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Comparison Study on Human Health and Safety Loss for Rural and Urban Areas in Monetary Value Subjected to Gas Pipeline Failure

Norhamimi Mohd Hanafiah, Libriati Zardasti, Nordin Yahaya, Norhazilan M. Noor, Nursamirah Hassan and Alireza Valipour
Faculty of Civil Engineering, Universiti Teknologi Malaysia, Malaysia

Corresponding Author: Norhazilan M. Noor, Faculty of Civil Engineering, Universiti Teknologi Malaysia, Malaysia

ABSTRACT
Consequence assessment is an integral part of the risk assessment process carried out by the industry to minimize impact of assets failure on the environment, human safety, assets integrity and business reputation. A few components of consequences loss occur due to the pipeline failure, such as asset loss, environmental loss, production loss, public loss and Human Health and Safety Loss (HHSL). This study focuses on HHSL by considering the losses in term of monetary value between rural and urban areas due to pipeline failure. Based on the current technical standard practiced in the industry, the calculated consequences are speculated to generate an equal risk value to any area of the pipeline throughout the country, regardless of the areas unique local factors and consequences. Hence, this would lead to the deterioration in the quality of the estimated risk. As for the damaged area, Areal Locations of Hazardous Atmospheres (ALOHA) software was employed in the calculation of risk by considering the pipeline data and the details of selected sites such as atmospheric and demographic condition. The HHSL was calculated using a developed mathematical equation of quantitative risk assessment in terms of the number of fatalities or injuries or both in monetary value. The results of the assessments from rural and urban areas were then compared with one another to identify the occurrence of any significant dissimilarity. The major finding of this research showed that there is a possibility to enhance the decisive value of risk by implementing the proposed approach of HHSL estimation for consequence assessment.

Key words: Risk assessment, consequences modelling, monetary model, human health and safety loss

INTRODUCTION
In the last decades, the world has seen a wide range of major accidents with a number of fatalities, economic losses and damage to the environment (Cravens *et al*., 2003). Attempts have been undertaken to prevent these accidents and to reduce the risk to a level as low as reasonably practicable (ALARP) without resorting to the costly protective systems (Dey, 2002). This was done through the identification and assessment of major risk contributors, which can be accomplished using quantitative risk assessment techniques and implementation of risk control measures. Risk assessment is a process used to determine the likelihood and Consequences of Failure (COF) due to a potential threat such as corrosion attack. Risk is the product of the likelihood of failure times the consequences of the failure (Khan and Haddara, 2004). As an integral part of risk assessment, the consequences of a failure have to be determined in detail by considering the major losses in

order to improve the decisive value of risk (Norhamimi *et al*., 2015). A pipeline failure may lead to different types of consequences loss such as asset loss, environmental loss, production loss, Human Health and Safety Loss (HHSL) (Falck *et al*., 2000).

Risk assessment should be carried out in a project that possesses a risk of failure due to exposure to a potential hazard, such as a buried steel gas pipeline operation which is discussed in this paper. A buried steel pipeline is one of the most common mediums used to transport products such as crude oil and gas and it is exposed to risk from numerous types of threat (Noor *et al*., 2011). These buried pipelines are exposed to several environmental conditions and they may experience corrosion attack that can lead to a disastrous event (Berstad *et al*., 2011). Steel pipeline deterioration due to corrosion attack is well known as a common and serious problem for pipeline operators in Malaysia. It is a problem that involves a considerable cost and may cause inconvenience to the industry and the public. Since, buried gas pipelines are typically located in populated areas, the consequences of failure can be catastrophic due to the potential hazard for HHSL (Hanafiah *et al*., 2015). The main key is that HHSL should be calculated in detail by considering the unique local factors.

Hypothetically, the outcome of this research is to provide a deeper understanding between the HHSL consequences model by considering local factors and the impact on the calculated value of risk assessment as a whole. This is essential for a better understanding of risk assessment of oil and gas pipeline damage subjected to fire, thus a well-planned pipeline inspection and maintenance can be developed for industrial needs.

MATERIALS AND METHODS

Site selection: For the site selection, high consequence areas are chosen for the case study. The criterion is based on the parameters contributing to corrosion such as site condition which includes soil parameters, site accessibility and safety, pigging data and maintenance records. In Malaysia, corrosion is one of the major problems faced by the pipeline operators. Generally, soil parameters are taken into consideration because it contributes to the corrosion activity in the external part of the pipeline. Another factor that has been considered in deciding the high corrosive area is based on the pigging data where it involves the detection of metal loss due to the internal and external corrosion of pipeline. The corrosion data gathered by the pipeline maintenance personnel is used to identify the high consequences area due to corrosion. It is done by examining the critical part of buried corroded pipelines through the report from previous inspections and maintenance records. All sites had a record of high corrosion activity and have been listed as high consequence areas.

In this study, four sites in Malaysia are selected from the list of high consequence areas due to corrosion to represent a rural and urban area. The sites of Gebeng and Bukit Istana represent urban areas, while Jabor and Kapeh represent the rural areas. Rural area was classified by Statistical Department of Malaysia for populations which are less than 9,999 people in every calculated block area whilst urban area are for a population of more than 10,000.

Damage area assessment: The damage area assessment is made after the highly corrosive area has been decided throughout the site selection study. Areal Locations of Hazardous Atmospheres (ALOHA) software was used to model the damage radius. It is an emergency response model intended primarily for rapid deployment by responders and also for emergency preplanning (ALOHA., 2007). The ALOHA deals specifically with human health hazards associated with

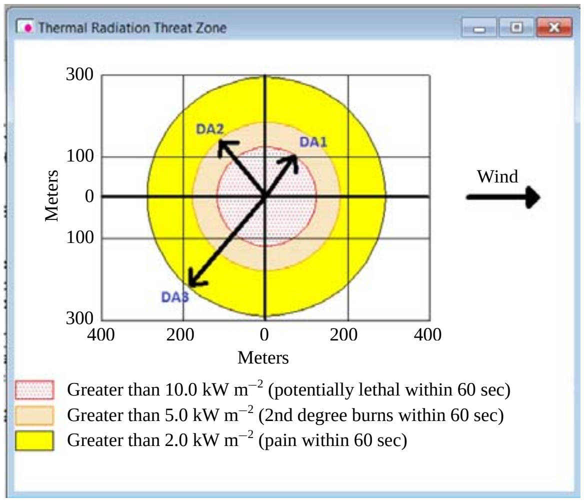

Fig. 1: Thermal radiation threat zone ALOHA results of Gebeng area

Table 1: Inputs of ALOHA

Pipeline data	Input
Diameter	36 inches
Length	16,000 m
Type	Smooth surface finish
Pressure	70 bars
Temperature	50 degrees
Chemical type	Methane

inhalation of toxic chemical vapors, thermal radiation from chemical fires and the effects of the pressure wave from vapor-cloud explosions. However, in this study only the effects of vapor-cloud explosions were used for the analysis as it fitted the natural gas pipeline explosion case study.

The procedure of ALOHA incorporates source strength as well as Gaussian and heavy gas dispersion models and an extensive chemical property library (Gharabagh *et al*., 2009). Table 1 shows the basic input needed for ALOHA in terms of pipeline details. Other required data is local condition information such as the atmospheric conditions of the selected site. The ALOHA generated results of damage radius used in the analysis and were used for the estimation of HHSL.

In Malaysia currently, industrial personnel use the potential impact radius equation as shown in Eq. 1 to calculate damage radius for consequence assessment which uses only the data of pressure and diameter of the pipeline. This equation as practiced does not yield the critical layer that illustrates the accident severity to calculate the HHSL in more detail:

$$R = 0.69(pd^2) \quad (1)$$

Urban area: Figure 1 and 2 show the result of damage area in Gebeng and Bukit Istana respectively. Both represent an urban area for the case study and are quite highly populated. The DA1, DA2 and DA3 are damaging area for the first, second and third radius damage, respectively. The results from the ALOHA software indicate that DA1 is found to be greater than 10.0 kW m^{-2}, which leads to be potentially lethal within 60 sec and will cause the loss of live. Next, thermal radiation threat zone radius which is greater than 5.0 kW m^{-2} could result in serious injury and second degree burns. Lastly, DA3 could leads to the causing of pain within 60 sec and will impel in the formation of slight injury as the thermal radiation is greater than 2.0 kW m^{-2}.

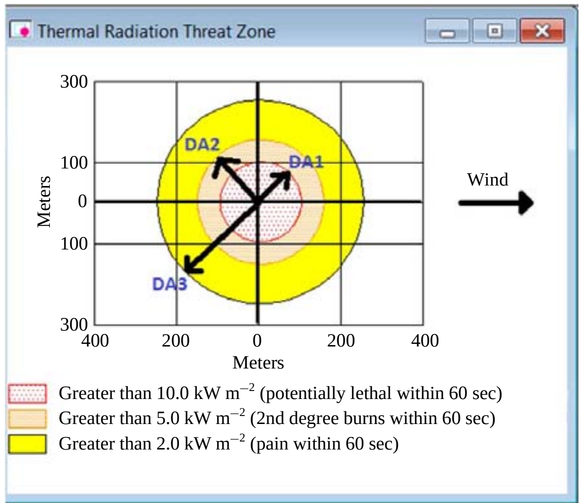

Fig. 2: Thermal radiation threat zone ALOHA results of Bukit Istana area

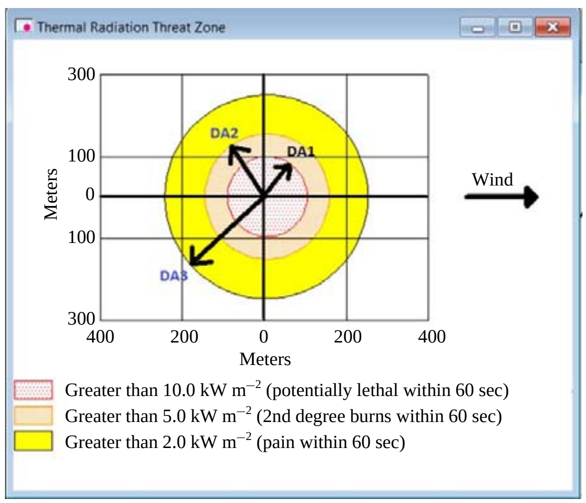

Fig. 3: Thermal radiation threat zone ALOHA results of Jabor area

Table 2: Radius of damage area for all the sites

	Damage radius of urban area (m)		Damage radius of rural area (m)	
Damage area	Gebeng	Bukit Istana	Jabor	Sungai Kapeh
DA1	106.25	121.95	110.00	116.66
DA2	156.25	180.49	160.00	170.83
DA3	243.75	287.80	250.00	270.82

Rural area: Graphical results in Fig. 3 and 4 illustrate the radius of damage area at Jabor and Kapeh area, respectively. The figures show similar consequences pattern of thermal radiation threat as described in section 2.1 for the urban area.

The damage radius data gathered from ALOHA software for the damage area assessment are simplified in Table 2 for the respected sites. Even though the threat zone radiuses are similar among urban and rural categories, but the result of the analysis from ALOHA show different value

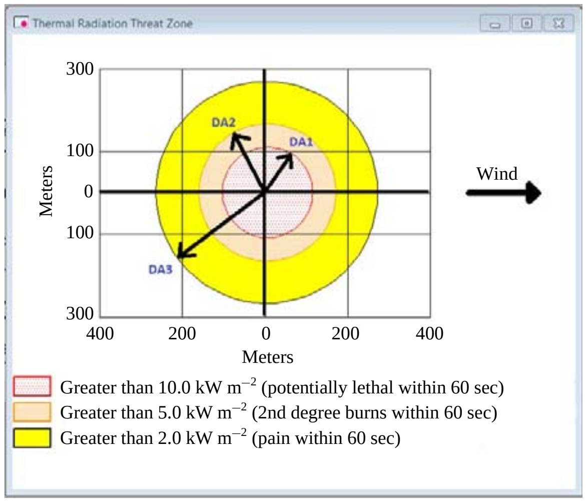

Fig. 4: Thermal radiation threat zone ALOHA results of Kapeh area

for the damage area in meter for each site. The discrepancy of the damage radius could be attributed by their unique local factors. All the values will be contributed to the estimation of HHSL in section 4.0.

Evaluation of value of statistical life: The Value of a Statistical Life (VSL) is considered to be an important factor for the estimation of HHSL for each site. The steps for evaluating VSL are important as it is the main key to differentiate the value of HHSL between the rural and urban areas. The VSL is a form of summarized tradeoffs value between monetary wealth and fatal safety risk, a measure that is widely used for the evaluation of public policies in medicine, the environment and transportation safety (Ashenfelter, 2006). In economic terms, VSL is the amount of money a person or society is willing to spend to save a life. Since, there is no formal market for lives, the only way to measure VSL is through indirect methods that are available in the literature. Understanding the value of life is important for government policies in which citizens live are at risk or where the goal is to save lives. Even though VSL can be estimated directly by asking workers or consumers how much they would be willing to sacrifice or pay for slightly greater safety, the more typical approach is to estimate wage or price change in an implied VSL (Way, 2013).

A ratio method had been used by Arunraj and Maiti (2009) and Alexander (2002) to estimate VSL by comparing the ratio of GDP per capita between the countries. Ashenfelter (2006) in his study measured VSL by considering wealth or personal income as one of the contributing factors. However, in this study, Life Quality Index (LQI) method was used as proposed by Jonkman *et al*. (2003), because this method can be used to differentiate the VSL for rural and urban area. While for the cost of moderate and slight injury, the value was estimated in collaboration from the local hospital as RM 10,000 and 1,000, respectively. These values are assumed to be the same for both the areas during the analysis.

Life Quality Index (LQI): Life Quality Index (LQI) was used as a measure of VSL on the basis. It is a social indicator derived to reflect the expected length of life in good health and the quality of life enhanced by wealth (Arunraj and Maiti, 2009). The general equation to calculated LQI is shown in Eq. 2:

Table 3: Result of value of statistical life using LQI method

Area	VSL (MYR)
Urban	1,642,249
Rural	1,516,599

VSL: Value of a statistical life

Table 4: Population density data

	Radius (m)		
Site area	0 - 150	151-200	201-300
Gebeng	6	15	45
Bukit Istana	5	25	30
Jabor	-	-	5
Sungai Kapeh	-	-	15

$$\text{Life Quality Index (LQI)} = g^q e \tag{2}$$

where, g is the Gross Domestic Product (GDP) for Malaysian in units of MYR/year, e is the expectancy of life in years and q is the average work ratio and derived as in Eq. 3 where, w is the part of human life used for economic activities (Arunraj and Maiti, 2009). The data to calculate the LQI is from Malaysia historical economic data and government authorities based on the latest value:

$$q = \frac{w}{(1-w)} \tag{3}$$

The outcomes of calculated VSL were tabulated in Table 3. The VSL value of the urban area was found to be slightly higher than the rural area as the GDP of rural for Malaysian is 7% lower than urban.

Population density assessment: The data for population density and personal income in the area of study for all sites was obtained from the government authorities statistical record. The personal income data was used for the VSL estimation above and the population data were used for the HHSL calculation. In the case of consequence due to the re, loss was estimated by considering all the people in the population to be present within the damage area. Table 4 shows the number of population in the research area taken from Malaysian Poll data, which has been verified through several site visits. This data was later used to calculate HHSL for each site.

Human health and safety loss analysis: Loss due to the occurrence of fatalities and/or injuries resulting from a failure of a system is known to be as the Human Health and Safety Loss (HHSL) (DeWolf, 2003). The HHSL injuries suffered may vary from fatalities to light scratches. Since buried gas pipelines are known to be as one of the safest ways to transport natural gas, they are buried across Malaysia, crossing both rural and urban areas (Norhazilan *et al*., 2012). As mentioned previously, the greatest threat of a pipeline comes from corrosion attack, either internal or external of the pipe. In a condition of failure that occurs due to the corrosion, a disastrous event can create a serious impact in terms of safety of living life as well as financial situations. Therefore, a detailed assessment considering all related aspects in estimation of HHSL is vital, since one's life is invaluable.

Table 5: Human health and safety loss result in monetary value

	Urban area (MYR)		Rural area (MYR)	
COF	Gebeng	Bukit Istana	Jabor	Sungai Kapeh
HHSL	73,912,205	49,278,470	7,593,995	22,759,985

HHSL: Human health and safety loss, COF: Consequence of failure

Table 6: Percentage difference of human health and safety loss for urban and rural area

COF	Urban area (MYR)	Rural area (MYR)	Percentage difference (%)
HHSL	73,912,205	22,759,985	69.21

HHSL: Human health and safety loss, COF: Consequence of failure

The accident scenario considered in this study is a fire that leads to an explosion. The failure is presumed to be due to a rupture, which is common for a failure caused by corrosion. Arunraj and Maiti (2009) suggested that HHSL calculations should include the damage area and population density in a quantitative assessment. The severity of injuries should also be considered along with the number of people injured during the accident. The HHSL for a fire is estimated using Eq. 4 as proposed by Arunraj and Maiti (2009) in the consideration of possible death effects, possible injuries and possible annoyance:

$$\text{HHSL for fire} = \{(\text{NF1} \in \text{DAF1} \times \text{VSL}) + (\text{Cost of injury 2 of NF2} \in \text{DAF2}) + (\text{Cost of injury 3 of NF3} \in \text{DAF3})\} \quad (4)$$

In reference to the results of ALOHA, DA is the damage area of the accident. The DAF in Eq. 4 are the flammable damage area caused by the vapor cloud. NF1, NF2 and NF3 refer to the number of people present within the damage areas DAF1, DAF2 and DAF3, respectively. The VSL is the value of statistical life in Malaysia which had been further discussed in section 3.1, cost of injury 2 is the estimated cost of a moderate injury and cost of injury 3 is the estimated cost of a slight injury.

Human health and safety loss results: Table 5 displays the calculated result to represent a clear comparison of HHSL between the urban and rural area. As for urban area, Gebeng obtain higher HHSL value than Bukit Istana while for rural area, HHSL value for Sungai Kapeh is found to be higher than Jabor. The results of HHSL are presented in the monetary value of Malaysian Ringgit (MYR).

Table 6 shows the percentage difference of HHSL between the rural and urban area, which is 69.21%. The highest HHSL value of each category was taken for the comparison purpose.

DISCUSSION

The results of HHSL for rural and urban areas show significant dissimilarity since all areas have different environmental factors and income values of the people. This study proved that each site should utilise its own VSL values accordingly since the impact of pipeline explosion on HHSL should be different by taking into consideration the variability of human life for different site.

In terms of current practice, pipeline operators in Malaysia calculated HHSL qualitatively by an expert evaluator using standard technical procedures and without consideration of the VSL and the severity area of the explosion. The Life Quality Index (LQI) method used in this study was compared with another method in the literature as discussed above, such as Arunraj and Maiti (2009) and Alexander (2002) methods. The other methods show significant similarity with VSL for urban area but LQI method is more suitable as it can distinguish the impact between urban and rural area. The results from this study is also compared with VSL for Malaysian motorists (Yusof *et al*., 2011) but it shows some contradiction as the field of study is dissimilar. The used of ALOHA to estimate damage area is compared with safety distances method by Sklavounos and Rigas (2006) but it had limitation in generating severity layer from the explosion.

The previous studies focusing on quantitative analysis by Jonkman *et al*. (2003) and Henselwood and Phillips (2006) allocated HHSL loss with individual and societal risk. However, the risk is considered on the population as proposed by Arunraj and Maiti (2009) to be in line with industrial needs. The current practice of pipeline risk assessment of the overall consequences loss is implemented by following a technical standard which is developed based on best practice guidelines. However, the procedures only focus on qualitative method, which is considered too general due to negligence of including the local factors such as topography, demography, potential damage radius, infrastructure layout, geography, environment, agricultural activities and livestocks (Hanafiah *et al*., 2015). This leads to the deterioration of quality of estimated risk as the calculated consequences will generate an equal risk value to any area of pipeline throughout the country regardless of the areas unique local factors and consequences values. In simpler term, the existing procedure might under calculate the Consequences of Failure (COF), hence increases the failure probability and cost of failure. A new model consists of new loss categories and parameters which being discarded in the present technical procedures is proposed for an improvement. However, this study focuses only on one integral part of the overall consequences loss which is HHSL.

The advantage of considering local factors can be illustrated using the percentage difference's value as shown in Table 6. There is a huge percentage difference which indicates the contribution by considering the demographic factors as proposed in this research. Nevertheless, it is possible that HHSL may contribute to the changes in the overall consequences calculation, hence the risk value itself. The result can be adopted in the present risk assessment procedure in Malaysia that uses the risk matrix. It is possible that the risk matrix position may change from medium impact to high impact with the change in HHSL value. Therefore, Integrity Management Plan (IMP) can be improved further because the pipeline failure will have a massive impact on the country and society.

The above mentioned investigation verified that detailed consideration of local factors such as population area and consideration in estimating damage area could change the direction of the consequence assessment, especially for HHSL. Based on the current practices by the industry in Malaysia, environmental and demographic factors will not have much effect on the consequences value as long as it carries the same products with the same pipeline sizes across the country. However, the results from this study validate that the value of HHSL should vary if the location of the case study and its parameters are taken into consideration.

CONCLUSION

As a conclusion, the wages or income values are important as they affect the VSL value. The development of VSL is important and needs to be calculated based on its suitability according to a specific case and situation. In this study, the VSL for Malaysian have been developed with current technique and it can be referred in other field for HHSL modeling. Nevertheless, there can be a high degree of subjectivity associated with assigning a dollar value to a fatality. Despite the fact that the value of human life is immeasurable, attempts have been made to apportion it by adopting worker compensation costs, insurance costs and rehabilitation costs.

The outcome of this study can serve as eye opening to pipeline operators regarding the serious impact of pipeline failure on the environment in general and on human health and safety when HHSL is calculated quantitatively by differentiating the assessment area. Hence, by adapting risk consequences model that represents localized factors in risk assessment, cost efficient, sustainable and a better Integrity Management Plan (IMP) can be executed. Moreover, the overall risk assessment accuracy can be improved for a better environmental impact monitoring in the gas industry.

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