A Case of Quantitative Risk Assessment of Dangerous goods Container Yard in Chinese Port

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Abstract: The safety management of dangerous goods container yard has drawn great attention from Chinese society and regulatory authorities since a particularly serious fire and explosion accident happened in Tianjin Port on August 12, 2015. The clause "large and medium-sized hazardous chemicals depots should maintain a distance of at least 1,000 m with surrounding public buildings, industrial and mining enterprises" of a Chinese national standard "Opening Conditions and Technical Requirements for Hazardous Chemicals Operators" aroused much controversy. This study attempts to research whether the yards which were surronded by crowded places such as public buildings in the 1000m area could be reopened through the method of quantitative risk assessment. Taking a small yard in the southeast coast of China as an example, category of dangerous goods could be division 6.1, class 8 and class 9 by analyzing the class of goods to be transported. And on the basis of that, individual risk value and societal risk value of the yard are calculated as the number of containers increases. The maximum amount of contaniers in the yard is got when the individual risk value or societal risk value reaches the standard limits.

Keywords: QRA, Societal Risk, Individual Risk,Dangerous goods Container, TNO.

1. INTRODUCTION

A particularly serious fire and explosion accident occurred at the dangerous goods warehouse of Ruihai Company in Tianjin Port on August 12, 2015 . The accident caused heavy casualties (165 deaths, 8 missing persons, 798 injuries) and   huge property damage (direct economic loss is $1.06 billion). According to the accident investigation report[1], the direct cause of the accident is as follows, spontaneous combustion of   nitrocellulose in the container occurred due to accumulating heat, and this induced long-term and large-scale combustion of nitrocellulose and other dangerous goods in adjacent containers, result in explosion of dangerous chemicals such as ammonium nitrate in containers. The energy of the explosion is equivalent to 500 tons of TNT by assement[2].

The accident has aroused great concern from the domestic and international community. The management of the storage and transportation of dangerous goods containers in the port has received great attention from the social and regulatory authorities. Particularly,dangerous goods containers are required to pile up centrally and set at special yards in Mainland China.

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In this incident, the clause "large and medium-sized hazardous chemicals depots should maintain a distance of at least 1,000 m with surrounding public buildings, industrial and mining enterprises, etc." of a Chinese national standard "Opening Conditions and Technical Requirements for Hazardous Chemicals Operators" (GB18265-2000) aroused much controversy.

At present, more than half ot the 21 port dangerous goods container yards in Mainland China are surrounded by public buildings within 1,000 m according to investigations.Some dangerous goods container yards have to be temporary suspended. It was pointed out later that "1000m is just a requirement for the distance between large explosive warehouses and surrounding facilities". But there is no relevant standard specification for the safety distance between the surrounding sensitive facilities and yards of no pile of explosive goods containers.

According to the "Individual Acceptable Risk Criteria for the Production and Storage of Dangerous Chemicals and Socially Acceptable Risk Standards (Trial)" and its interpretation[3], the external safety protection distance for production and storage of dangerous chemicals can be determined by quantitative risk assessment.

From another perspective, in order to solve the problem of whether or not the current dangerous goods container yards can continue to operate and how to operate, it is necessary to study how to control the risk value of the yards at acceptable level under the condition that the external distance is established.

According to the theory of quantitative risk assessment, the factors that affect the risk value include the probability of the accident and the expected consequences. The probability of an accident is generally obtained by statistics within the industry, and can be corrected according to the actual situation of the company. The main factors affecting the consequences of accidents include the characteristics of dangerous goods and the total amount of dangerous goods. The following section will explore how to control risk values from mitigating the severity of consequences of accidents.

2. Research of A Case

2.1. Backgound of the Case

A dangerous goods container yard (Figure 1) in a port on the southeastern coast of China is taken as an example. There are three residential areas within the range of 380~760m around the yard. The population informations of residential areas are shown in Table 1.

The dangerous goods piled up in the yard in recent years include categories 3, 4, 5 , 6, 8 and 9. Since categories 3, 4 and 5 have relatively high hazards of combustion and explosion and low traffic volume . It is suggested that containers holding cargoes of classes 3, 4 5 are loaded and removed directly from the port, not piled up in the yard anymore. Only containers holding cargoes of division 6.1 and classes 8, 9 are piled up in the yard.

Characteristics of dangerous goods are analyzed as follows in this situation. Goods of division 6.1 are not only toxic, but some are also flammable. When the concentration reaches the explosion limit, they may also explode, such as acrolein, methyl chloroacetate, etc. Some goods of class 8 are also flammable and explosive, such as acrylic acid, ethylene diamine, acetic anhydride, etc. Some of the 8 corrosive substances are also toxic, such as red smoke nitric acid, fuming sulfuric acid and so on. The hazardous properties of these cargoes may be mainly toxic and flammable which may cause large-scale damage to the surrounding population. Therefore, it is necessary to control the risk value by limiting the number of containers with goods of divison 6.1 and class 8 with a secondary hazard of 6.1 or 3.
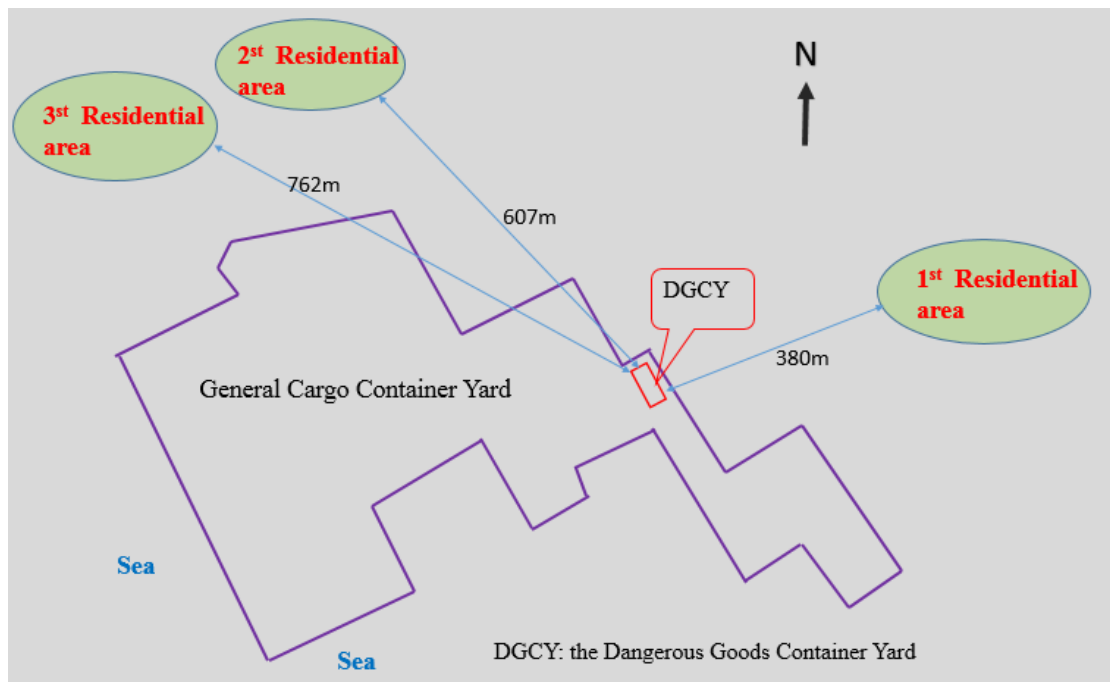

Fig 1: The dangerous goods Container Yard of One Port in Southeast Sea of China

Table 1: Population information of residential areas around the yard

	Place Name	Number of People
1	1st residential area	1800
2	2st residential area	1200
3	3st residential area	900

2.2. Tool Used in Quantitative Risk Assessment

The quantitative risk assessment tool used in this study is the TNO-RISKCURVES-QRA software which is produced by the Netherlands Organisation for applied scientific research[4]. The software includes leakage modules, diffusion modules, combustion, radiation , explosion, and toxic modules, and it will present calculation results in a range of ways, including individual risk contours, FN curves and risk ranking reports.

2.3. Main parameters of quantitative risk assessment

2.3.1. Loss of containment events(LOCs) and its' frenquencies

Table 2 shows the Frequencies of LOCs for single-containment tank according to the TNO Purple Book[5]. This assessment selects the immediate release of instantaneous leaks for calculation based on the principle of consindering the most dangerous situation.

Table 2: Frequencies of LOCs for single-containment tank

	Instantaneous	Continuous 10 min	Continuous Ø10 mm
Frenquencies	5×10^{-6}/year	5×10^{-6}/year	1×10^{-4}/year

2.3.2. Selection of cargo types

Acrolein with high flammability, high toxicity and wide explosion limit is selected as representative cargo species to simulate, according to the list of division 6.1 (toxic substances) in the *Recommendations on the Transport of dagerous goods: model regulations* [6] . The physical and chemical properties of acrolein are shown in Table 3.

Table 3: Physical and chemical properties of acrolein

Name	Relative air density	Boiling Point(k)	Flash Point(k)	Upper Explosion Limit(%)	Lower Explosion Limit(%)	LC50 (mg/L)
acrolein	1.9	326	247	31	2.8	0.018

2.4. Assessment Process and Results

2.4.1. Physical Effects of Release of Acrolein from Containers

Liquid acrolein may flow on the ground to form a liquid pool when it releases from the container. At the same time, a part of acrolein will volatilize into the air because of its small steam pressure. The gas clouds are gradually dissipated and the surrounding people who inhals toxic vapors may be acute poisoning as long as the cloud is not ignited. Only fire occurs if direct ignition occurs. Flash fire or a strong explosion wave may occur if there is delayed ignition when a large number of steam clouds have formed. It is to be modelled using two independents events, namely, a purely flammable event and a purely toxic event[5,7]. The tree of events is shown in figure 2. Risk values of purely flammable event and purely toxic event are calculated seperately, because these two events can not happen at the same time. The methods to calculate individual risk and societal risk are outlined in 'Purple book'[5].
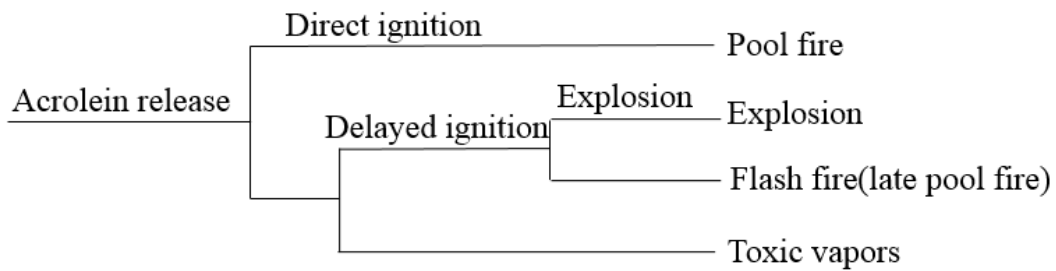
Fig 3: Tree of events for the release of acrolein from containers

2.4.2. Risk Calculation for a Single Tank Container

Risk value is calculated based on assuming that 1TEU(20-foot) tank container which is full of acrolein bursts instantaneously when a purely flammable event occurs . The individual risk contour map and the societal risk F/N graph are shown in Figure 3 and Figure 4 respectively.

According to the stand of "Measures for the Supervision and Administration of Major Hazardous Sources in Ports (Trial)"[8], there are no high-sensitivity sites (such as schools, hospitals, kindergartens, nursing homes, etc.) , important targets (such as party and government agencies, military administrative areas, cultural relics protection units, etc.) and special high-density venues (such as large stadiums, large transport hubs, etc.) in the personal risk curve with a contour line(green line) of 3×10^{-7}/year. An individual risk curve with a contour line(yellow line) of 1×10^{-6} /year exists within the yard. The societal risk criteria (F-N) curve is within the acceptable zone.
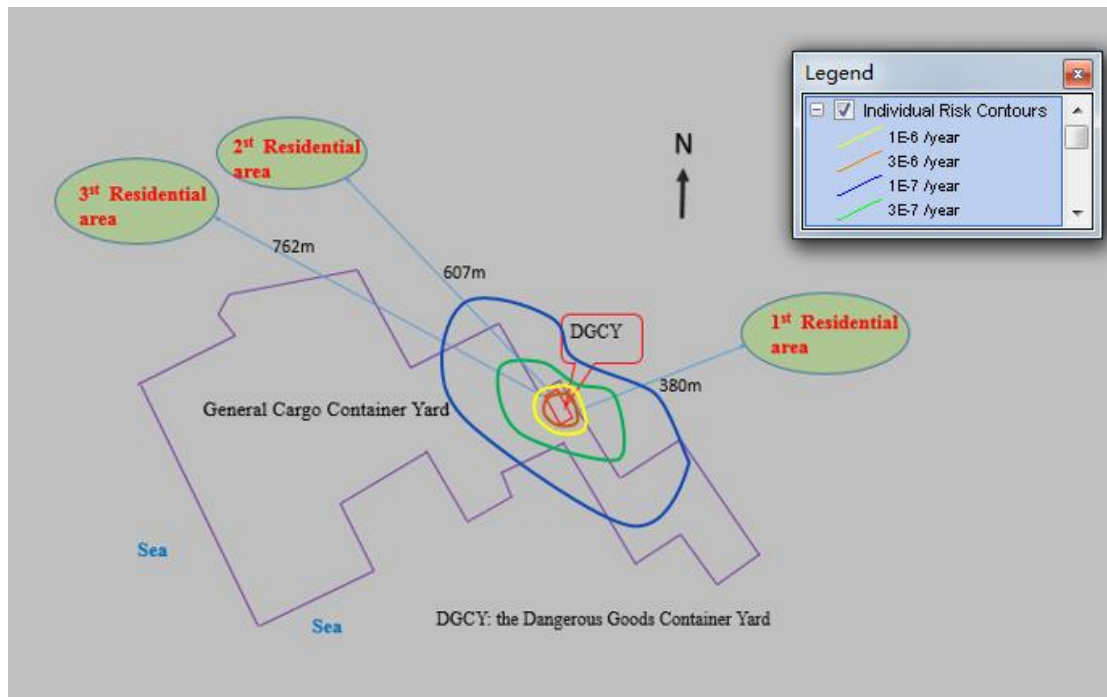

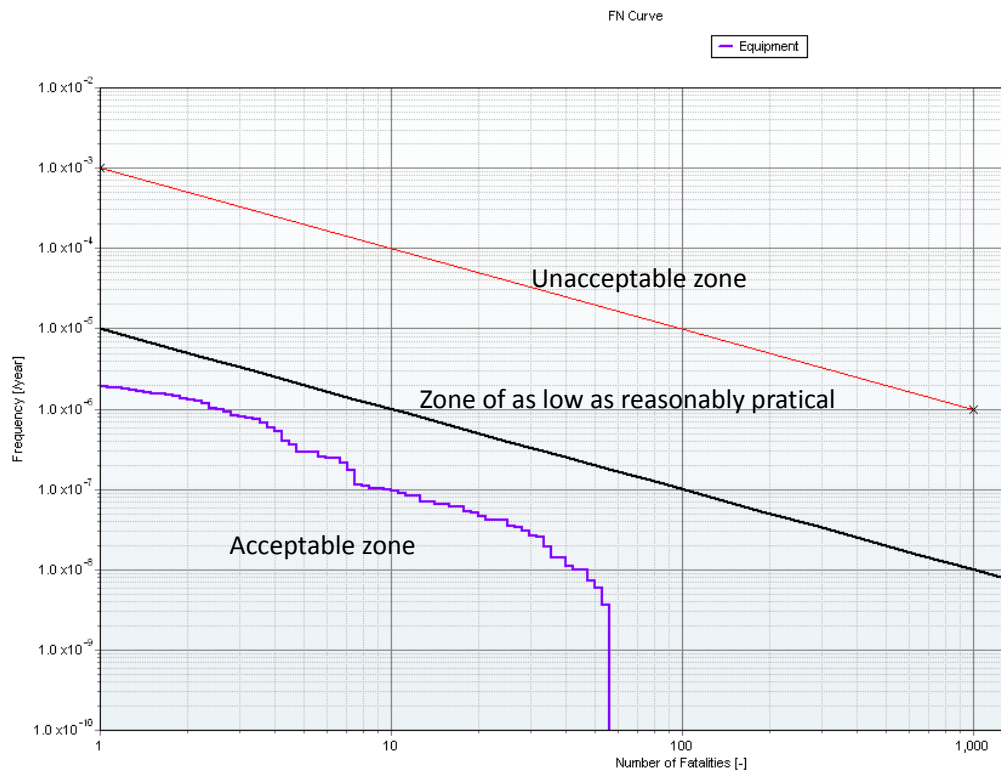**Fig3: Individual risk contour of LOC for 1TEU tank container which is full of acrolein**

Fig 4: F/N curve of LOC for 1TEU tank container which is full of acrolein

2.4.3. Maximum Amount of Containers when Risk Value reaches the Standard Limit

From Figures 3 and 4, it could be seen that LOCs of 1TEU (20-foot) tank container has no personal resident in the allowable individual risk curve of 1×10^{-6} /year. Social risk is also within the allowable area. The risk value increases as the amount of containers increases. The individual risk curve of 1×10^{-6}/year is close to the 2st residental area(see figure 5) when the number of containers increases to 8TEU, and the F-N curve has entered the zone of as low as reasonably pratical but not entered the unacceptable zone(see figure 6).
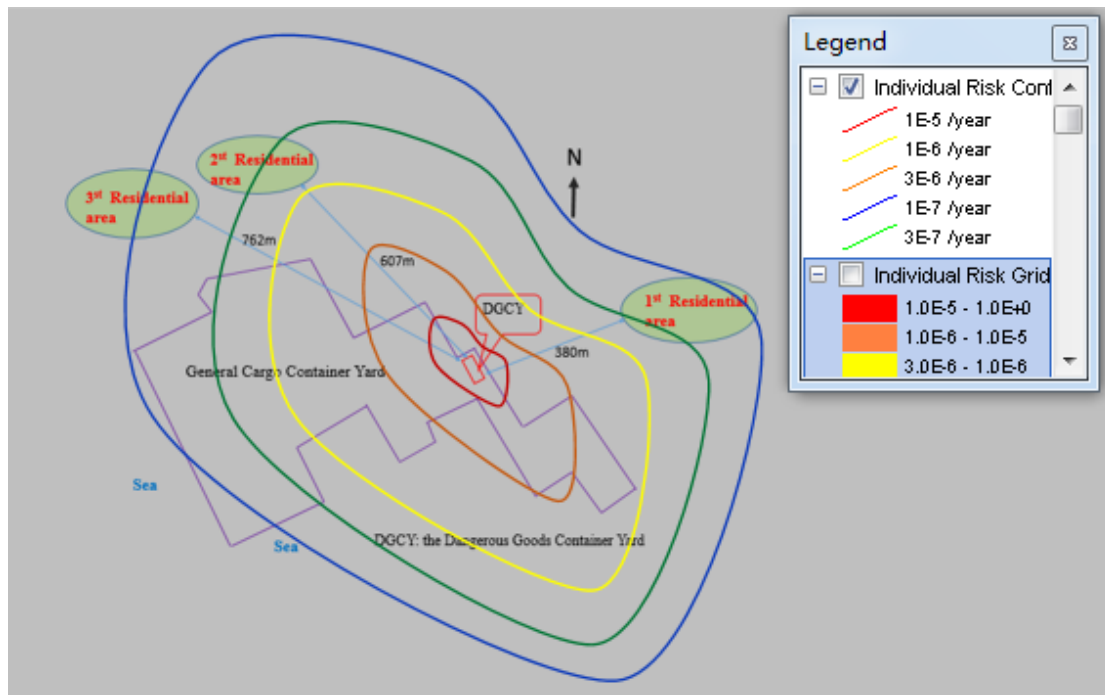
Fig 5: Individual risk contour of LOC for 8 TEU tank containers which are full of acrolein

2.4.4. Risks Checking for 8 TEU tank containers of Acrolein when a purely toxic event occurs

Risk values of purely toxic event are calculated in the same way as the purely flammable event. Individual risk for 8 TEU tank containers of acrolein is slightly lower. Both individual and societal risks are within the limits of the standard requirements.

2.4.5. Risks Checking of LOC for 8TEU tank Containers with Other Typical Toxic Substances

In order to further verify the reliability of acrolein as representative species,some other toxic typical goods of division 6.1, such as phenol, aniline, and hexachlorocyclopentadiene, are selected to calculate their individual risks and societal risks. All risks are within the limits of the standard requirements according to the calculation results.

2.4.6. Application of Evaluation Results

The following conclusion could be obtained through the above anyalysis: under the current internal and external conditions, if only containers with goods of division 6.1 and class 8, 9 are piled up in the yard, and the number of containers with goods of division 6.1 and class 8 with a secondary hazard of 6.1 or 3 is no more than 8TEU, the risk of the yard is acceptable.
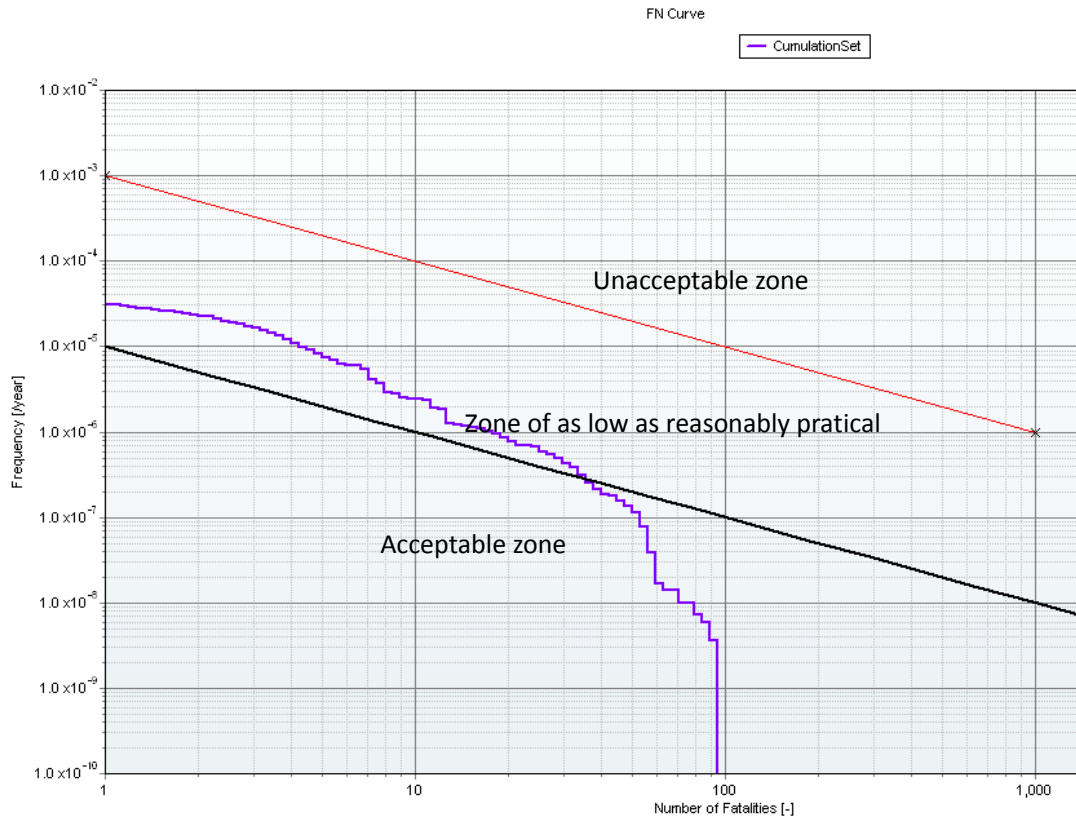
Fig 6: F/N curve of LOC for 8 TEU tank containers which are full of acrolein

2.5. Discussion of the case

The risk analysis of the case above is based on a specific cargo type and a specific LOC. But the actual situation is very different. First, only liquid cargo with combustion, explosion or toxicity is considerd durling the analysis, if there are other types of cargo, such as class 4 and class 5, how to deal with them. Second, there are many kinds of other types of containers besides tank containers and the loss of event is also very complex, the above model is not suitable anymore.

What is more, the reliability of the major conclusion obtained in this case is based on the software used, and may be it is necessary to use other software to validate it in the future research.

3. Conclusions

In the Chinese port, all dangerous goods containers are required to be piled up centralized in the yards. And this requirement will not change in a short time. The case above provides an idea for the management of of dangerous goods container yards in this situtation:the risk of sensitive facilities around dangerous goods containers yard can be controlled at an acceptable level by controlling the type and quantity of containers since the external distance is established.

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