Risk Assessment of Underground Gas Pipeline Leakage Incorporating Geographical Information System (GIS)

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Abstract. Major accidents caused by pipelines, such as explosions, deterioration can be harmful to the population's safety, public health and environment. Therefore, wide attention in preserving pipeline assets is needed to derive risk assessment of the pipelines from the accidents. This paper proposes a pipeline risk assessment method of space and visualisation focused on the existing state of gas pipeline risk assessment using an annotative geographical information system (GIS)-based approach to improve the administrative level of pipeline protection among the human physical area. This study aims to identify the losses of pipeline damage, calculate its losses in physical and monetary terms, and validate the calculated losses and its risk indexes with previous work. The calculation of overall consequences losses focuses on specifically Production Loss (PL), Asset Loss (AL), Human Health and Safety Loss (HHSL), Environment Loss (EL), Public Loss (PubL) and Reputation Loss (RL). An urban area of Bukit Istana is chosen for stimulation and to be investigated. As a result, the consequences loss assessment is produced and shown in the monetary unit. Assessment of hazard- affected bodies around the pipeline in Bukit Istana are also identified through spatial analysis and been visualized. This paper concludes by introducing the application of the environmental risk management method under the influence of the risk estimation system, obtaining the spatial distribution impact of environmental risk visualisation, and providing policymakers with a consistent decision basis.

Index Terms: Risk assessment, Pipeline, Consequences, GIS, Inspection

I. INTRODUCTION

The safety of oil and gas infrastructure from uncertainties risk leads to critical to quality, health and safe human environment. For example, a recent accident event in January 2014 involved one of the PETRONAS Sabah- Sarawak interstate gas pipelines. The fiery blast at about 2 a.m. has ripped apart a section of the pipeline located between Lawas town and Long Sukang in the northernmost district of Sarawak. The explosion's impact has caused a temporary shutdown of the 4 billion Malaysia Ringgit (MYR) PETRONAS project. Fortunately, evacuation of nearby villagers was immediately taken in action resulting in no fatalities were involved. Therefore, it is imperative to identify the risks and their impacts to provide possible risk reduction measures through a quantitative risk analysis (QRA) [1]. A number of attempts that involve identifying and comprehensive assessment of significant risk contributors can be made and achieved by using appropriate risk assessment techniques and implementing risk control measures [2] however, although comprehensive implementation of various QRA in many industries, application on risk assessment for the pipeline in oil and gas industry especially on representing local loss factors is considered less popular as it involves complex and time-consuming analysis [3].

The research aims to integrate a local risk consequences assessment model for underground gas pipeline damage with GIS. By coupling with GIS, it helps to map and identify consequences losses then calculate the identified losses caused by pipeline damage in the GIS environment. For the result validation, the calculated categorised losses will be validated by comparing with previous works. In this research, there are six (6) categories of identified losses which consist of Production Loss (PL), Reputation Loss (RL), Human Health and Safety Loss (HHSL), Asset Loss (AL), Public Loss (Publ) And Environmental Loss (EL). Therefore, the potential of GIS technology in safety measure management in the oil and gas industry, mainly to keep pipeline assets safe for the environment and public, is possible to perform. Thus, the integration of GIS technology and risk modelling for gas pipeline networks is worthwhile to be proposed and learnt, which these models may be effectively applied to natural gas pipeline safety and management [4].

1.1 Problem Statement

Throughout the years, many efforts in risk assessment of pipelines for the oil and gas industry have highlighted the relevance of analysing hazard-affected bodies that result in pipeline failure. Therefore, it plays a significant role in

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improving the high-level decisions subjected to potential events that occurred. With the use of current practices and available standards, it can be said that the safety of oil and gas production is not guaranteed. The implementation is not uniform depending on each location of the pipelines, and therefore, they cannot be fully utilised and optimised. This is because the earth surface is irregular in every place. For example, the topography or local terrain on each pipeline route in the urban area cannot be compared to those in rural areas. This will create inaccurate analysis in terms of the environmental and public safety due to the pipeline damage.

One of the limitations of previous works is that risk assessment of spatial features or hazard-affected bodies due to pipeline deterioration is too general and simple. For example, risk assessment of urban gas pipeline results from Hanafiah [15] shows that some local factors were neglected and not considered in the existing risk assessment guidelines. The author also added that lack of consideration on the neglected local factors would not represent the actual world situation, affecting the decision in the end. On the other hand, most recent research focuses on the underlying specifications of gas pipelines, despite focusing on financially estimating the risk and neglected environmental factors. Furthermore, since most experiments lack a visualisation output, extracting the spatial pattern of risk distributions could be impractical, making it difficult for managers to make appropriate decisions in sensitive circumstances [5]. Therefore, the needs of spatial distribution visualisation of hazard-affected bodies are needed.

1.2 Significant study

Along with the industrial revolution 4.0, the terms of digital terms is commonly heard in nowadays era. Therefore, special software should be embedded to gather real-time data from all related agencies to make decisions quickly and efficiently. Around the world, oil and gas companies are implementing GIS technology as a solution to help them map, monitor and analyse the physical spatial data of their assets. Spatial technology solutions can simplify everything from mapping fixed assets like pipelines and their surroundings to developing and implementing an emergency response program. In other words, in the event of an emergence of a natural disaster and its spatial information are essential to risk assessment and management, and with the aid of GIS, it dramatically improves natural hazard analysis [6]. Thus, less human intervention is needed in conducting the in-situ inspection of the gas pipeline. Furthermore, combining qualitative and quantitative risk assessment analysis with GIS knowledge creates a 'one-ness' system that covers the whole operation such as survey, installation, seismic survey up to maintenance, and remote monitoring system.

Therefore, by introducing pipeline GIS technology and use its efficient spatial data management, query, and visualisation capability to hold vast analytical data in the system. It allows obtaining a meaningful global risk assessment for a country based on charts that provide pipeline risk analysis and assessment and pipeline risk distribution and risk level [7]. The implementation and integration of pipeline risk management are significantly aided as an outcome of this. On this basis, the risks posed by pipeline to different nearby hazard-affected bodies can be further evaluated and expressed. The detailed environmental risk, as well as its spatial distribution characteristics, can then be found. It can also help relevant agencies and corporations with pipeline management and construction planning decisions more scientifically.

1.3 Scope of study

According to recorded data from a previous study, there are high corrosion activities in the Bukit Istana which is suitable to perform risk assessment in the event of pipeline explosion. Bukit Istana area is selected due to high human activities in high consequences (HCA). Therefore, it is suitable to indicate the losses involved in a place where there is a highly-populated area.

Figure 1 A snapshot of Bukit Istana area (Urban) [8]

The model uses the input parameters, divided into two categories: spatial and non-spatial data. Spatial data or geographic features will be accumulated into each feature class in this GIS system software, such as area topography, vegetations, features of local manufactured and natural landscapes within the high consequence area are pre-processed and digitised in mapping software. For non-geospatial data, in this research, details of risk severity matrices and assessments existing hazard assessments that focus on estimation of damage losses in the monetary unit due to pipeline failure are also considered.

The damage losses are well-defined and categorised, including its consequences of failure value in a monetary unit, including assets, production, environmental, and reputation. The distribution of population within the high-risk area is also included to estimate human health and safety damage. The software that will be used in this research is ArcGIS Pro version 1.2 software. Qualitative judgments from the experts using the Delphi method and validation survey from the previous study will be applied in the final stage to verify and validate the models with the aid of the outcome risk maps. Therefore, an

understanding of GIS components and specifications is required for the development of a database.

II. LITERATURE REVIEW

Risk analysis of urban natural gas pipeline networks has been the subject in several research. During early 2000s', the investigation of the risk posed by a high-pressure pipeline rupture was done where hazard distances were established in that study to range from 20m for low-pressure pipelines with small diameters to 300m for high-pressure pipes with big diameters [9]. A quantitative approach to risk analysis, including fatal length and cumulative fatal length parameters where the individual and social risks were the outcomes of their efforts [10]. Jo and Ahn [11] proposed a new method for quantitative risk analysis, which they tested on a pipeline with a diameter of one metre and a pressure of 50 bar at a depth of 130 cm from the ground. They employed pipeline geometry and population density in their investigation.

A comparison of quantitative and qualitative risk assessments was conducted and executed on small and large urban locations. Many consequences are considered in the quantitative approach, resulting in a high precision outcome, whereas many causes for failure are considered in the qualitative technique, resulting in a more effective output [12]. A new technique of assessing quantitative risk for urban natural gas pipeline networks based on pipeline section grid differences (GDPSs) was then focused to create relationship between pipelines and stations, they employed graph principles. First, a number was assigned to each location in the region as individual risk, and then contour lines were produced using ArcGIS. According to the findings, more pipelines generate more danger, shown by contour lines [13]. Then, by integrating geographic information systems, they provided a unique approach for quantitative risk assessment for urban gas pipeline networks. The computation of failure rate, the quantitative analytical model of accident consequences, and the evaluation of individual and society hazards are the three aspects of this technique. Thus, GIS plays a vital role in improving accident management and control.

A risk assessment for Iran's distribution gas network was conducted in 2014. In the same way as Jo and Ahn

[14] focused on the consequences of jet fire and explosion, they applied the proposed technique to estimate the individual and societal risk.

III. METHODOLOGY

The research design process is influenced by the research strategy, which involves steps from data collection to creating risk maps to achieve the purpose and objectives of the proposed study. Figure 2 shows the details of the research design.

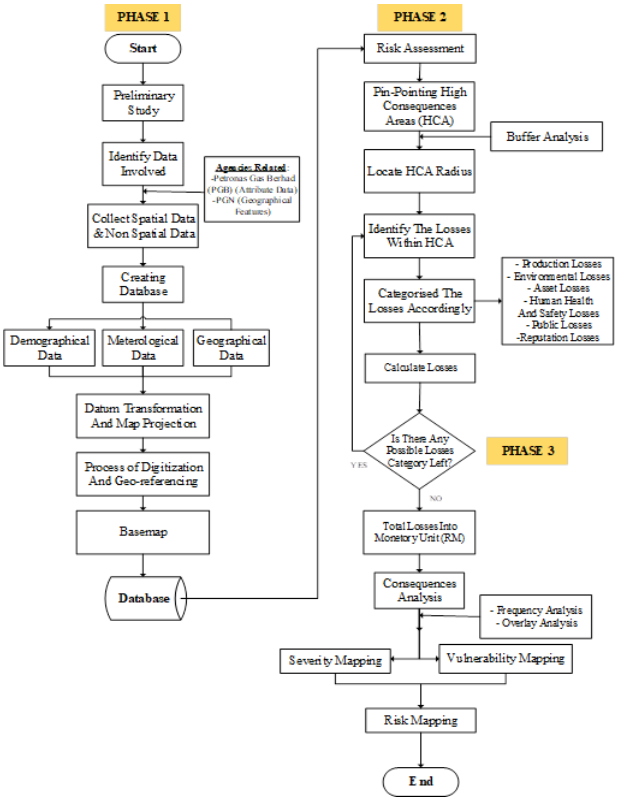

Figure 2 Flowchart of research design.

The first phase is referred to as plan the strategy incorporating the potential use of GIS to conduct a risk assessment of underground gas pipeline. The first step involves a preliminary study which problem research; the research aims to integrate a local risk consequences assessment model for gas pipeline damage with GIS, and the research objectives are supported and answered with literature reviews. Moreover, most of the analogue data are derived and obtained from secondary data sources through several related works of literature, previous research papers, journals, books, official documents and maps from related agencies involved. Spatial data or Geospatial data representing geographic information (with coordinates) of the physical objects on Earth are also collected to be transformed and digitised manually in the ArcGIS Pro interface. Coordinate system conversion is needed due to standardising the whole data used in the data frame of the GIS database (WGS84 is used).

Risk assessment procedures are taking into account potential hazards and risk sources. Personnel, vehicles, residential buildings, land, vegetation, water body, and other facilities and properties are among the hazard-affected bodies [7]. The sensitive risk sources such as buildings, schools, and commercial centres in this research are identified, placed, and weighted to access their relative importance. Since this research is adapted from previous work has employed the Aerial Location of Hazardous Atmospheres (ALOHA) program, commonly in risk assessment, to compute the damaged area or thermal radiation zone [15]. Primary inputs of parameters are keyed in to produce damage radius for all sites. Proximity tools include Buffer Analysis is used in

ArcGIS Pro to map and locate the damage radius on each inspection site. Consequences loss factors due to pipeline explosion are identified by locating the same damage radius from previous work in the GIS database. There are six (6) categories of identified losses which consist of Production Loss (PL), Reputation Loss (RL), Human Health and Safety Loss (HHSL), Asset Loss (AL), Public Loss (Publ) And Environmental Loss (EL).

By adopting the models of estimation loss value for each category in a monetary unit from previous work, the calculate of newly identified losses within damage radius in this research can be made. The severity of incidents and the vulnerability of the hazard-affected body can be analysed using the pipeline database on the GIS platform. GIS spatial analyst software can calculate quantitative risk and visualise it near-real-time [7].

A vulnerability map is produced to visualise the affected infrastructures in the high consequences area and features due to pipeline explosion for the pre-inspection process. With the aid of ArcGIS Pro, the attribute table for vulnerable features available within the damage radius provides the visualisation of accident severity to the analyst for better inspection. Tabulation of vulnerable features within the damaged area is also computed, allowing categorising each of losses into a detailed manner for easy calculation later on. The estimation of losses will be evaluated in a monetary unit, and in this research, the result will provide in both MYR and USD currency. In the validation process, summations of estimated loss value will be compared and verified with previous work to ensure the reliability of the result.

IV. RESULT AND DISCUSSIONS

The author reported in a previous work that the loss factors associated with pipeline damage were established through an extensive search of recent literature [15]. These identifications are confirmed with the assistance of oil and gas industry experts and aligned with their guidelines. As a result, six (6) loss factors are mentioned in the categories, including HHSL, PubL, PL, AL, RL, and EL. However, due to insufficient data available at this moment, particularly in Bukit Istana site area focuses exclusively on all six (6) loss factors associated with the damage radius area without taken account of livestock, agriculture (e.g. palm oil) and infrastructure (e.g. bridge) into the calculation.

To achieve the study's first objective of identifying and categorising local loss elements associated with pipeline explosions into an acceptable component of loss within the damage radius, it is essential to consider the amount of threat impact to the vulnerable. The estimated loss values are used to determine how maintenance resources should be allocated in the event of pipeline disruption, aligning them with the vulnerable infrastructures within a 1.0km damage radius. The the damage radius was calculated subject to pipeline explosion, and then the author added, although ALOHA provided modelling for a variety of failure models, only damage radius results were required [15]. Table 1 shows the calculation and description of the damage area radius formed.

Table 1 Description of damage area calculation

Software used	Basic pipeline inputs	Result
ALOHA version 5.4.7 – Used to calculate the thermal radiation or threat zone radius.	• diameter of the pipeline, • material type, • operating pressure, • operating temperature • chemical type • the atmospheric conditions of the case study sites	DA1= 325m DA2 = 450m DA3 = 675m Note: Approximately damage radius used for all sites = 1km

Proximity relationships can be discovered using the tools in the Proximity toolset for feature data. These tools generate data in the form of buffers or tables. Typically, buffers are used to denote protected zones surrounding features or to indicate areas of influence. By implementing this to the study area, Bukit Istana, the first objective of the research can be achieved. In this study, a 1-km radius buffer represents the pipeline explosion impact to map and allocate the losses in the study area within the radius, as illustrated in Figure 3 below.

Figure 3 1.0km buffer allows the simulation of the pipeline explosion in Bukit Istana area.

For consequences assessment, ArcGIS Pro provides a tabulation of vulnerable features in table form. The tabulation of vulnerable features helps to allow sorting and giving information of features in a detailed manner, such as their types, name of the place, and geometry of the features. For Within a 1km radius of HCA in the study area, several vulnerable features have been identified. Below Table 2 shows identified losses result within a 1.0km damage radius. According to Table 2, each category loss factor in the monetary unit (MYR) is produced. Moreover, the attribute table in the software shows the number of loss features in each category within a 1.0km damage radius.

Table 2 Identified losses result within 1km damage radius for each category.

	PL	AL	HHSL	EL	RL	PubL
Bukit Istana	Customer Fined + Opportunity Loss	*Mc* + *Cc* + *ComC*	(N1∈ DA× VSL) + (Cost of injury 2 of N2 ∈ DA2) + (Cost of injury 3 of N3∈ DA3)	Environmental Cleanup cost + Remediation cost + Environmental act fine	PL, EL, HHSL	Agriculture, Transportation and public buildings

The assessment of the consequences to be performed thoroughly with the aid of a mapping system in ArcGIS Pro software, and the overall estimated cost for the losses of each category available can be calculated. For example, "Residential building" makes up the majority of vulnerable losses in the PubL category in study area within a 1km damage radius (588), while "Public infrastructure" contributes for the least number of features (18). Figure 3 shows a detailed pie-chart of consequences losses in the percentage form, while Figure 4 shows the number of losses for each type involved.

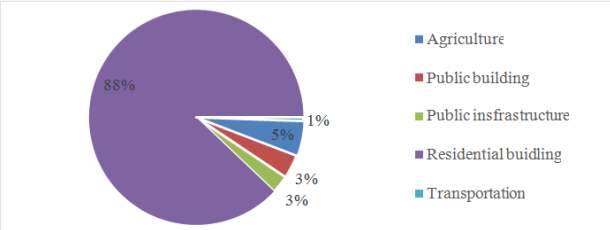

Figure 3 Percentage of consequences losses in Bukit Istana area.

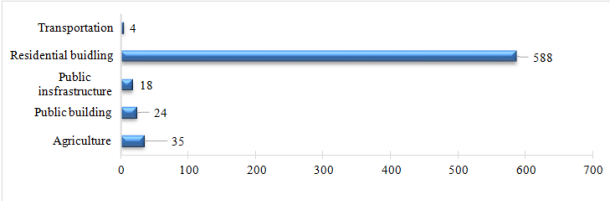

Figure 4 Number of identified with its types in Bukit Istana area.

The calculation for consequences assessment is made to estimate the overall cost impact subject to pipeline explosion. This analysis is given to address the need and requirements in the industry's current risk consequences assessment technique, particularly in pipeline gas [15]. The final summation of six main categories of losses, namely PL, AL, HHSL, EL, PubL and RL, as stated in Table 2. For HHSL and PubL category, in the event of pipeline failure at day time, less presence of people in their home, assuming that one house or public infrastructure available within 1.0km damage radius, represents one feature on the map. Table 3 shows the overall summation of losses in MYR and USD units by adapting the Bukit Istana area. Note that the currency conversion between MYR and USD is 1MYR equivalent to 4.14USD.

Table 3 Overall summation for all category losses in the monetary unit.

Type of losses	Equations	Value (MYR)	Value (USD)
PL	CF + OL	4,350,000	1,050,725
AL	Mc + Cc + ComC	557,000	134,541
HHSL	[{(60 ϵ 300m * 1,104,864) + (10,000 * 46 ϵ 450 m) +(1,000 * 422 ϵ 670 m) }]	67,173,840	16,225,565
EL	Environmental Clean-up + Remediation + Environmental act fine	1,150,000	277,778
PubL	Residential Building + Public Building + Single carriageway	32,580,000	7,869,565
RL	0.4(HHSL) + 0.4(EL) + 0.2(PL)	27,416,536	6,622,352
	Total	133,227,376	32,180,526

The validation and result comparison are needed to ensure the reliability of output models from this research to be compared with previous work. In this section, the estimation losses value in the monetary unit as discussed in the last section has been successfully computed and shows differences in both results as expected. Detail and description of the differences in overall summation of losses in monetary terms is shown in Table 4, and Figure 5 shows the comparison loss results for both works in the percentage form.

Table 4 Comparison of loss factors estimation values between this study with previous work in Bukit Istana.

Type of losses	Current result Value (MYR)	Hanafiah [15] Value (MYR)	Differences	Changes in percentage (%)
PL	4,350,000	4,350,000	0	0
AL	557,000	557,000	0	0
HHSL	67,173,840	5,624,320	61,549,520	92
PubL	32,580,000	16,678,704	15,901,296	49
EL	1,150,000	1,150,000	0	0
RL	27,416,536	3,579,728	23,836,808	87

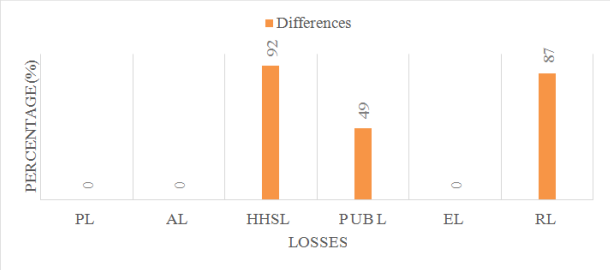

Figure 5 Differences between the results in percentage form.

There are significant differences in the overall summation of loss factors due to pipeline explosion in the monetary unit, as shown in Table 4. A big contrast shown by the value of loss estimation for HHSL is that previously, some losses features were not taken into account in the previous work. Therefore, with the aid of ArcGIS Pro, it enables the analyst to visualise the "missed" features on the map and, at the same time, less time-consuming for in- situ measurement or site visitation to be performed (Wang et al., 2013). Based on Figure 5, the differences between the two results in terms of its estimation loss value in percentage form -for HHSL (+92%) while the second-highest value in differences in – RL (+87%) This is due to the calculation for RL is directly influenced by the value of HHSL, EL and PL. It is also expected to have changes in value of estimation loss results for other sites because the availability of features for each category loss is not similar depending on its site location. Therefore, it can be concluded that risk assessment of urban and rural areas will show different outputs in visualizing the vulnerable features in their damage area radius in the pipeline explosion.

V. CONCLUSION

In conclusion, this proposed research discusses and provides a clear explanation of the methodology used for the study, starting from the process of risk assessment of pipeline failure, which involves data collection, processing, design, modelling, estimation of cost involved with integrating the development of GIS database and with the analysis tools used. Finally, the data analysis, visualisation through maps and validation of overall risk assessment with integrating GIS tools are briefly discussed to show the expected outcome from this proposed research. However, due to this current situation, some of the data are not available to be collected, and alternative ways have been taken to tackle the problem according to the best fit of this research.

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