A RISK ASSESSMENT MODEL APPLIED TO TRANSPORTATION PROBLEMS

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This paper describes how a computerised risk assessment package SAFETI has been used to assess the risks of the rail transportation of chlorine as part of a larger exercise. A brief description of some parts of the model is given to illustrate how it has been possible to use it for a transient hazard. Some of the problem areas are discussed, and an indication is given of how the risks are presented in terms of isorisk contours and/or F-N curves.

INTRODUCTION

Some 5 years or so ago Dienst Centraal Milieubeheer Rijnmond (DCMR), the environmental department of the public authority in the greater Rotterdam area, embarked on an exercise to assess the risks from 6 hazardous objects of different types in their area. The results of this exercise, the COVO study, are now well known, DCMR (1). In the subsequent years both DCMR and the Dutch Ministry responsible for Environmental Affairs, now VROM, sponsored development projects in order to establish simpler but still satisfactory methods which would permit the risk to be assessed of the whole of the hazardous material inventory in the Rijnmond area. This development in methodology carried out by Technica has been described in a recent paper by Ale and Whitehouse (2) and will only be briefly summarised in its final stages in this paper.

The application of this computerised method of risk assessment using the package known as SAFETI (System for the Assessment of Fire Explosion and Toxic Impacts) has continued during the last few years to a number of large and small projects. Whilst originally designed for application to plants, its use has been extended, by relatively simple adaptions, to other types of installations. This paper will descibe its application to risks from the transportation of hazardous materials. The particular features of this project were the transient nature of the hazard which is usually static in plant situations, and to the increased area subjected to risks as a result of the movement along extensive routes in the area.

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The project considered the movement of ammonia and chlorine by bulk sea carrier, barge, road, rail and pipeline. To illustrate the methodology, the example described here will be the transport of liquid chlorine by rail. This has been modelled elsewhere on several previous occasions and results have been compared by Harris (3) but the SAFETI package provides a very significant improvement in the quality of such risk assessments.

CHLORINE TRANSPORTATION BY RAIL

Although chlorine is manufactured by one company at Botlek, the demand for chlorine in the area greatly outstrips the supply. Consequently, the shortfall is brought into the Rijnmond area from other manufacturing sites in the Netherlands. Road transport of liquid chlorine in bulk is not permitted, so this movement is made by rail. The various authorities require it to be conducted in dedicated chlorine trains moving direct from site to site. This movement is required to take place at night, between midnight and 6 a.m. when the extensive passenger traffic on the NS rail system is minimal. No other trains may move in the area whilst the chlorine train is in transit. This has two effects. Firstly the meteorological and population files required are the nighttime ones only, discussed later, and secondly, the risk of collision is reduced by the elimination of the second moving train as the cause. Speed is also restricted to 60 $km.h^{-1}$ which is less than the track limit in many instances.

The amounts transported total about 154,000 te/yr with a near equal split between a route into Rijnmond from the north east which is diesel hauled, and therefore proceeds direct to Botlek and a route from the south east which is electric hauled as far as the Kijfhoek marshalling yard where a diesel locomotive replaces the electric locomotive.

The tank cars and rail system

The rail tank cars used in the Netherlands come from several tank car operators. They are on 4 axles and typically have a capacity of about 57 te, have no openings below normal liquid level, are fitted with remote operable valves which close automatically on demand, but no relief valve. They conform to RID regulations. They are unlagged and as such regulations forbid them being moved in any train in proximity to flammable materials. Without this lagging they are of course vulnerable to BLEVEs, as at Mississauga, but unlike that accident, they are unlikely to be in the same proximity as such an incident. Furthermore, the absence of combustible lagging also prevents failure due to ignition of the lagging which could lead on to an Fe-Cl burn hole occurring in the gas space, as happened to one tank car in the Montanas accident (4).

The main risk to the integrity of these tank cars as is a result of collision or derailment. Hence the curtailment of train speed and other train movement in the same locality have positive effects on the potential accident rate. The ease of puncture of a tank car is known to be related to strength of the vessel, speed at impact (or perhaps deacceleration forces), and sharpness of puncturing object. Very sharp objects, such as the moving part of a track switch have penetrated fuel tank cars at very low speeds, but liquefied gas tank cars are much thicker and stronger. North American chlorine tank cars are very thick at their ends, but have been unable in some derailments to resist penetration by the massive coupler when this disengages. They have therefore retrofitted shelf couplers to prevent disengagement.

RAIL ACCIDENT DATA

There are no direct statistical accident data available for chlorine on which to base any assessment, so recourse is made to wider and more extensive data bases. Consideration was given to data in Table 1 amongst others.

Table 1 Some Rail Accident Data and Estimated Accident Rates

	In Accident* per train km	In Accident*	Damage only	Minor Leakage	Major Leakage
		per wagon km			
(a) DATA					
European LPG tank cars (10systems)	-	-	1.35×10^{-7}	5.4×10^{-8}	1.4×10^{-8}
NS Freight Trains 76-82	0.88×10^{-6}	3.4×10^{-8}	-	-	-
BR Freight trains 76-82	0.35×10^{-6}	-	-	-	-
US 1981	5×10^{-6}	-	-	-	-
* Accident = Collisions plus derailments					
(b) VARIOUS ESTIMATES for Chlorine Rail Tank Cars					
Finland			4×10^{-8}	0.4×10^{-8}	
Netherlands				1×10^{-8}	0.1×10^{-8}
U.K.				1×10^{-8}	
US				6×10^{-8}	1.5×10^{-8}

An alternative method of assessing the detailed failure rates to supplement the overall system rate is to examine the location and number of track and operating hazards, e.g. switches, tight bends, level crossings, and marshalling activities. These have been examined in the course of this project, and the base failure rates for plain track for major and minor losses of containment are supplemented according to systems based on the degree of potential hazard. As an example an obstruction on a level crossing, many of which are automatic in operation, can lead to a derailment and possibly to a release. The risk is small but is nevertheless in addition to plain track hazards. It is modelled as an additional failure rate for the 100 m square in which it exists. Marshalling activities have been notorious as the cause of many accidents to freight wagons. The chlorine trains are not marshalled, but are assembled locally. They may enter the Kijfhoek marshalling yard where the electric locomotive is replaced by a diesel for the final transit along the non-electrified line to Botlek. No marshalling occurs.

With the ability to identify and locate accident possible locations with an accuracy of 100 m, the potential for improving the predictions using the SAFETI package is great, but it is essential to ensure that the overall accident rates for this more detailed approach are compatible with the general system accident rates.

CHLORINE TANK CAR FAILURE SCENARIOS

Some of the less likely events have already been discussed, and the remainder fall into three groups which are used in the assessment. Least likely (only one has ever occurred) is an instantaneous release of all the tank car contents in a rupture. Next most likely is a puncture of some kind, and the calculations are based on a continuous release through a 75 mm equivalent diameter hole, probably below liquid level in a filled tank car under pressure. Thirdly, and the most likely are very small leakages, the effect of which is generally so localised that only those immediately involved could suffer serious injury. After checking, these were therefore excluded from the fatality calculations. Any error in the F-N curves, discussed later, due to this omission will be at N=1 or 2 range, and the ratio of such incidents is not greater than a factor of 10 up, but the ratio of such effects would be increased much less than 10.

The releases will usually take place on the track where most of the liquid ejected and raining out will fall. This is permeable ballast which will add to the vapour rate. A suitable increase in the adiabatic flash rate is therefore included in the calculations.

The dispersion of these vapour releases will be as dense gas clouds, visible by day, and pungent at all times. Their effects are calculated in the SAFETI model using the method of Cox and Carpenter (5). As with almost all dispersion models, no allowances are made for the effect of obstructions, dykes, ditches, canals, etc. In general the area is flat, with the railway line elevated on embankments in many places.

TOXICOLOGY

Although the general toxicology of common toxic gases such as chlorine and ammonia has been known for a very long time, the quantified effects involving lethality to humans are still relatively ill defined. Recourse has to be made to small animal test data in order to provide any reasonable quantification. Accordingly, the US Coast Guard in 1975, as part of the first stage of their Vulnerability Model (6) had prepared a probit equation for chlorine lethality to humans. Over the succeeding years this was tried in various assessments, and also checks were made in retrospect for certain reasonably documented accidents. In most cases it appeared that the USCG probit equation overestimated the number of fatalities.

As further experience and test data became available, two independent reviews were conducted in 1984. One was by a Working Party of the I.Chem.E's Loss Prevention Panel who will be reporting in 1985 (7) The other was conducted at M.I.T. on behalf of the DCMR project committee and used by them, in conjunction with other data, in drawing up a new probit equation. The one selected has general agreement from all parties concerned and the LC50 line lies amid the bulk of the animal LC50 test data. The equation, with c expressed in ppm and t in minutes as used in this project is

$$Pr = 0.5 \ln (C^{2.75}t) - 5.3$$

This indicates 50% chance of lethality at slightly greater concentrations than predicted by the USCG, whose probit was used in the COVO study. This might not be the ultimate version, but any future changes are likely to be only very minor.

Mitigation and Escape

The gas dispersion model will predict for selected wind and weather conditions the concentration and duration of the cloud at a series of downwind distances (permitting interpolation in between). By reference to the probit equation, the probability of death can be assessed by inserting the corresponding values of C and t. Thus the probability can be assessed with distance and hence, by addition of weather probabilities and accident frequencies, individual risk rates can be assessed at a series of locations. The SAFETI package can in fact carry out the permutations to provide this data based on a 100 m x 100 m *grid array, and from the matrix it can then draw iso-contour risk lines for* say 10^{-5}/year, 10^{-6}/year, 10^{-7}/year etc.

Such a model is relatively straight forward to set up, but it contains one flaw which must be dealt with. The very nature of the toxicity probit is to say for instance that there is a 50% chance of being killed if exposed at that location to a chlorine concentration of 400 ppm for say 30 mins. It does not follow that any one or every one at that location will remain there, unmoved, for 30 minutes. Such reaction would be most unnatural. Even at Bhopal people tended to try and escape despite their total unpreparedness and the night time conditions obscuring any "cloud" effects. Nowadays, emergency planning is encouraging those outdoors to go inside and shut doors and windows, but many people will already be inside, particularly at night. So in an area like the Rijnmond, a significant degree of avoidance or mitigation is expected to occur. This is included in the modelling, with different factors applied to night and day conditions. It remains however an area of some uncertainty, demonstrating the vital need for a degree of disciplined public "first aid" among local communities.

In addition, there are problems of toxicology associated with intermittency, as such toxic gas clouds are never homogeneous (8). However, it is absolutely essential to match modified toxicology incorporating intermittency factors with the corresponding dispersion estimates also incorporating such variation factors. At the present time the latter is not yet developed adequately for use, so the overall adjustment cannot justifiably be made without introducing positive bias to the results. This has not been included and awaits the detailed deliberations of those studying the results of Heavy Gas Dispersion Tests at Thorney Island, Maplin Sands and China Lake.

SOCIETAL RISK

In the Netherlands it has been possible, using census data and postal address data to draw up population densities for each 500 m x 500 m square of the National Grid. And by more careful attention to detail, and a major increase in effort, this data can be applied to each 100 m x 100 m square.

So if we are able from the gas dispersion model coupled to the probit equation to estimate,for each release, the probability in each square of being killed, it is possible with the addition of the population density to assess the number of people likely to be killed together with the related frequency.

The SAFETI package can assess this for each incident and each square, and by keeping a file it is possible to summate this data and present it in a F-N curve, the frequency of killing N or more people. Mitigating factors must be included as before, but a further complication arises in the use of two population files, thus necessitating all such calculations being repeated twice for each file.

The night population allows for everyone being at home, less those shift workers who are on site. The day file allows for the absence from home of those shift workers and day works who are now on site. Allowance is also made for workers who live outside the area. Difficulty is however experienced in commercial areas, especially where occupancy is variable as in shopping or sports centres. Since the production of a third population file would increase computation by at least 50%, it is better to concentrate on two good quality files, for day and night (which match day and night meteorological files). In the particular example here, of chlorine transport in bulk by rail, only night time movement is permitted, so it is necessary only to use the basic nighttime files for the Rijnmond area.

RESULTS

The graphical results of this exercise will be shown at the symposium. As expected, the risk contour lines (e.g. for 10^{-6}/yr individual risk) tend to run parallel to the rail track at distances related to the level of risk and the rate of decay of risk levels. In general levels of toxic risk decay more slowly with distance than do flammable risks. Another feature of the results is the concentration of risk on the inside of major bends in the routes of which there are several, and around specific nodes where the hazards are greater than from plain track, e.g. at crossings and in marshalling yards.

Finally, although a change in the total amount moved annually along a certain route might occur, no change would be expected in the sizes of incident, e.g. the number of people killed or injured, but there would be a proportionate change in the frequency, and hence in the risk contour levels. The effect on the F-N curve would be a displacement to larger or smaller F values for the same values of N. However, if the movement were to change in character in any way, for instance a change in size of rail tank car or the method of operation, then more significant changes in risks would occur.

SAFETI has the ability to reprocess the information, using previous exercises, and rapidly identify the actual change in risk. In fact this sort of comparison generates greater confidence in the results than existed in the absolute values which had been calculated. It has already proved an invaluable aid in another exercise of route planning where a reduction in societal risk was sought.

In the transportation exercise for the Rijnmond area, the risks for the transportation of liquid ammonia and liquid chlorine were assessed and compared. They can be added together as is the real case, and the relative contribution to the total of each material and of each mode assessed. From the wide variety of quantified data and information now available, the Rijnmond Authority are able to make more meaningful decisions on the future policy for transportation of hazardous materials in the light of the knowledge of the relative importance of the various contributing factors which have been highlighted in the overall exercise.

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