New Technique for Road Transportation of Hazardous Materials (Hazmat) in Malaysia via Quantitative Risk Analysis Approaches

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Abstract— Quantitative risk analysis was recognized as a proper method for assessing the risk level of a hazardous activity, however, when this technique is applied to a transport case, there were several parameters and assumptions need to be considered before starting the Transportation Risk Analysis (TRA) calculation. This paper aims to describe how the modified TRA methodology is used for predicting the accident scenarios and their impact to humans and environment. The analytical technique was applied to a case study of liquefied petroleum gas (LPG) by road tankers. The transportation of LPG via five existing routes was studied in detail, and the corresponding societal risk were evaluated and compared.

Index Terms—Accident, risk analysis, transportation, methodology

I. Introduction

For the past 30 years, quantitative risk analysis (QRA) has been successfully applied in a particular studied risk area to analyze, to assess and to evaluate hazards from fixed facility of chemical process industries (CPI) [1,2,3]. A similar technique has also used to analyze and to evaluate risk for the impact from transportation of hazardous material. However, the practical application of this well-known procedure to a moving risk source gives rise to a number of problems. Historical evidence has shown that incidents due to hazardous materials (HazMat) releases during transportation can lead to severe consequences [4-6].

In the United Kingdom, probabilistic safety assessment is not mandatory in the safety report. However, the Health and Safety Executive (HSE) find it is easier to accept conclusions, if the risk assessment is supported by quantified arguments. Up to now, quantitative risk criteria have been published most as far as the control of land use in the vicinity of industrial facilities is concerned. Advisory Committee on Major Hazards (ACMH) in its third report put a serious attention on the major hazard potential from the transport of hazardous materials (ADMH, 1979, ADMH 1984, ACDS, 1991) [7-9].

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II. Review the Existing TRA Model of Hazardous Materials

Risk has two elements: the frequency of occurrence and the potential consequences. Transportation risk analysis (TRA) concerns risk arising from the release of hazardous materials as a result of accident- and/or non-accident-initiated events. In mathematical formula, generally the risk, $R_{LPG\ (Case\ study\ 1)=LCS}$ for accident scenario LCS can be expressed as:

$$R_{LPG\ (Case\ study\ 1)=LCS}=f(F_{LCS}, C_{LCS}) \qquad (1)$$

being F_{LCS} the frequency of occurrence and C_{LCS} scenario consequences. Quantitative risk analysis was recognized as a proper method for assessing the risk level of a hazardous activity, however, when this technique is applied to a transport case, there were several parameters and assumptions need to be considered before starting the TRA calculation. For these matter, the authors have to refer to the existing TRA model guidelines developed by the Center for Chemical Process Safety (CCPS) Risk Assessment Subcommittee (RASC) (CCPS, 1996; CCPS, 2000, CCPS 2009) [10-13], the methodology used by Health Safety and Executive, United Kingdom, for the assessment of societal risk for the road transportation of hazardous chemicals (HSE, 1991), the methodology strategy developed by Swiss federal Office for Environmental Protection, Forestry and Landscape (BUWAL) (Nicolet and Gheorghe, 1996; L. Nardini et. al, 2003; Boywecick, 2006), and others published TRA researchers work (Rhyne, 1994; Spadoni et.al, 1995; R. Bubbico et al,1998; R. Bubbico et. al, 2000a; R. Bubbico, 2000b; R. Bubbico et. al, 2004a; R. Bubbico et. al, 2004b; R. Bubbico et. al, 2006) [14-19]. From the studies, the authors found that these considerations were due to several reasons, firstly, the approaches technique which is required by the transportation hazardous materials analysis is quite complex, compared to chemical fixed facility. The reason for this is because TRA is analyzing risk associated with moving or linear risk sources, in comparison to fixed facility which related to discrete point hazard sources or static. Therefore, risk analysis is essential during transportation of hazardous material and various assumptions and precautions need to be undertaken to ensure safety to the surrounding population, property and environment. Accident is unpredictable, it can occur at any time, any location and without warning. Furthermore, different type and quantity of chemical will give different impact to the surrounding population, property and environment.

The calculations of consequences effect from the impact become more complex when some parameters are the dominant contributors in the TRA analysis, also changing along the selected route. For example, in meteorological conditions for modeling, wind roses and direction must be determined due to 16 probability of wind directions with their weightage ratio; N, NNE, NE, ENE, E, ESE, SE, SSE, S, SSW,SW,WSW,W,WNW, NW and NNW. Meanwhile, atmospheric stability class distributions will also vary from location to location, as does the ambient temperature and humidity. Probabilities for ignition sources also vary along a route, and it may be very difficult to get the specific route data. The consideration of risk to injury or damage caused by the escape of hazardous materials depends on the extent of the presence and the nature of population distribution surrounding the area. However in TRA analysis the injury, fatality, or damaged caused by the release of chemicals is difficult due to population distribution (density) constantly changes along the selected route. For instance, the population density around a traffic accident can vary dramatically, from a large city to a rural area. The effect of population density towards risk analysis becomes vital in minimizing fatality and casualty if accident happened during transportation of hazardous material. Therefore, the selected route was ideally through the landuse with lowest population density. Generally, population density categories for urban area, sub-urban area, rural area and remote area are different. Since the parameter involve in the TRA analysis varies along selected route travel, therefore the calculations should be repeated at every point. Even though several researchers (G. Spadoni, 1995: R. Bubbico, 1998) had utilized the developed guidelines of Center for Chemical Process Safety of American Institute of Chemical Engineers (CCPS, 1996; CCPS, 2009) and some simplified the calculation from the transportation accident scenario, however the usage still limited to capability to extract data (available data) or knowledge of territorial information of the selected route transportation. Data access become more complicated if it was involving multi- agency and when some information are difficult to be gathered since they are depending on the efficiency of that particular department or organization in collecting, extracting, recording and updating their data. Method of data storage also important since it can facilitate TRA analysis. For instance, some organization and department in Malaysia has been practicing online data access for humidity, temperature, wind speed, accident rate and land use. Department such as MIROS, had recorded data of death from the accident other related safety issues and on road traffic accidents. If the data has not yet recorded in the database, the data could be determined via MIROS published mathematical model which is commonly used for estimating accident rate from a particular route. The author think these mathematical model are more applicable in the TRA analysis calculation in Malaysia compared to other models such as in CCPS of AIChE, BUWAL and or other data’s (CCPS, 1996; CCPS, 2000; CCPS, 2009, Rhyne 1994; BUWAL) [10-14]. This is considering some data such as accident rate, traffic flow etc depending on geographical characteristics and scenario accident in Malaysia. Meanwhile, data from CCPS, BUWAL and other proposed data from several researchers were adapted to the geographical condition of each particular country. Therefore, the result of TRA calculation has become more accurate by using local data of the studied area. Data from outside sources can be utilized if it is not available in Malaysia. For author, with the application of the above method, at least it can provide more accurate picture on accident scenario, its consequences and bring more accurate and precise of Malaysia acceptable risk for any transportation of hazardous materials activities in Malaysia. This factor is a reason why some TRA software such as TrHazGis, TRAT2, and STRAPP are not suitable for Malaysia usage.

III. MATERIAL AND METHOD FOR MALAYSIA TRA

In CPQRA, most of TRA risk analysts often considered and estimate risk of irreversible injury or fatality for determination of appropriate levels of concern for overpressure, thermal radiation, and toxicity hazards [10-13]. Nevertheless, these CCPS guidelines estimation (CCPS, 1996: CCPS, 2000, CCPS, 2008) will open more space for inaccuracies in the TRA results evaluation. For instance, most of the individual risk results in TRA consider the total individual risk of fatality by excluding the injury condition, in assessing the level of risk from selected route of the transportation of hazardous materials. In order to estimate the risk of injury and fatality, the CCPS TRA equation has been modified by the authors as follows:

$$IR_{x,y} = T.T_{NYI}.T_{TP\%}\left[\frac{1}{T_{NYI}.T_{TP\%}} \pm 1\right].A_{MIROS}.\sum_{i=1}^{n} R_i.\sum_{j=1}^{m} L_{i.j}.W_j.\sum_{k=1}^{S_i} CorrectedP_{i,j,k}.\ ratio(HD:MD:MiD:UED) \quad (2)$$

where

$IR_{x,y}$ = the total individual risk of injury and fatality at specific geographical location x, y coordinate

T = number of trips per year

T_{NYI} = number of year (after projected number of trip per year)

$T_{TP\%}$= percentage of road trip projection (increase / decrease)

A_{MIROS} = accident rate per kilometer according to Malaysian Institute of Road Safety Research

R_i= release probability for ith release size

$L_{i,j=}$ length of release location zone j

W_j= the probability that wind blows in the direction of concern

$CorrectedP_{i,j,k}$=the probability of injury and fatality at coordinate x,y given that accident k occurs

m = number of release location zones and wind direction affecting coordinate x, y

n= number of release sizes considered

S_i = number of incident outcomes for release size i

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i = release size counter
j= release location zone counter
k= incident outcome counter
HD= Probability of the highest level of damage for Corrected$P_{i,j,k}$ (fatality)
MD=Probability of major level of damage for Corrected$P_{i,j,k}$ (injury or fatality) MiD=Probability of minor level of damage for Corrected$P_{i,j,k}$ (injury, such as first degree burn)
UED=Probability of no damage for Corrected$P_{i,j,k}$ (no fatality and no injury)

From equation (2), the number of road trip per year can be predicted based on the company product sales performance either increase or decrease over the years.

In most instances, enroute accident rates are the most important components of a truck (HAZMAT) tanker risk analysis. Generally, the rate is affected by numerous parameters such as road conditions, environmental, trucking operation, types of road (urban, sub urban, rural and remote routes area). However, most of the truck tanker risk analyses are normally based on accident rates characteristic of broad classes of route types for which useful data are available. With the influence of rapid economic growth in Malaysia, the number of vehicles on the road, and highways can be expected to increase. A mathematical model has been developed to forecast the number of road traffic deaths and crashes in Malaysia. The equation (3) and (4) are used for predicting the number of road crashes and deaths for a given year are as follows:

Number of Road deaths =

$$2289.e^{(0.0007\,Vehicles\ x\ Population\ x\ Road)}.e^{0.2073\,Data\ system} \quad (3)$$

Number of Road crashes=

$$43478.e^{(0.00011\,Vehicles\ x\ Population\ x\ Road)}.e^{0.2447\,Data\ system} \quad (4)$$

Data system factor is equal to 1 for Peninsular Malaysia and equal to 2 for East Malaysia.

The effect of hazardous consequences in terms of injury and fatality will be dependent on the intensity of the consequences experienced by a person and also on the exposure duration. This is true for radiation hazards from a fire event, blast wave overpressure from an explosion and toxic gas release. In order to express percentage injury and fatality among humans in terms of the intensity of a hazardous event and duration of the exposure, probit equations are used to determine fatality levels among the exposed population. The probit equation is as follows:

$$Pr = k_1 + k_2 lnD \quad (5)$$

Where, k_1 and k_2 are constants' depending on the type of damage and D is a function of the hazard dosage in terms of intensity and duration.

To apply equation (2) for thermal radiation from explosion, the following steps must be carried out:

- Selected probit equations, Probit equations (P) are in general from shown by Eq. (5).

$$Pr = k_1 + k_2 lnD$$
$$= k_1 + k_2 \ln[f(I_e.t_e)] \quad (6)$$

In the case of thermal radiation, D isthe combination of effective radiation intensity, I_e (W/m^2) and effective time duration (s), t_e.

- Results from thermal radiation equations must be corrected, since they refer to different degrees of the same type of damage, lower levels of damage and the highest level damage.. Assume results as

$Pr_{HD} = -36.38 + 2.56\ln[f(I_e.t_e)]$, percentage of highest damage to human = lethality = R_{HD}% (7)

$Pr_{MD} = -43.14 + 3.02\ln[f(I_e.t_e)]$, percentage of major damage to human = 2nd degree burn = R_{MD}% (8)

$Pr_{MiD} = -39.83 + 3.02\ln[f(I_e.t_e)]$, percentage of minor damage to human = 1st degree burn = R_{MiD}% (9)

$Pr_{LD} = -37.23 + 2.56\ln[f(I_e.t_e)]$, percentage of lowest damage to human = protected by clothing = R_{LD}% (10)

- The above results must be corrected and rearranged from the highest level of damage to unaffected impacts.

The highest level of damage, actual R_{HD}%= R_{HD} (11)

2nd degree burn caused by thermal radiation, actual R_{MD}% = R_{MD}- R_{HD} (12)

1st degree burn caused by thermal radiation, actual R_{MiD}% = R_{MiD} -(R_{MD}+ R_{HD}) (13)

The lowest level of damage, actual R_{LD} = R_{LD} –(R_{MiD} +R_{MD}+ R_{HD}) (14)

The remainder people are not affected, R_{UED} = 100-(R_{LD}+ R_{MiD} +R_{MD}+ R_{HD}) (15)

For the societal risk , the frequency of $F_{g,i,k}$ of accident outcome k for release size i on segment g and the number of associated number of fatalities $N_{g,i,k}$ can be estimated as:

$$F_{g,i,k} = T.A.R_i.L_g P_{i,k} \quad (16)$$

$$N_{g,i,k} = CA_{i,k}.PD_g.CorrectedPF_{i,k} \quad (17)$$

where $CA_{i,k}$ is the consequences area associated with incident outcome k,PD_g the population density for g, and $PF_{i,k}$ the probability of fatality and injury [20-37].

Population density

Population density data were derived from Department of Statistics Malaysia records, and referred to the most recent census, taken 2010. For mukim of Port Dickson the population density is 3.19756 people per hectar. Mukim port Dickson is under control of administration of Port Dickson District Office. For District of Port Dickson, the population density is reduced to 1.6079 people per hectar. From the above results showed that the mukim of Port Dickson is the highest populated density area among the rest mukim of Port Dickson district. In this case study, the authors took the population data from Environmental Impact Assessment (EIA) report of MCWR [38], where the population distribution has been divided into 2 sets of population distribution: (i) day time population, and (ii) night time population. Table 1 shows the detail information of population distribution by point location.

Table 1 population distribution

Point location	Day time population	Night time population
A	517	2598
B	280	1400
C	882	1743
D	408	707

Note: daytime refers to the period from 0700 hour to 1900 hour GMT, whilst nighttime to the period 1900 hour to 0700hour GMT.

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In this case study, the information in Table 1 has to be mapped out before detailed distribution could be identified and determined. The population distribution in table 3, then will be worked out into spatial distribution and by risk assessment sector diagram (RASD) [39].

Meteorology condition

The meteorological data records (Meteorology Department, Malaysia) available from Malacca meteorology station nearby, allowed the setting of average weather conditions as follows: average temperature of 28 and 32°C in winter and in summer, respectively, with a humidity of 70% and a prevailing wind velocity of 3.3 to 5 m/s during hot season. The Pasquill atmospheric stability class was assumed as D (i.e. neutral) through the year.

Release scenarios

Two release scenarios were assumed: a spill from a hole 25 mm in diameter in the tank, lasting for 10-15min, and catastrophic rupture of the tank, with discharges of the entire content from > 250mm hole in about 30 s. In both cases the possible consequences of the release include jet fire, pool fire, flash fire, and UVCE and BLEVE fireball. The explosion of the tank, due to thermal decomposition of LPG, may also occur because in the event of a pool fire under the tank. For the analyst, the result will only show the explosion event in the catastrophic scenario. The catastrophic release probability is set to 0.35.

Route segmentation

The characteristics of a particular route such as population density, weather condition, topography, accident frequency and etc, could vary from point to point, so the route will be divided into similar features.

IV. DESCRIPTION OFCASE STUDY

In this case study, risk analysis assessment is implemented, to estimate and to evaluate the risk impact of an accident involving LPG trucks. To estimate the risk related to LPG truck accident, the actual accident scenario is taken. To make this case study relevant, the selection of accident scenario is based on the actual events that occurred in Malaysia, according to information gathered from database in (National Institute of Safety and Health (NIOSH), and Malaysian Institute of Road Accident and Safety (MIROS) Bangi, Malaysia. Based on review of the report from NIOSH, a specific accident scenario can be created according to the truck condition, time and features of the accident scene. The truck accident scene is analyzed over five routes which involves a daily movement of 34.5 m^3 of Liquefied Petroleum Gas (LPG) through approximately 15- 20 km length route from Middle West Coast Refining (MWCR) Company in Port Dickson to Petrol and Gas service station in Port Dickson. The MWCR processed crude oil of 55,000 barrels per stream day (BPSD) and produce the following products or domestic consumption for LPG, naphtha, mogas, kerosene, diesel and Low Sulphur Waxy Residue (LSWR). Export of MCWR products by road currently generates approximately 400 lorry trips per day; with the commissioning of the Multi product pipeline, the number of road trips is expected to reduce to 219 per day. From 1998 to the year 2000, road trips are projected to increase by 6% per year. By completion of new highway linking to new international airport at Sepang (KLIA) to Port Dickson, it is expected the road trips increases to 8-10 % per year. At present, the loading activities are currently daytime activities, occurring between the hours of 8.00 and 16.30 but will be extended to a 2 shift activity in the future.

V. RESULTS AND DISCUSSIONS

From the case study, authors will implement the TRA conceptual methodologies, link all the possible outcomes and calculate the consequences to ArcGIS 9.3.1. In the case study, the expected results are capable to classify road by risk ranking, to analyze and simulate the day and night risk impact from data interpolation and spatial analysis. In this section, the discussion is limited to the BLEVE and fireball impact.
First, it can be noticed that the total risk curves in Figure 1, for road transport (route 5) shows the maximum individual risk value of 2.49x 10^{-4} km/year at time 3.2023 s lay well above than of individual risk at time (0.9s, 1.0s, 1.8s, 2.8s, 3.01s, 3.5s -9.61s), the individual risk value were increased from time 0.9s- 3.1s and slowly decreased from time 3.5s till 9.61s. This value is maintained constantly from > 0 m up to 200 m distance from source of accident. The individual risk start to reduce from 1.25 x10^{-4} km/year at 200m distance and drastically reduce to very minimum value at 400m to 500m at value 3.51x 10^{-16} km/year. At 300 m distance the value was save for human, building and property which is 4.19 10^{-7} km/year less than Malaysian guidelines tolerated value for risk assessment, 1.0x 10^{-6} km/year fatalities per year. Therefore at distance above than 300m, this value 4.17 x 10^{-7} km/year injuries and fatalities km per year indicates public acceptance of existing risk without additional measures. These results, in the former cases the “safe” zone starts at 290 m from the point of release. Even though, in the latter a distance of 420 m should be exceeded. For road transport routes, either in motorway, or express highway, or main road, the trend of the curves, will be only depends on the relative probability of the final accidental events and on the consequence analysis, and, due to the higher average value of the accident rate. The total risk by time in figure 1, represent the overall individual risk at particular time and distance. Meanwhile, the area under the curves of total risk at 3.2024s, represent risk for 1st degree burn, 2nd degree burn, lethality, and probability of risk provided the individual is protected by clothing, building. This result (Figure 1) is confirmed by observing the societal risk curves, shown in Figure 2, which also account for the presence of people in the impact zones. In fact, the F–N curve obtained for total impact from BLEVE fireball is still higher than those of BLEVE fireball impacts (for first degree burn, second degree burn, lethality and protected). Moreover, the results rank also shows a same agreement of ranking results by other researchers. In figure 2 , the societal risk for 2nd degree burn at 3.2024 fall from the third rank risk at 1.8s to the very reasonable and practicable risk. All protected individual drastically reduce and become unsaved from the accident impact between the duration times of 2.8s till 3.2023s. This phenomenon may be due to

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maximum radiant heat emitted by the surface of the fireball between > 0s to 3.2s as shows in figure 18. It has to be noticed that, according to U.K. standards (Health and Safety Commission, 1991), the individual risk for road transport modalities run almost entirely in the ALARP zone, being higher than 10^{-4} fatality/year, when number of fatalities and injuries increased approaching to 1000 individuals affected. The road transport falls into the so called unacceptability zone (10^{-3}–10^{-4} fatality/year),. The risk may be accepted provided that it has been reduced as low as reasonably practicable. The societal risk level appears globally higher than the individual one. In fact, also the curves relevant to road transport, which is the most hazardous transport modality, fall well within the limits of the U.K. ALARP zone (Health and Safety Commission, 1991) (dotted lines). However, assuming the limits proposed by Dutch regulations (Dutch National Environmental Policy Plan, 1989) (dashed lines), different in slope and more severe than the U.K. ones, almost all the curves exceed in their final part (i.e. in the high mortality zone) the intolerable zone limit. In conclusion, the risk level for the study case appears moderately high, and a sensible reduction can be obtained by preferring small tanker transport to road, increase the thickness of the container and its resistance. However, should road transport be adopted, the best choice of an itinerary which does not cross towns, even if about 30% longer than the other, represents very an effective mitigative action.

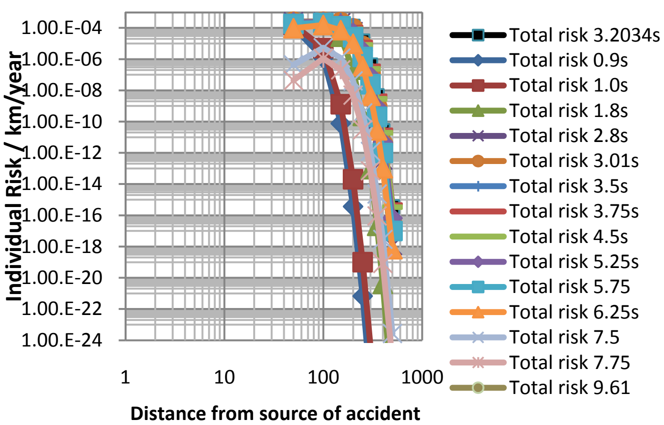

Figure. 1. Individual risk vs. the distance from the route 5 for the LPG transport case varies with time

This analysis provides input to the overall decision-making process. The risks along each route can be compared and a decision made on which route to use based solely on fatality risk, environmental impacts, and delivery time into considerations well. If neither set of results is tolerable, mitigation or a more rigorous analysis can be considered. Societal risks are used to emphasize the difference between the routes. As shown in Figure 3, the likelihood of one or more fatalities is greater for Route 4. The lowest risk is route 2. Initially the societal risk is about same for routes 1, 2, and 3, however the risks slowly become less than those for Routes1 and 3. The maximum number of fatalities is limited to roughly 1000. Thus, if the goal is to reduce consequences, Route 2 is the clear choice. If the chance of one or more fatalities is the greatest concern, the choice is less obvious. MCWR might consider the potential benefits of transporting an itinerary which does not cross towns or highly populated area.

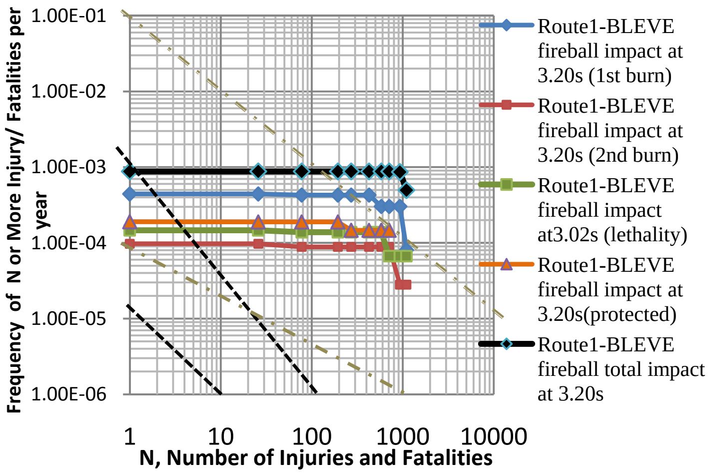

Figure 2. Societal risk for the LPG transport case; dashed lines: limits of the Dutch ALARP zone; dotted lines: limits of the U.K. ALARP zone.

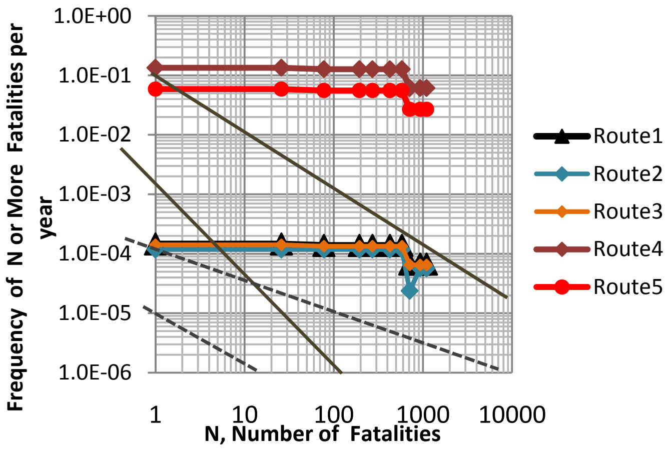

Figure 3 F-N curves for LPG tank truck via five routes as comparison

VI CONCLUSION

An LPG transport activity actually represents a risk for the population, due to the transport modality (pressurized liquefied gas), to the flammability characteristics of the product (high probability of UVCEs), to the relatively large capacity of the tankers and to the great number of trips needed for supplying many differently located end users. The application shows that, in the study case, ROUTE 2 is a safer transport route with respect to road, mainly due to its lower accident rate, even if, in case of accident, the amount of the spill, and hence the impact zone, is larger. However, this result cannot be directly extended to other products, since it arises from the combination of the frequencies and the consequences of each final accidental event. A more general conclusion is that the population density along the route and the accident rate, rather than the length of the route, are the most important factors for discriminating among different itineraries: in fact a route running distant from populated

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areas, even if longer than an alternative one, gives rise to lower individual and societal risk curves

Finally from the case study, it was proven that the new technique can be used as a tool for people working with hazard analysis and transportation risk assessment in Malaysia. Furthermore, with the advantage of using GIS map the point of accident can be moved to any location on it (in online basis via GIS server), hence a new result will be displayed for a new potential damage of transportation accident.

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