DEVELOPMENT OF MATHEMATICAL MODELS FOR QUANTITATIVE RISK AND SAFETY ASSESSMENT IN OIL AND GAS REFINERIES

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LIST OF SYMBOLS

$\Pr(HE)_A$	Probability of human error in actual company
$\Pr(HE)_O$	Probability of human error from original company
S_K	Skills and knowledge
Y_W	Years of work
A_{ac}	Adequate Atmospheric condition
A_s	Appropriate safety equipment
A_t	Available Time
A_{tc}	Adequate Thermal Condition
A_w	Adequate Working Environment
F_n	Formation before starting new task
H_R	Human reliability level
P_w	Physical Working Environment
S_a	Safety
S_t	Stress
W_p	Work Pressure
W_p	Work Pressure
w_i	Weights

LIST OF ABBREVIATIONS

AHP	Analytic Hierarchy Process
AIChE	American Institute of Chemical Engineers
ALARP	As Low As Reasonably Practicable
AMDEC	Analysis of Failure Modes, Effects and Criticality
BE	Basic Event
BHF	Basic Human Factor
BLEVE	A boiling liquid expanding vapor explosion
BSBN	Bayesian Statistics and Bayes Nets
C	Consequences
CCPS	Center of Chemical Process Safety
CE	Critical Event
CHAIR	Construction Hazard Assessment Implication Review
CSB	Chemical Safety Board
D	Darkness
E	Event
E_x	Experience
ETA	Event Tree Analysis
F	Formation
FARADIP	Failure Rate Data In Perspective
fLOPA	Fuzzy Layer Of Protection Analysis
FMEA	Failure Mode and Effects Analysis
FMECA	Failure Modes, Effects and Criticality Analysis
FN	Frequency Number

FP	Failure Probability
FTA	Fault Tree Analysis
FUV	Fuzzy Utility Value
H	Humidity
HAZAN	Hazard analysis
HAZOP	Hazard and operability study
HEA	Human error analysis
HEP	Human Error Probability
HF	Human Factors
I	Instructions
IE	Initiating Event
IEEE	Institute of Electrical and Electronics Engineers standard
IF	Intermediate Factor
IFL	Intermediate Factor Level
IFLA	Intermediate Factor Level Actual
IFLO	Intermediate Factor Level Origin
IHF	Intermediate Human Factor
IHF	Intermediate Human Factor
IPL	Independent Protection Layer
JHA	Job Hazard Analysis
JSA	Job Safety Analysis
KHALFI	Characteristic of Hazard Analysis based on Logic Factors Identification
LOPA	Layer Of Protection Analysis
MCS	Minimal Cut Set
N	Noisiness

OE	Output (Outcome) event
OREDA	Offshore Reliability Data
OT	Occurrence Time
PFD	Probability of Failure on Demand
pfLOPA	Piping Fuzzy Layer Of Protection
PHA	Process Hazard Analysis
PHA	Preliminary Hazard Analysis
PL	Probability Lower
PM	Probability Median
Pr	Probability
Pr(EA)	Probability of Event Actual
Pr(EO)	Probability of Event Origin
PROBIST	Probability Binary State
PRODET	Probability Determination
PU	Probability Upper
QRA	Quantitative Risk Analysis
RAS	Representive Accident Scenario
RDB	Reliability Block Diagram
REGUIA	Reliability Guide Analysis
RM	Risk Matrix
SIL	Safety Integrity Level
SIS	Safety Instrumented System
SQRA	Semi-Quantitative Risk Analysis
T_r	Training
T	Temperature

TE	Top Event
THF	Top Human Factor
UVCE	Unconfined Vapour Cloud Explosion
V	Verification
WRAC	Workplace Risk Assessment and Control
WS	Wind speed
$HRL_{A/O}$	Human Reliability Level Actual /Original

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ABSTRACT

Risk assessment is a systematic process to identify hazards, analyze and evaluate the risks associated with hazards that can harm the workers, people, environment or properties using qualitative, semi-quantitative or quantitative approach to determine the appropriate ways to eliminate or control the hazards. Quantitative risk assessment (QRA) is an effective approach used in petrochemical industries to estimate the likelihood of an accident and the severity of its consequence. However, uncertainty is still the main problem faces quantitative risk assessment in spite of its significant progress. Therefore, this thesis proposes mathematical models to address the uncertainties of quantitative risk assessment as follows: i) reliability guide analysis (REGUIA) is developed to identify the main components of accident scenarios and to determine the factors which can affect the failure probabilities, ii) human reliability model based on five matrices with mathematical equations is developed to determine the level of human reliability and to precise probability of human error, iii) characteristics of hazard analysis based on logic factors intermediates (KHALFI), linear and nonlinear models are three models developed to determine the failure probability of the events at any geographical location, considering the factors: temperature, humidity and wind speed where root mean square error (RMSE) of the three developed models are 2.38E-5, 2.10 and 1.94, respectively, iv) risk and safety models to analyze the accident scenarios based on Bowtie method and Bayesian network with new classification of safety integrity level with mathematical equation are developed, v) probability binary state is employed to define the range of failure probability, vi) probability determination (PRODET) is a mathematical model developed in this study to determine the exact probability of the equipment at the specific operation time, vii) occurrence time (OT) is also developed to find the required time for the event to occur, viii) risk matrix model with mathematical equations are developed to compute the level of risk. Finally, Simulink model is developed to implement the developed models to automate the calculation and to facilitate the analysis of the results with graphical representation of the inputs and the outputs. The results show plausible and reliability of the models and demonstrate that the developed models are more reliable and precise than the classical models. The results of risk and safety analyses revealed that 86% of the basic events on average gained 180% increased reliability.

ABSTRAK

Penilaian risiko adalah satu proses yang sistematik untuk mengenal pasti bahaya, menganalisis dan menilai risiko yang berkaitan dengan bahaya yang boleh menjejaskan pekerja, alam sekitar atau harta dengan menggunakan pendekatan kualitatif, semi-kuantitatif atau kuantitatif untuk menentukan cara-cara yang sesuai bagi menghapuskan atau mengawal bahaya. Pendekatan kuantitatif adalah yang terbaik untuk penilaian keselamatan risiko dan memperolehi kebarangkalian serta potensi risiko yang lebih tepat menggunakan model matematik. Penilaian risiko kuantitatif telah terbukti penting untuk mengelakkan dari terdedah kepada bahan-bahan berbahaya dalam industri minyak dan gas. Walau bagaimanapun, ketidaktentuan data dan model masih menjadi masalah utama dalam menghadapi penilaian risiko secara kuantitatif. Oleh itu, tesis ini mencadangkan model matematik untuk menangani ketidaktentuan penilaian risiko kuantitatif seperti berikut: i) analisis panduan kebolehpercayaan (REGUIA) dibangunkan untuk mengenal pasti komponen utama senario kemalangan dan untuk menentukan faktor-faktor yang boleh memberi kesan kepada kebarangkalian kegagalan, ii) model kebolehpercayaan terhadap manusia berdasarkan lima matriks dengan persamaan matematik dibangunkan untuk menentukan tahap kebolehpercayaan terhadap manusia dan juga kebarangkalian lebih tepat terhadap kesilapan manusia, iii) ciri-ciri analisis bahaya berdasarkan logik faktor perantaraan (KHALFI), model lelurus dan model tak lelurus merupakan tiga model yang dibangunkan untuk menentukan kebarangkalian kegagalan peristiwa-peristiwa di mana-mana lokasi geografi, dengan mengambil kira faktor: suhu, kelembapan dan kelajuan angin di mana punca-min-ralat persegi (RMSE) daripada tiga model yang dibangunkan ialah 2.38E-5, 2.10 dan 1.94, iv) membangunkan model risiko dan keselamatan kelembapan dan kelajuan angin untuk menganalisis senario kemalangan berdasarkan kaedah Bowtie dan rangkaian Bayesian dengan klasifikasi baru tahap integriti keselamatan dengan persamaan matematik, v) binari digunakan untuk menentukan pelbagai kegagalan kebarangkalian, vi) kebarangkalian penentuan (PRODET) adalah model matematik yang dibangunkan dalam kajian ini untuk menentukan kebarangkalian yang tepat semasa operasi tertentu, vii) kejadian masa (OT) juga dibangunkan untuk mencari masa yang diperlukan untuk sesuatu process, viii) model matriks risiko dengan persamaan matematik yang dibangunkan untuk mengira tahap risiko. Akhir sekali, model Simulink dibangunkan untuk melaksanakan model yang dibangunkan untuk mengautomasikan pengiraan dan untuk memudahkan analisis keputusan dengan perwakilan grafik input dan output. Keputusan menunjukkan munasabah dan kebolehpercayaan model dan menunjukkan bahawa model yang dibangunkan adalah lebih dipercayai dan tepat daripada model klasik. Keputusan analisis risiko dan keselamatan menunjukkan bahawa 86% daripada aktiviti asas secara purata mendapat 180% peningkatan kebolehpercayaan.