Quantitative Risk Assessment to Site CNG Refuelling Stations

Naser Badri, Farshad Nourai, Davod Rashtchian

Department of Chemical and Petroleum Engineering, Sharif University of Technology
Azadi Street, Tehran, Iran

This study considers the application of quantitative risk assessment (QRA) on the siting of compressed natural gas (CNG) stations and determining nearby land use limitations. In such cases the most important consideration is to be assured that the proposed site would not be incompatible with existing land uses in the vicinity. It is possible by the categorization of the estimated levels of individual risk (IR) which the proposed site would impose upon them. An analysis of the consequences and likelihood of credible accident scenarios coupled with acceptable risk criteria is then undertaken. This enables the IR aspects of the proposed site to be considered at an early stage to allow prompt responses or in the later stages to observe limitations. According to the results in many cases, not only required distances have not been provided but also CNG stations are commonly located in vicinity of populated areas to facilitate refueling operations. This is chiefly because of inadequate risk assessment studies and ambiguities to define acceptable risk criteria.

Keywords: Quantitative risk assessment; Consequence analysis; Siting; CNG station.

1. Introduction

Siting is among the earliest steps in design, and is quite costly to modify once the site is constructed. Optimum siting must minimize material and construction costs, but more importantly, must minimize the risk of losses throughout the site's life cycle. Siting provides a fundamental aspect of risk management. It separates sources of potential fire and explosion from adjacent areas that might become involved in the incident or be harmed by its potential consequences (CCPS, 2003 & Rigas et al., 2004). This is also a key component in inherently safer design. Inherently safer strategies can impact a potential incident at various stages. Inherently safer design can also reduce the potential for an incident to escalate. Lastly, an inherently safer strategy can limit the incident sequence before major impacts on people, property, or the environment by a proper siting (Cozzani et al., 2006). QRA is a measure to weigh up whether enough precautions have been taken or should be improved to prevent fatality, injury and destruction mainly in process industries. The need for QRA of process plants has become exceedingly critical due to the trend towards larger and more complex units. Moreover, the potential damage has been magnified by the proximity of many such operations to densely populated areas (Khan et al., 2002).

The flammable nature of methane (Cheremisinoff, 2000) high pressure condition and vicinity to densely populated areas are the most significant reasons which emphasize on importance of CNG station siting studies. This paper presents the QRA study carried out to evaluate a typical CNG station siting providing methane as a fuel for natural gas vehicles and the main purpose is to quantify the probable hazards and their consequences to estimate the risk to surrounding population.

2. CNG Stations Description

One of the largest CNG stations in Tehran (Figure 1a and 1b) selected as a case study to obtain required information. For this station fed by public distribution pipeline, five main components can be distinguished as follows:
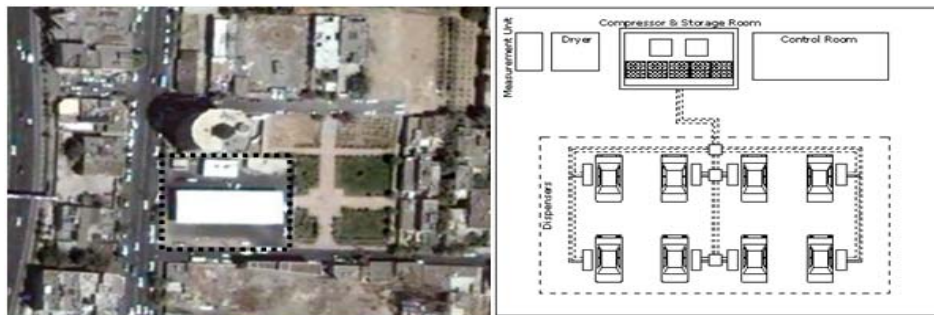

Figure 1a. Top view of selected station   *Figure 1b. Layout of selected station.*

Metering Unit: A metering unit is required at the CNG station inlet to record gas flow at low pressure (20 bar).

Dryer: The moisture content of CNG must be controlled at the filling station as it can cause operational problems in the station or the vehicle.

Compressor: This station uses two large reciprocating compressors which are electrically powered. These compressors are been designed to pressurize gas to 250 bar through three stages.

Cylinders: Compressed gas is stored in cylinders mounted vertically in each holding several cylinders. Gas is stored at three pressure levels; Low (160 bar), Medium (200 bar) and High (250 bar). There are 36 cylinders at Low, 27 cylinders at Medium and 12 cylinders at High pressure level.

Dispensers: The dispenser is the interface of the CNG filling station with the vehicles. In this station eight dispensers are connected to gas cylinders by pipeline conveying gas at three pressure levels.

3. Risk Assessment

The present study was aimed at following a systematic QRA procedure (Figure 2) to assess the imposed risk due to CNG station operation (CCPS, 2000).
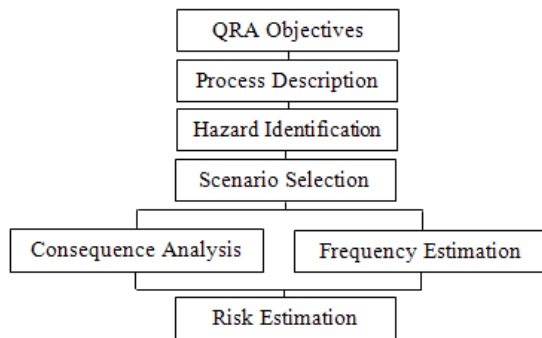
Figure 2. Flow diagram of the procedure used for QRA (CCPS, 2000)

QRA objectives and process description were discussed in former sections. Following sections complete the study.

3.1 Hazard identification and scenario selection

This step is so critical, because a hazard omitted is a hazard not analyzed. Scenarios usually result in the loss of containment of material from the process. Typical incidents might include the rupture or break of a pipeline and a hole in a cylinder or pipe (CCPS, 2007). Finally, after screening low frequency and low consequence scenarios the most credible ones in the selected CNG station have been determined as below:

Sc-01: Rupture in dryer pipes.

Sc-02, 03: 5mm and 25mm hole diameter in cylinders.

Sc-04, 05: 5mm hole diameter and rupture in dispenser pipes.

3.2 Consequence analysis

Consequence analysis is supposed to be carried out through several steps to model the effect of each scenario. Once the scenario is defined, source models are selected to describe how materials are discharged. The source model provides a description of the discharge rate and the total quantity discharged. A dispersion model is subsequently used to describe how the material is dispersed to some concentration levels. Then, fire and explosion models convert the source model information on the release into hazard potentials such as thermal radiation and explosion overpressures (CCPS, 2000). All of the mentioned steps have been modelled using PHAST 6.5 software package developed by DNV. Finally, effect models convert results obtained by software into effects on people represented by probability of death. Probit equations (Equation-1) are commonly used to quantify the expected rate of fatalities for the exposed population.

$$Y = k_1 + k_2 \ln(V) \tag{1}$$

Where Y is probit variable, k_1 and k_2 are constants and V represents the dose of hazard (radiation and overpressure). A useful expression for performing the conversion from probit variable to probability of fatality (P) is given by Equation-2 (CCPS, 2000).

$$P = 0.5\left[1 + \frac{Y-5}{|Y-5|} \text{erf}(\frac{|Y-5|}{\sqrt{2}})\right] \qquad (2)$$

All of the selected scenarios have been investigated in two different atmospheric conditions (Table 1) corresponding to day and night.

Table 1. Atmospheric conditions corresponding to day and night.

Parameters	Day	Night
Wind velocity (m/s)	2.5	2.1
Atmospheric stability	A	D
Ambient temperature (°C)	27	3
Humidity	35%	70%

3.3 Frequency estimation

Frequency estimation is the methodology used to estimate the number of occurrences of a scenario through a year. Estimates may be obtained from historical incident data on failure frequencies or from failure sequence models, such as FTA (Less, 1996). Depending on scenario type both techniques have been used to estimate scenario frequencies (Table 2).

Table 2. Estimated frequencies of credible scenarios

Scenario No.	Scenario description.	Estimated frequency
01	Rupture in dryer pipeline	7.5E-5
02, 03	5mm and 25mm hole diameter in cylinders	3.8E-5 and 1.0E-7
04, 05	5mm hole diameter and rupture in dispenser pipes	6.8E-2 and 1.7E-2

3.4 Risk estimation

One popular measure to risk monitoring is IR usually shown on a risk contour plot. The IR is defined as the probability of death at any particular location due to all undesired events. It can be expressed as the probability of a person at a specific location becoming a casualty within a year and analysed area. The calculation of IR at a geographical location near a plant assumes that the contributions of all scenario effects are additive. Thus, the total IR at each point is equal to the sum of the IR of all scenario effects at that point (Equation-3).

$$IR(x,y) = \sum IR_i(x,y) \qquad (3)$$

Where, $IR(x,y)$ is the total IR of fatality at geographical location (x,y) and $IR_i(x,y)$ the IR of fatality at geographical location (x,y) from scenario i as Equation-4.

$$IR_i(x,y) = F_i.P_i(x,y) \qquad (4)$$

Where, F_i is the frequency of scenario i from frequency analysis and $P_i(x,y)$ is the probability that scenario i will result in a fatality at location (x, y) from the consequence and effect models (CCPS, 2000).

Figure 3 presents the IR contours of the selected CNG station to investigate in detail as a case study. For example, a person located within the 1.0E-6 IR contour for one year has one chance in a million of being fatally injured by the hazards associated with releases of methane in the CNG station.
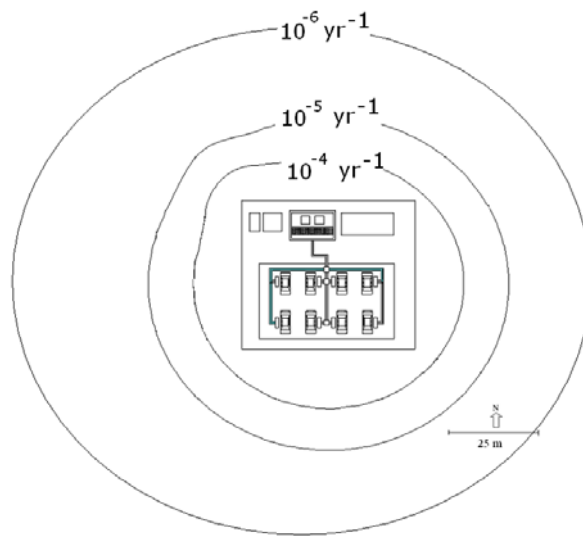

Figure 3. IR contours for selected CNG Station

When considering proposals to site a process industry or any development in its neighbourhood, four general categories of development are distinguished: industrial, shopping, housing and sensitive. Within the Inner zone (where the IR is greater than 1.0E-5 yr^{-1}) UK HSE normally advises against all developments other than small or moderate industrial developments and limited numbers of other small developments. Within the Outer zone (where the IR is between 1.0E-6 yr^{-1} and 3.0E-7 yr^{-1}) only sensitive developments are advised against. Across the Middle zone (1.0E-5 yr^{-1} to 1.0E-6 yr^{-1}) and where developments straddle zone boundaries, each development proposal is considered on its own merits (Hirst et al., 2000). By comparing these general criteria with numerical results extracted from Figure-3, safe distances from CNG station borders can be determined for each zone (Table 3).

Table 3. Safe and real distances from CNG station borders for each zone

Safe distance from station borders (m)	Real distance from station borders (m)
Inner zone (18)	-*
Middle zone (30)	12
Outer zone (82)	0

* No industrial development is available

In present case study; Sensitive locations such as houses, recreational places and high traffic roads are located exactly adjacent to CNG station borders (Figure-1a) which are absolutely advised against and these areas must be out of the Outer zone characterizing by more than 82m as a safe distance. Shopping places are also located in close CNG station neighbourhood (Figure-1b) which are advised against too and they must be out of the Middle zone characterized by more than 30m as a safe distance.

4. Conclusion

As shown in Figure-3 and Table-3 there are such calculated distances between CNG station and general acceptable risk borders that usually are not followed (e.g. present case study), these distances usually are not intended more important in comparison with other aspects to determine proper distances such as site area value and accessibility for vehicles.

Obtained results obviously introduce many limitations to site a CNG station toward following all acceptable risk criteria for all construction developments, these limitations show that a large number of parameters should be considered to select optimal site for a CNG station in a populated city. This undesirable outcome is almost always present; to ignore these criteria means imposing unacceptable risk on people living and working in the neighborhood. The number of CNG stations and their close vicinity to populated areas, residential and office buildings and other reasons, especially in Iran, prove that enough studies have not been taken in this field. Thus, although CNG stations have an important role in the country's economy and environment but it creates a source of hazard which its evaluation is still a challenging research. On the other hand, lack of studies to define acceptable risk criteria for different societies is clearly a deficiency.

References

CCPS, 2000, Guidelines for Chemical Process Quantitative Risk Analysis, 2nd ed., AIChE., New York.

CCPS, 2003, Guidelines for facility siting and layout, AICHE, New York.

CCPS, 2007, Guidelines for Hazard Evaluation Procedures, 3rd edn, AIChE, New York.

Cheremisinoff, N.P., 2000, Handbook of Hazardous Chemical Properties, Butterworth-Heinemann., London.

Cozzani, V., Tugnoli, A., and Salzano, E., 2006, Prevention of domino effect: From active and passive strategies to inherently safer design, Journal of Hazardous Materials, 139, 209.

Hirst, I. L., and Carter, D. A., 2000, A Worst Case Methodology for Risk Assessment of Major Accident Installations., Process Safety Progress, 19 (2).

Khan, F.I., Abbasi, S.A., 2002, A criterion for Developing Credible Accident Scenarios for Risk Assessment, Loss Prevention in Process Industries (15).

Lees, FP., 1996, Loss prevention in the process industries, 2nd edn, Butterworth Heinemann., Oxford.

Rigas, F., and Sklavounos, S., 2004, Major hazards analysis for populations adjacent to chemical storage facilities, Process Safety and Environmental Protection, 82 (4).