Quantitative Risk Assessment for the Transport of Ammonia by Rail

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Risk assessments are considered to be an essential tool in ensuring the safety of engineering projects. The benefits of using risks assessments have prompted its acceptance in the safety legislation for a number of industries. The use of quantitative risk assessment for rail transportation of hazardous materials has gained more attention in recent years, because the amount of the transported hazardous materials is large, and the transportation route often passes through populated areas, such as cities. In this study, the risk for the ammonia transportation by rail in Malaysia was conducted by combining the results from a previous failure frequency analysis and consequence analysis. The assessment results acknowledged the significant effects of train speeds on the overall individual risk. The risk with a tolerable risk limit of 1×10^{-6} per year increased significantly with more train accidents occurring at increasing speeds. Most of the surrounding populations along the transportation route analyzed are exposed to higher risk levels than the tolerable limit. This risk exposure to the public demonstrates the need for proper planning of moving ammonia through populated areas. © 2009 American Institute of Chemical Engineers Process Saf Prog 29: 60–63, 2010

Keywords: quantitative risk assessment; rail transportation; individual risk; hazardous material; logistics; SAFETI; railcar

INTRODUCTION

Major accidents throughout the world in recent years [1], including in Malaysia, such as the Bintulu synthesis plant explosion [2], have demonstrated the disastrous ways in which projects have gone horribly wrong. These accidents have attracted the attention of the public and raised concerns about the safety of engineering projects. As a result, several wide-ranging inquiries into safety, notably the offshore, chemical, transportation, and nuclear industries have firmly recommended risk assessment to help prevent accidents. In these fields, risk assessment has been widely adopted and written into legislation on safety [3]. Most of this legislation requires the quantification of the risks involved and an assessment of the risks against a predefined criterion. For example, following the Cullen Report on the Piper Alpha offshore platform incident [4], quantitative risk assessments have been adopted into the UK Safety Case legislation [5] as a mandatory activity for all offshore installations in the UK sector of the North Sea.

In the transportation industry, quantitative risk analysis (QRA) has been used as a tool to help determine the safest route for the transportation of hazardous materials [6]. The adoption of QRA in the transportation industry, especially for the transportation of hazardous materials by rail, has only been applied vigorously in recent years. Although the likelihood of a hazardous material release is low, the potential impact of the release to the surrounding population is significant, because most of the rail transportation routes are located close to the cities, and often passing through heavily populated areas. Case histories have shown many occurrences of rail/train accidents involving releases of hazardous materials that posed severe risk to the surrounding population, such as fatalities and loss of property. In view of this, QRA studies have been emphasized in the field of rail transportation, to anticipate the potential accidents, assess the significance of the risks, and helps decide whether or not the risks need to be reduced. The

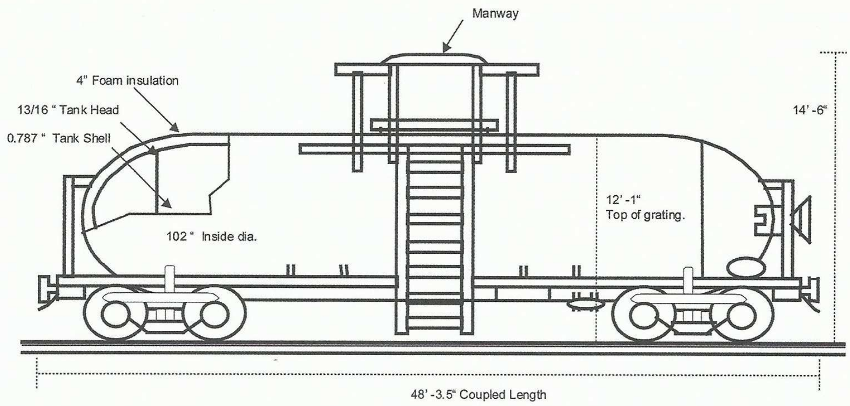

Figure 1. Rail tank car for ammonia transportation.

results of the QRA studies are then used as part of a cost benefit analysis to help determine the most effective means of reducing the risks to achieve risks that are "low as reasonably practicable."

In this study, the risk for the transportation of anhydrous liquefied ammonia by rail, from the Petronas Fertilizers Kedah (PFK) plant in Gurun, Malaysia to the Chemical Company of Malaysia (CCM) fertilizer facilities in Port Klang, Malaysia was assessed using the software package, Software for the Assessment of Flammable, Explosive, and Toxic Impacts (SAFETI) [7], together with the findings from previous failure frequency analysis and consequence modeling for the similar specified route. The overall QRA result is in the form of individual risk (IR), which depicts the risk experienced by a member of the public from the rail transportation of ammonia. Finally, the calculated results are compared to levels corresponding to the guideline IR criteria for the public in Malaysia, which stipulated that the acceptable risk level for residential areas is of 1.0×10^{-6} per year.

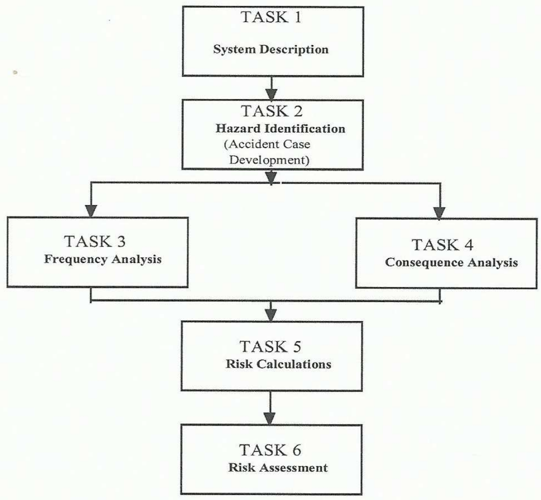

Figure 2. QRA methodology flowchart.

LITERATURE REVIEW

Quantitative Risk Assessment

Risk is defined as a measure of economic loss or human injury in terms of both the incident likelihood and the magnitude of the loss or injury [8]. It is estimated using two dimensions, which are likelihood and consequence. The likelihood may be expressed either in terms of a frequency (the number of events occurring per unit time) or in terms of a probability (the chance of the event occurring following a prior event), whereas the consequence is the degree of harm caused by the event. Risk assessment is used in many different applications and taking on different forms in each application [9]. When the estimation of risk is conducted quantitatively, it is termed as quantitative risk assessment.

In general, the basic steps of QRA include (1) system definition, (2) hazard identification, (3) frequency analysis, (4) consequence modeling, and (5) risk calculations and assessment. The effectiveness of the QRA depends on the use of appropriate generic data in the analysis, level of detail of the hazard identification process to identify a set of failure scenarios, and the use of reliable consequence models.

Previous Study on Failure Frequency Analysis

A failure frequency analysis has been performed for the aforementioned ammonia transportation route in Malaysia [10]. Our failure scenarios selection was based on the failure scenarios suggested by Rhyne [10], but with further screening to suite the actual condition. The releases considered are due to crush forces, impact forces, puncture forces, and nonaccidental release (due to faulty devices, leaks, etc.). Derailment and collision are considered as the main contributor to the rail accidents and are used for further failure scenario categorization.

Table 1. Individual risks associated with the transportation of ammonia by rail

Risk Level Criteria for Public (per year)	Effect Distance from Center of Railway Track (m)		
	Train Speed at 40 km/h	Train Speed at 70 km/h	Train Speed at 90 km/h
1.0×10^{-6}	480–600	700–870	880–950

The fault tree analysis approach has been used to determine the failure frequencies for all the identified failure scenarios. The approach used by liberty risk services [11] was adopted for the nonaccidental release scenario in this study, whereas the structure of the fault trees for the other scenarios (i.e., crush, puncture, and impact cases) was based on similar structures as used by Rhyne [10]. Because the probability of ammonia release upon a rail accident is depending on the hole size and train speed, three different hole sizes (25 mm, 100 mm, and rupture) were used to represent the infinite number of possible release sizes [12] and three train speeds (40, 70, and 90 km/h) were considered.

The study also highlighted the importance of human error contributions in the failure frequency analysis. The human error probabilities (HEPs) of the train driver were assessed by using the Human Error Assessment and Reduction Technique (HEART) [13,14], in parallel with the fuzzy arithmetic approach.

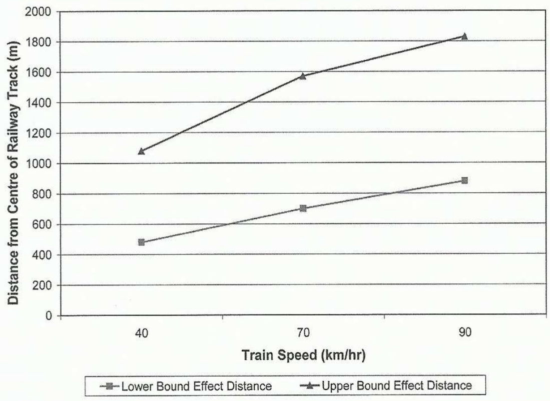

Figure 3. IR results at different train speeds. [Color figure can be viewed in the online issue, which is available at **www.interscience.wiley.com**.]

Previous Study on Consequence Analysis

The consequences of the ammonia release following a rail accident in the aforementioned route have been analyzed by using SAFETI. The accident events included railcar tank crush, puncture, and impact releases on the tank head, tank shell, liquid valve, gas valve, valve dome, and manway of the tank [7]. In this consequence analysis, the weather probabilities, used by the Liberty Risk Services Malaysia (LRSM) [11], were adopted. The 25 and 100 mm hole sizes are modeled as continuous releases, whereas the rupture scenario is considered as instantaneous releases.

Because ammonia is difficult to ignite in the open air, the consequence modeling concerned toxic cloud dispersion rather than fire or explosion. The toxic effects of ammonia were based on the immediately dangerous to life and health exposure limits and the "Probit equation," which were incorporated within the SAFETI program. Sensitivity analysis was also performed to identify the impacts of atmospheric conditions on ammonia gas dispersions, where a temperature range between 15 and 35°C and a relative humidity range between 60 and 90% were analyzed.

BACKGROUND OF CASE STUDY

The transportation route is 450 km length, with the majority of the train track from Gurun to Rawang is single track. Double tracks only exist near the stations where they are used for shunting and turning around of trains. From Rawang onward to Port Klang, the track changes to double track [11]. There is about 42 crossings en route from Gurun to the final destination at Shah Alam [11], and some residential areas are situated as close as 3–6 m from the track along the route. Ammonia is transported in the form of pressurized liquid above its boiling point. The total amount of the transported ammonia is 35,000 ton/year, which requires almost 70 trips in a year. Figure 1 shows the rail tank car used for the transportation risk analysis by Rhyne [10], which is also similar to the one used in this ammonia transportation case study. During the transportation, each tank car has a maximum capacity of 30 tons. However, as a safety precaution, each wagon is filled up to 25 tons to allow for the expansion properties of ammonia.

METHODOLOGY

The QRA methodology adopted for this study was based on the common approach used in the chemical process, oil and gas, and transportation industries, specifically from the approach recommended by the AIChemE [8] and DNV [9]. The methodology adopted is illustrated in the flowchart as shown in Figure 2, which includes the following: definition of the system being analyzed, identification of all potential hazards for the system defined, estimation of failure frequencies and consequence modeling for all the hazards identified, and finally calculations of the risks for the defined system. The risks are then assessed against a criterion to determine whether they are within acceptable limits or whether further analyses to identify ways to reduce the risks are needed.

RESULTS AND DISCUSSIONS

The results presented in this study are limited to the risks from accidental releases of ammonia during rail transportation mode only and do not include the risks during loading and unloading activities as well as the return voyage of empty rail tanks. Table 1 presents the overall risk results in terms of IR for the three different train speeds considered in this analysis. The IR is expressed as the effect distances from the center of the tank car to the area with a tolerable risk criteria of 1.0×10^{-6} per year The effect distances are presented as within a range due to inclusion of the lower and upper bound failure frequencies estimated after inclusion of HEPs, which were estimated using the fuzzy arithmetic approach [7] in the determination of the IRs.

Figure 3 shows the differences between the lower and upper bound IR effect distances from the center of the tank car for the three train speed considered in this analysis.

The IR results clearly show that the effect distances increase at increasing train speeds. Therefore, more people of the surrounding population along the railway track route will be exposed to risk levels higher than the tolerable criteria of 1×10^{-6} per year if the train accident occurred at higher speeds. Studies carried for the US Department of Transport [15] and by Helmersson [16] and Mazzarotta [17] also indicated similar importance of train speeds in the risk analyses of hazardous material transportation.

On the basis of the location of the surrounding population along the railway track, it is evident that most of the surrounding populations are exposed to risk levels higher than the tolerable risk limit, that is, these people are subject to unacceptable risk exposure. This is however not surprising, because the clearance zone for residential areas and industries specified by the Malaysian government is only about 15 m from the tracks. The clearance zone specified is obviously not based on a risk assessment or similar type of approach. The consequence modeling from the previous study [7] has confirmed that ammonia gases go large distances before being diluted to concentrations not harmful to people.

CONCLUSIONS

This study demonstrates the use of QRA in calculating the risk posed by the transport of hazardous material. It shows the significant effects of train speeds on the overall IR results. The effect distances to the specified tolerable risk limit of 1×10^{-6} per year for the public were assessed as increasing significantly with train accidents occurring at increasing speeds. Most of the surrounding populations along the route analyzed have been found to be exposed to higher risk levels than the tolerable limits.

Another case study concerning the transportation of ammonia is in a previous PSP article [18].

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