

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 |

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

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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 lurus dan model tak lurus 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.