic,2004(b)).

New formed information value is:

$$I_{v\,(new)} = H = -\sum_{1}^{n} p_i \log_2 p_i \qquad (4)$$

where I_v new information value, H entropy of new information value and p probability of scenario occurring.

$$\Phi_i = I_v / N \; x \; t \qquad (5)$$

where N number of sequencies, t time and Φ_i information flux, *Byte/s.*

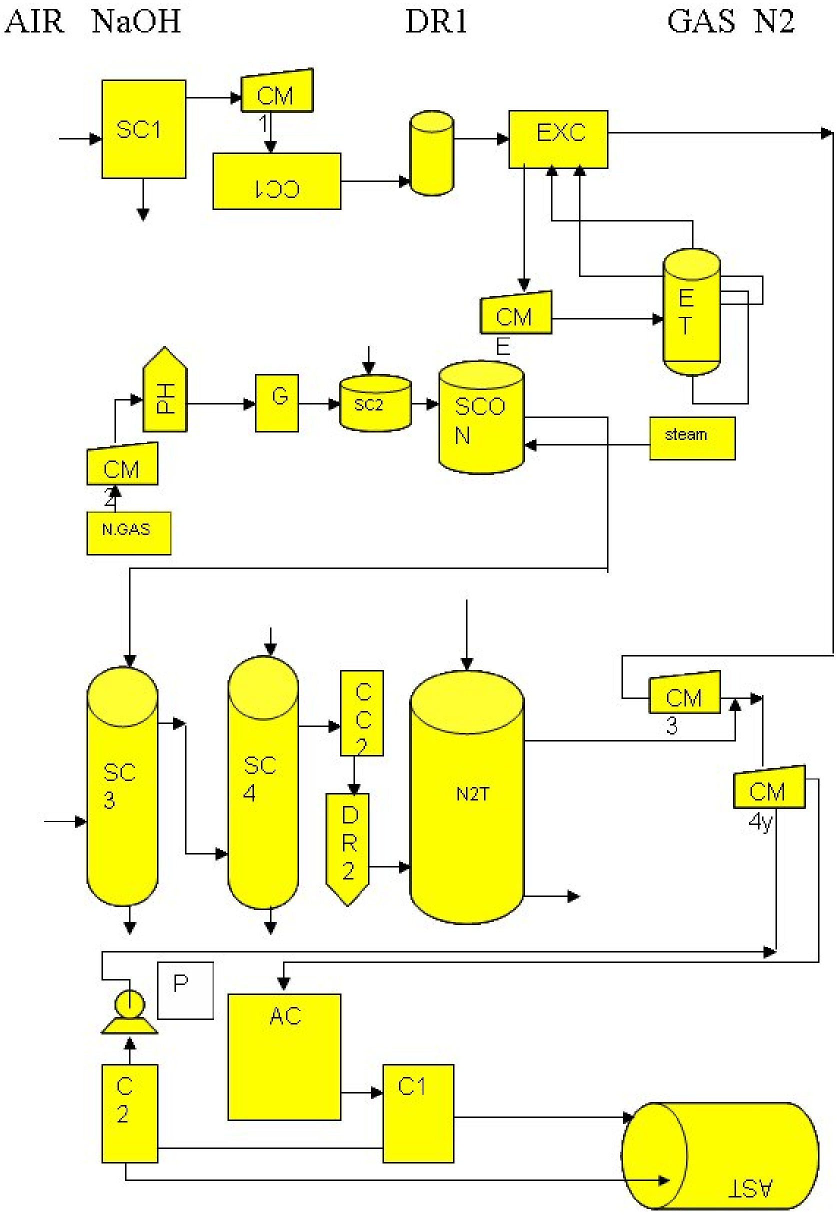

Figure 1. Ammonia production plant

6. Conclusions

This paper illustrates hazard identification, frequencies and probability rules and reliability analysis for the ammonia production plant. The simulator for reliability system and prevention of accidental situation is realized through development of logical frame. Its knowledge base is composed of information streams and equipment units, and database is composed of occurred events and faults at a single unit and process variable state data. This paper describes the new information value obtaining from information streams. If the difference in information between scenarios is high, and the amount of time needed to observe this symptom is low, then the information value of the tested symptom is high. The obtained results have shown successful application cognitive dispersion modeling for process reliability analysis. Expression for information flux was derived.

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Notation

Φ -information flux, Byte/s
I- information value, Byte
H- uncertainty (entropy)
p- probability

Abbreviation

AC- ammonia converter	C- cooler	CM-compressor
AST-ammonia storage tank	CC - chillercooler	P-pump
SC-scrubber	DR - dryer	PH-preheater
SCON-shift converter	ET- expander tower	N2T-nitogen tower

1.1.1.1 EXC-exchanger G-gas generator

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