RISK CONSEQUENCES ASSESSMENT OF GAS PIPELINE FAILURE INCORPORATING LOCAL LOSS FACTORS

NORHAMIMI BINTI MOHD HANAFIAH

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Faculty of Engineering
Universiti Teknologi Malaysia

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DEDICATION

In the name of ALLAH, the Most Gracious, Most Beneficent. I dedicate this thesis special from the bottom of my heart to: My beloved husband for his unconditional love, patients and never ending support…Ahmad Izad Bin Ahmad Shokree My beautiful daughter and adorable son.. Amna Iman and Ahmad Iyad; … My beloved parent for their trust and never giving up on me… Normah Abdul Fatah (Mama) and Mohd Hanafiah Asari (Ayah) … My dear siblings who always endlessly supports me… Norhana (Kak Ana), Norhani (Kak ani), Mohd Shahrizman (Abg Man), Nornabilah (Bilot), Late Mohd Norhaniff (Haniff), Mohd Norhaziq (Haziq) and Zulkifly (Dekzul)… My lovely family in-laws for their support and never giving up on me…Ahmad Shokree (Abah), Faridah (Mak) Haffiz (Angah), Siti Adilah (Dila), Mohd Iqbal (Achik), Hazirah Hanis (Anis), Nur Asmida (Asmida);… My playfull nieces and nephews who motivates me… Jauhar Rhea Nabiha, Jauhar Elya Nafeesa, Jauhar Ayna Nadjwa, Nur Husna Hani, Mohd Aqil Haniff. Nur Hasya Huda, Muhammad Al-Fateh, Muhammad Nazran, Nur Syafia, Siti Aisyah Humaira, Siti Aliah Hafizah, Muhammad Adam; …My super awesome supervisors who always trust me and inspire me.. Professor Dr. Nordin Yahaya, Associate Professor Dr. Norhazilan Md. Noor and Dr. Libriati Zardasti. Thank you for everything. May ALLAH bless and grant us Jannatul Ferdous.

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ABSTRACT

Risk consequence assessment of gas pipeline damage is normally conducted to determine the losses of a failure event such as human, asset, production, public necessities and environmental loss. The current practice of pipeline risk consequences assessment is considered imprecise due to exclusion of the local loss factors, which led to the deterioration of the quality of estimated risk. As a result, the calculated consequences generate an equal risk value to any areas of the buried pipeline throughout the country regardless of the area's unique loss factors and consequences values. This study presents three separate risk consequences models to assess seven different sites which cover rural and urban areas. Similar frameworks are used for all the models but differ in terms of analyses and procedures in the assessment, to generate the risk ranking. $Model_1$ involved quantification of direct summation of all possible losses in terms of monetary value which is highly demanded by the industry. $Model_2$ deployed the use of the Fuzzy Analytic Network Process, Super Decision software and Complex Proportional Assessment (COPRAS) analysis procedure. Lastly, $Model_3$ utilised a series of Survey Analyses that provides outcome as priority vectors for each loss factors. In order to assess the validation of the developed models, the overall risk ranking category was calculated by comparing the obtained results of all models with the existing technical standard which is Pipeline Technical Guideline (PTG11.36.04). Results show percentage difference of 28.6 %, 57.1% and 17.14% for $Model_1$, $Model_2$, and $Model_3$, respectively. The difference can be observed spectacularly on sites with high scores of the public loss value, environmental loss factors considered in the assessment as well as classification of the selected areas. The finding shows significant differences of risk between the existing technical standard and the proposed models. However, $Model_3$ provided the lowest percentage difference can be considered as the most comprehensive and representative model because it involves prioritization of each loss factor in every loss category in monetary form. Through structured model validation and result verification process, the findings indicated that all models are considered comprehensive, fulfilled the objective, reliable, well-defined and practical. In conclusion, this research outcome is possible to be merged with existing technical standards towards the development of automated intelligent Pipeline Integrity Management System (i-PIMS). Consequently, these models are capable of prolonging the long-term integrity of pipeline assessments and simultaneously securing the pipeline owner’s annual profit margins.

ABSTRAK

Penilaian risiko akibat kegagalan saluran paip biasanya dijalankan untuk menghitung kesan kerugian seperti kematian manusia, kehilangan aset, gangguan pengeluaran, kerosakan kemudahan awam dan kerosakan alam sekitar. Piawaian sedia ada dalam menilai kesan kerugian letupan saluran paip gas dianggap tidak tepat kerana terdapat kekangan dalam mempertimbangkan faktor tempatan yang menjurus kepada kemerosotan kualiti risiko yang dinilai. Dengan itu, kesan kerugian yang dihitung adalah sama pada mana-mana bahagian saluran paip yang ditanam di seluruh negara tanpa mengambil kira faktor tempatan yang unik pada setiap tempat dan nilai kesan daipada kegagalan tersebut. Kajian ini membentangkan tiga jenis model penilaian risiko untuk menilai tujuh tapak kajian yang meliputi kawasan bandar dan luar bandar. Kerangka model yang hampir sama digunakan untuk setiap model tetapi berbeza dari segi analisis dan prosedur didalam penilaian untuk menilai tahap risiko. Model1 melibatkan perjumlahan langsung daripada semua kehilangan yang berpotensi terlibat dengan menggunakan kuantifikasi dari segi nilai wang ringgit yang sangat diperlukan oleh industri semasa. Model2 melibatkan Proses Rangkaian Analitik Fuzzy, Perisian Super Decision dan prosedur analisis Complex Proportional Assessment (COPRAS). Model terakhir iaitu Model3 menggunapakai siri analisis kaji selidik yang menghasilkan vektor keutamaan untuk setiap faktor kehilangan yang dikira. Dalam usaha untuk menilai validasi model-model yang dibangunkan, perbezaan keseluruhan kategori risiko dikira dengan membandingkan keputusan kesemua model dengan piawaian teknikal sedia ada iaitu Pipeline Technical Guideline (PTG11.36.04). Hasilnya menunjukkan peratusan perbezaan sebanyak 28.6%, 57.1% dan 17.14% untuk Model1, Model2 dan Model3 masing-masing. Perbezaannya dapat dilihat secara ketara di kawasan yang mempunyai markah tinggi dalam nilai faktor kehilangan awam, faktor alam sekitar yang dikira dalam penilaian serta klasifikasi kawasan yang dipilih. Dapatan daripada kajian ini menunjukkan perbezaaan risiko yang siknifikasi antara piawaian teknikal sedia ada dengan model-model yang dibangunkan. Walaubagaimanapun, Model3 yang menghasilkan peratusan perbezaan terendah boleh dianggap sebagai model yang paling komprehensif dan berpotensi kerana pengiraannya melibatkan pengutamaan setiap faktor kehilangan di setiap kategori kehilangan dalam bentuk penilaian wang ringgit. Melalui proses pengesahan model dan verifikasi dapatan kajian yang berstruktur, keputusannya menunjukkan bahawa model-model ini dianggap komprehensif, memenuhi objektif, boleh dipercayai, jelas dan praktikal. Kesimpulannya, hasil kajian ini boleh digabungkan dengan piawaian teknikal sedia ada kearah pembangunan automasi Pipeline Integrity Management System pintar (i-PIMS). Dengan itu, model-model ini berupaya untuk memanjangkan integriti jangka panjang aset saluran paip dan pada masa yang sama menjamin keuntungan tahunan pemilik.

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LIST OF ABBREVIATIONS

ALARP	As Low As Reasonably Practicable
PIMP	Pipeline Integrity Maintenance Plan
CoF	Consequences of Failure
PGU	Peninsular Gas Utilisation
PIMS	Pipeline Integrity Management System
QRA	Quantitative Risk Assessment
PEAR	People, Environment, Asset and Reputation
SSGP	Sabah-Sarawak Gas Pipeline
RM	Malaysian Ringgit
USD	United States Dollar
API	American Petroleum Institute
PIA	Potential Impact Area
HVAC	Heating, Ventilation and Air-Conditioning
ALOHA	Areal Locations of Hazardous Atmospheres
PL	Production Loss
AL	Assets loss
HHSL	Human Health and Safety Loss
DA	Damage Area
VSL	Value of Statistical Life
LQI	Life Quality Index
GDP	Gross Domestic Product
ASME	American Society of Mechanical Engineers
ECI	Environmental Consequences Index
EL	Environmental Loss
PubL	Public Loss
ANP	Analytic Network Process
AHP	Analytic Hierarchy Process
FANP	Fuzzy Analytic Network Process
COPRAS	Complex Proportional Assessment
TFNs	Triangular Fuzzy Numbers

PPP	Public-Private Partnership
EIA	Environmental Impact Assessment
RoW	Right of Way
PGB	Petronas Gas Berhad
DOSM	Department of Statistic
JUPEM	Department of Survey and Mapping
MET	Malaysian Meteorological Department
GPS	global positioning system
GTS	Group Technical Solution
MPIC	Ministry of Plantation Industries And Commodities
DVS	Department of Veterinary Services
JKR	Public Works Department
KPKT	Ministry of Housing and Local Government
TNB	Tenaga Nasional Berhad
bscf	billions of standard cubic feet
Mc	Material cost
PLEG	Public Loss Estimation Guidelines
km	kilometre
PoF	Probability of Failure
Ker	Kerteh
Ktn	Kuantan
Seg	Segamat
NDT	Non Destructive Test
LOC	Level of Concern
NE	Number of People
DAE	Damage Area due to Explosion
psig	per square inch gauge
ft	foot
JKR	Public Works Department
mil	million
id	identification
R	Radius of the impact circle
Rs	Safety distance

Pa	pressure in the pipeline
Pb	atmospheric pressure
Dp	pipe inside diameter
En	nozzle efficiency
IoT	Internet of Things
CPS	Cyber Physical System
ICT	information and communications technology
EA	Enterprise Architecture
EI	Enterprise Integration
CR	consistency ratio

LIST OF SYMBOLS

Kw/(sq.m)	-	Kilowatt per Square Metre
d	-	outside diameter of the pipeline
p	-	maximum allowable operating pressure
$	-	dollar
∈	-	Area within
g	-	GDP for Malaysian
$Index_{max}$	-	maximum index
$Index_{min}$	-	minimum index
N	-	number of rating scale index
X	-	object set
U	-	goal set
gi	-	goal
m	-	extent analysis values
Si	-	fuzzy synthetic extent
M2	-	degree of possibility
d	-	ordinate of the highest intersection point
k	-	convex fuzzy numbers / number of attributes
W'	-	weight vector
Pi	-	attributes values which larger values are more favourable
Ri	-	attributes values which smaller values are more favourable
Qi	-	Relative weight
e	-	expectancy of life
q	-	average work ratio
w	-	part of human life
v	-	present value of 2014
¢	-	based value of 2014
ř	-	percentage of raised
Ƥ	-	present year
ƅ	-	year of based value taken
%	-	percentage

◦C	-	degree Celsius
*	-	times
W	-	weight

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CHAPTER 1

INTRODUCTION

1.1 Preface

Oil and gas pipelines accidents are susceptible to the environment and human as any leak or rupture in pipelines will cause product to spill and cause enormous negative impacts as well as life-threatening impact on human (Alzbutas et al, 2014; Shabarchin and Tesfamariam, 2017). Buried pipelines is built cross-country even though it is delicate to the environment due to its condition where it navigates through diverse terrain of crop fields, forests, rivers, population areas and mountains. In order to prevent accidents and to reduce risk, attempts have been made through identification and assessment of major risk contributors which can be accomplished by using appropriate risk assessment techniques and implementation of risk control measures (Singh, 2017). As an integral part of risk assessment, the consequences assessment must be devoted in detail by considering related major losses in order to improve the decisive value of risk thus an appropriate risk measures can be defined (Alzbutas et al, 2014). Although quantitative consequences modelling is widely applied in many industry, its application on risk assessment for buried gas pipeline are still literally minimal especially on representing local loss factors as it involves complex and time-consuming analysis (Paez and Roy, 2010).

1.2 Background and Motivation

Risk assessment in oil and gas industry is an important issue in terms of safeguarding human and the ecosystem from damages (Arunraj and Maiti, 2009a). The damage varies based on the initiating event that may lead to explosion, jet fire, flash fire or combination any of it (Amir-Heidari et al, 2017). The comprehensive nature of risk assessment can be represented by quantitative aspect: (i) inclusion of complex mathematical models to calculate the failure probability and consequences, (ii) incorporation of local loss factors related to site conditions of the failed pipeline, and (iii) future-proof readiness (Tong et al, 2016; Bonvicini et al, 2015; Ma et al, 2013). A lot of work has been carried out focusing in probability assessment e.g. reliability and statistical modelling (Cuny and Lejeune, 2003; Markowski and Mannan, 2009; Agrawal and Srivastava, 2014; Shabarchin and Tesfamariam, 2017; Singh, 2017). As an integral part of risk assessment, consequence assessment plays an important role nonetheless. Typical consequence estimation process involves simple assimilation of losses without considering all consequence factors that reflect site conditions. Among local loss factors that referred site conditions are population density, topography, vegetation and soil condition, just to mention a few. These factors are considered as local when the assigned value is exclusive to that particular site only. Hence, risk assessment of pipeline failure will be more representatives and vary according to site condition (Nazim, 2015).

Consequences modeling that reflect to particular site conditions have many advantages (Singh and Markeset, 2009). However, the inclusion of too many loss factors will make the risk assessment framework becomes complex, time-consuming and less practical (Amir-heidari et al, 2014; Fouladgar et al, 2012). The use of such simple methodology can ensure less computational time and less expert's user, making it more practical to the industry (Heino and Kakko, 1998). This creates such a dilemma in defining the best risk assessment framework for oil and gas industry, considering practical aspect versus representative aspect. A complete information is needed for the comprehensive risk assessment of pipelines but obtaining information in consequences estimation using quantitative method is not readily possible (Vianello and Maschio, 2014; Jonkman et al, 2003). A quantitative risk assessment means the calculation of risk and its components, including probability and consequences in single currency or monetary value instead of index value. Therefore, in order to risk assessment to be comprehensive, its framework should be quantitative-orientated geared towards monetary value in the calculation of consequence loss.

The use of monetary value to define Consequences of Failure (CoF) for comprehensive risk consequences assessment permit one to distinguish between prioritization made on each assessed category (Cunha, 2016; Khan and Haddara, 2004). A monetary loss approach as an inherent loss control procedure provides a single currency evaluation could also be employed as a support to decision-making in risk management (Brandie, 1996). In addition, detailed information on local environmental loss factors may help to increase the integrity level of a pipeline (Dey, 2002). If a reliable model of consequences risk assessment which incorporate site condition and local loss factors can be developed, a risk-based maintenance program can be well executed to prolong the integrity of the pipeline and might as well reduced the overall operating cost (Khan and Haddara, 2003). The results may provide a clear picture on the frequency of inspection as well as to determine the level of protection as part of mitigation measures in risk management of pipeline failure.

1.3 Research Problem

The current available standard is considered too general and not site specific because of the absence of local loss factors such as topography, demography, potential damage radius, population density, infrastructure layout, geography, environment, agricultural activities and livestock's in the assessment of risk (Shahriar et al, 2012). This method assigns weightage on priority of the loss factor and its severity is based on expert's judgment by using a subjective assessment where assessor's preferences may vary depending on his/her experience in assessing the risk of pipeline damage. The consequence assessment model of buried pipeline damage which considers its local loss factors are scarcely available. Consequently, the estimated risk may be miscalculated by speculated consequence assessment due to negligence of local loss factors; inclusion of local loss factors was proven highly influential upon the development of a model (Md Noor et al, 2012). A realistic and comprehensive pipeline risk assessment is needed in order to achieve a better and efficient maintenance and repair planning scheme.

The absence of monetary model shows a loophole in comprehensive risk consequences assessment procedures. Risk consequences analysis is conceivably subject to direct monetary estimation, which corresponds to the expected loss in revenues due to various reasons (Khan and Haddara, 2004). Brito and Almeida (2009) agreed that quantification of loss factors in monetary value is able to reflect company's financial status depending on how serious the outcomes of the accidents. With the inclusion of local loss factors and the loss factors were represented quantitatively monetary, then the consequences assessment will become more realistic.

Refinement of the existing procedure needs to be validated. Practicality and feasibility of the developed models has to be definitely agreed by the industry (Valipour et al, 2015). A structured validation process required to be carried out to ensure that the developed framework follows the principal of assessment and valid. Detailed investigation and assessment on the local loss factors are crucial because studies related to this area is relatively less and inconclusive. It is hypothesized that if a consequence model of buried pipeline damage incorporates monetary conversion of all related loss factors can be developed in a structured framework, a more realistic yet comprehensive risk consequence assessment towards intelligent Pipeline Integrity Management System (i-PIMS) can be achieved. Moreover, there are few, if any, studies that focus on analysis and assessing the consequences for risk assessment of gas pipeline considering overall possible losses including local loss factors in monetary evaluation. For this reason, this study aims to fill this research gap.

1.4 Aims and Objective

The main aim of this research is to develop a comprehensive local risk consequences assessment model for underground gas pipeline damage involving explosion. The proposed models convey some exclusivity where the models reflect the specific local loss factors of consequence loss. The search objectives are outlined as follows:

1. To evaluate the risk consequences of pipeline explosion in monetary form for selected sites using its unique identified and categorized loss factors.

2. To produce validated comprehensive risk consequences assessment models that incorporating the local loss factors.

The outcome may contribute to the knowledge of risk consequence assessment for a pipeline explosion by exploring all related loss for future risk consequence loss modeling.

1.5 Research Scope

As gas pipeline traveled across different region in the country, an additional category of public losses is considered in conjunction of other generally computed losses e.g. assets, production, environmental, reputation and human health and safety loss. This study focuses only on gas pipeline route at Peninsular Gas Utilisation (PGU) from Kerteh to Segamat as portrayed in Figure 1.1. It was selected due to high corrosion activities that led to indication of high consequences area based on recorded data. Therefore, this research and all the parameters selected on the development of the models were limited to this route's topography, demography, potential damage radius, infrastructure layout, geography, environment, agricultural activities and livestock data within the high consequence area. This study focuses on failure due to leakage that leads to explosion as a worst-case scenario. The index method was used to rate the severity level of overall risk consequences for the modeling purposes. Qualitative judgments from the experts using Delphi method and validation survey applied in the final stage to verify and validate the models.

Figure 1.1 Pipelines network owned by PETRONAS Gas Berhad (Source: Oil Peak, 2012)

1.6 Significance of Study

The main challenge of the local risk consequences loss model development is to have a better understanding in the selection of the factors to reflect the site environment and local conditions in order to obtain higher accuracy of the model. Hence, the importance of the research is to develop models, which use a complex quantitative assessment in a simpler sequence to present a clearer picture of the consequences loss if failure happens to occur. Previous studies scarcely include local loss factors in the risk consequences assessment on the impact of pipeline damage subject to explosion. Therefore, the outcome of this study offers a model tailored to specific local condition and considering all possible losses. This research produces models of overall consequence assessment comprising all possible related loss and the quantitative nature can eradicate the subjectivity of index assessment with the use of monetization in quantifying the loss factors. These models fulfil the industrial needs by providing a future-ready assessment and subsequently contribute to the academia of knowledge. The validated models can be incorporated into Intelligent Pipeline Integrity Management System (i-PIMS) in order to improve the risk assessment by considering the local loss in the risk consequences modeling. If proven significant, the quantitative nature of each developed model with its own strength and flexibility may be used based on the preferred assessment method towards a realistic and comprehensive risk consequences assessment which can benefit both industry and the development of a body of knowledge, thus increase the pipeline integrity assessment.

1.7 Structure of Thesis

This thesis is separated into six chapters. The structure of this research is as follows:

1. Chapter 1 delivers the introduction of the research study. This section delves into the fundamental problem of the proposed research. It covers the background, research problem, research aim and objectives, scope and significance of the research. The research methodology and the structure of the research report are also outlined.

2. Chapter 2 comprises an extensive literature review covering the pertinent literature about definition and its level of practicality for the industry in term of pipeline integrity management. It aims to enlighten the readers about the importance of comprehensive consequences assessment. Particular attention is paid to the application of such approaches in Malaysia. Essential published literature on risk assessment, particularly on consequences analysis, is reviewed in this chapter.

3. Chapter 3 illustrates the overall research methodology for the research study. Different methods of data collection as well as designing process of factors to be considered in each loss category are explained in detail. The chapter describes the research design, process and data analysis procedures used.

4. Chapter 4 comprises of the process of identification and categorizing the consequences loss factors related to pipeline explosion within damage radius.

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