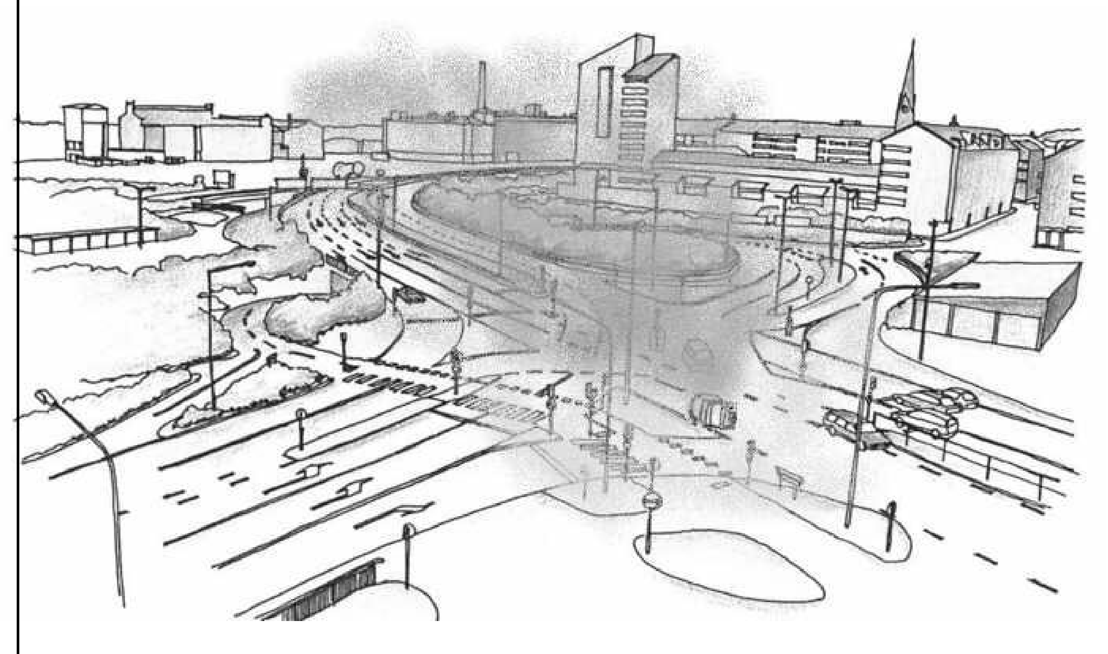
Risk Evaluation in Physical Planning

The Tretorn-area Helsingborg



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Appendices

1 Introduction

This project is a part of a course at LTH: "Physical Planning " where risk issues are closely looked at and connected to the total physical planning of the Tretorn-area in Helsingborg.

Helsingborg's site by the coast makes it ideal for in- and export from Sweden. This can be essential for some industries like the chemical industry where the need for continuous transportation can make the difference in hard concurrence. This also involves extra risks for the neighbourhood of the industries and the area close by the transportation ways.

The Tretorn-area is placed south of the central part of the city and is an old industry area and is today mostly occupied with offices and small-scale industry. Close by the area is heavy transport and hazardous goods are an essential part of that traffic. A shunting yard is also placed close by, where great amount of hazardous goods is shunted every day.

The object of this report is to gain an understanding of the risks in that confronts the Tretorn-area in Helsingborg. The judgement shall be based on risk identification, analysis of frequencies of certain incidents and possible consequences based on those.

Three cases will be analysed in full detail and an individual risk will be given for each case. Some simplifications have been done and no special risk analysis has been undertaken "in site".

2 Risk Analysis Methodology

In this Chapter the different steps in the risk analysis will be discussed and connected to the chapters of this report.

2.1 What is a Risk?

Put in word, the risk can be set as the frequency for an incident to occur times the consequence from that particular incident. In mathematical form it is stated as:

$$Risk = Frequency \cdot Consequence$$

It is worth to mention that the word "risk" is often used wrongly, only connected to the consequence of the incident. This should be avoided, as in many cases great consequences often happen very seldom and the frequency of the incident is low, resulting in a low risk for that specific incident.

2.2 The Steps in Risk Analysis

It is important to realise that before a risk can be assigned, there are several steps that must be taken on the way. These steps will be listed in this Chapter.

2.2.1 Risk Identification

The first step is to identify the possible risks that might influence the area in question and is done with a "risk identification", a course listing of all the risks that may influence in the area. The essential information needed for the "risk identification" is information about what chemicals are present in the area, in what amount and their placement.

This coarse risk identification should be combined with a simple frequency and consequence assessment. This is necessary to be able to rule out the unimportant objects and short the list that have to be looked at more closely in later steps. Some simplified ranking of the risks may also be possible and that could ease the priority settings for the different risk objects.

2.2.2 Risk Calculation

The risk can be calculated in two ways, with simple calculation methods or with the aid of computer programs. The two methods should be combined in order to minimise failures.

While there are several tools that makes it possible to calculate the consequence of a certain incident, the frequency assessment might possess a larger problem. Available data for frequency of incidents are rare and assumptions often have to be made in order to obtain a value.

Frequency can be assessed quantitatively or qualitatively. In the quantitative method a value for the frequency is set. This is often hard to do as mentioned and in stead a quantitative method is used where the frequency is coursed ranked.

The calculation should lead to a risk as a function of the distance from the incident.

2.2.3 Individual Risk

The risk mentioned above is actually the individual risk (IR) or "the risk to a person in a vicinity of a hazard" [CPQRA]. To account for the possibilities that different incidents may happen at the same time, all possessing a certain risk to the individual in the area, individual risk contours may be used.

With individual risk contours the effect zone of each incident is selected from the consequence calculation and the frequency is then applied to the effect zone. In the case the location is wind dependent that have to be taken into account and the frequency will be less. Dispersion is for example wind dependent while explosions can be considered as independent of the wind direction. The contours are then summarised to give a better total picture of the risk for the area in question.

A more detailed description of the calculation of individual risk contours will be given in Chapter 7, "Individual Risk".

3 Regulations

In the resent years, the questions regarding risk and risk based safety for individuals and society have been put forward, these leading to regulations that take those questions into account.

Members of EU have to fulfil the Sevesto directives, which are directives regarding chemical accidents in some industrial activation. Many regulations are more or less effected by the Sevesto directives as seen later in this Chapter. These are only minimum requirements and the activities under which the directives apply are:

1. Identification of risks for great accidents.
2. Take necessary precautions.
3. Provide the personnel with information and education.
4. Security information to governmental organs about chemicals stored in certain quantities.
5. Provide governmental organs with information if accident takes place.

In the planning of society it is important to realise the connection between the different regulations that interact in the risk area and later in this Chapter an attempt will be made to enlighten the reader on the regulations in Sweden.

3.1 Authorities jurisdiction

3.1.1 Arbertarskyddstyrelsen (ASS) and Yrkesinspectionen (YI)

ASS is responsible for the working safety and controls the YI. In it's duty among other things is to enforce the law that handle chemical productions as well as to secure that working safety law is fulfilled. It has also part in forming regulations according to the SEVESTO directives mentioned above.

3.1.2 Sprängämnesinspektionen (SÄI)

Management of flammable materials and explosives has to be well taken care of in a society and that is the job of SÄI. Its area of work is e.g.:

- Advisory,
- inspection,
- accepting explosives and giving permissions for production, and
- education and information.

3.1.3 Naturvårdsverket (NVV)

The issue NVV is dealing with concerns the environment and related laws. The requirements in the laws and regulations for chemical accidents can be summarised as follows:

- Risk analyses have to be carried out when judged necessary.
- The risk for great chemical accidents have to be prevented if possible and their consequences minimised [PSK].

3.1.4 Statens räddningsverk (SRV)

Transports of hazardous goods are placed under SRV and it has as well the authority over the local rescue services. In it's concern is also to supervise the risks and the risk development in the area, give information about hazardous goods and to co-ordinate regulations regarding transports of hazardous goods on ground, see and in air.

3.2 Laws and Regulations for Risk Planning

Many different laws and regulations have to be taken into consideration when is comes to risk planning in a society. These regard the individual both directly, as in the case of chemical dispersion, as well as indirectly in the case of environmental damages. Here a short description will be given of the laws of concern.

3.2.1 Räddningstjänstlagen (RäL)

In RäL there are directions about how the local rescue service shall be organised and managed. In this law there are also directions about accidents and precautions of how these shall be handled as well as the rights and persons obligations.

Of huge importance for planning of hazardous activities is the 43th paragraph of RäL. It states that every activity that might cause injuries to individuals or the environment is forced to take precautions in order to minimise the effects of these injuries. Later in this report, a list of objects that paragraph 43 applies to is given and their possible causes of incidents are mapped.

Note that there is a special law that deals with explosives and flammable chemicals and another one that deals with the transportation of hazardous chemicals.

3.2.2 Plan och Bygglagen (PBL)

Every planned construction has to fulfil PBL where the goal is to be a guide for planning and give permissions. PBL can be considered as an instrument for the local authorities to control the development of building areas. This law includes some regulations that personal safety has to be taken into consideration in a planning. A survey plan has to be made for every area and can be considered as a guide to a planning.

3.2.3 Naturresurslagen (NRL)

This law includes demands regarding the environment for those who use the ground. This law has to be considered when ground and water areas are planned for and the areas resources are used.

3.2.4 Miljöskyddslagen (ML)

This law's area of concern is the protection of people and environment from disturbances like pollution, and noise. It is suppose to help find suitable places for disturbing activities. Effects from dispersions can be placed under this law.

3.2.5 General Law Application

It is important to realise that to the same type of chemical there can be several laws that apply. Table 3.1 shows this law-chemical combination to enlighten the understanding. A suitable combination is marked with ✓.

	Very hazardous products that can be life threatening	Flammable goods	Explosives	Environmentally harmful chemicals
ASS	✓	✓	✓	
SÄI		✓	✓	
NVV	✓	✓	✓	✓
SRV	✓	✓	✓	✓

Table 3.1: Connection between laws and different chemicals.

4 Risk Identification

To be able to predict the risk possessing Tretorns-area it is necessary to chart all the risk objects that may influence on the area in question. As mentioned in Chapter 2 "Regulations" it is necessary to chart the so-called §43 objects according to Swedish laws.

4.1 General

The following table shows the risk identification for Helsingborg according to §43 and the chemicals stored at respective place. It also marks the possible type of accident for each chemical. Each chemical risk is identified by a number, which will be referred to in the following Chapters.

	Object	Chemical	Type of accident		
			B	E	U
1	Kemira Kemi AB	Sulphuric acid			✓
2		Hydrochloric acid 30%			✓
3		Sulphur dioxide			✓
4		Hydrogen peroxide			✓
5		Oleum			

	Helsingborg's Harbour				
6	Oil harbour	Gasoline	✓	✓	
7		Diesel	✓		
8		Propane	✓	✓	✓
9	Kopperverks harbour	-			
10	West-harbour	-			
11	Deployment area	Chlorine			✓
12		Ammonia		✓	✓
13		Gasoline	✓	✓	
14		Diesel	✓		
15		Propane	✓	✓	✓

16	Frigoscandia	Ammonia		✓	✓

	Rail road system				
17	City tunnel	-			
18	Shunting yard	Chlorine			✓
19		Ammonia		✓	✓
20		Gasoline	✓	✓	
21		Diesel	✓		
22		Propane	✓	✓	✓
23	DanLink	Chlorine			✓
24		Ammonia		✓	✓
25		Gasoline	✓	✓	
26		Diesel	✓		
27		Propane	✓	✓	✓

29	Roads	Chlorine			✓
30		Ammonia		✓	✓
31		Gasoline	✓	✓	
33		Propane	✓	✓	✓

Table 4.1: Risk identification for Helsingborg showing §43 objects, chemicals at each object and the possible accident for each chemical (B = BLEVE, E = Explosion and S = Spread of toxic chemical). Each chemical risk is identified by a number, which will be referred to in the following.

4.2 Fixed Risk objects

In the group "Fixed risk objects" are Kemira Kemi AB, Frigoscandia and the Water resource area. For Helsingborg's Harbour only the fixed part of the deportation of the harbour activity has been looked at. The harbour area can be divided into following parts: Oil harbour, Koparverks harbour, West-harbour and Deployment area.

After simple calculations some risk objects were considered as irrelevant to the observed area (Tretorn-area). These were: Frigoscandia, Kemira, Oil Harbour (except for the Propane tanks).

The risks at Frigoscandia are ammonia and the amount and the primary wind direction results in that the Tretorn-area will not be affected by an incident there. This means that no life threatening concentration of ammonia will be spread to the observed area. The same applies to incident at Kemira.

A fire in one of the gasoline or diesel tanks will only produce tremendous amount of black dense smoke. The smoke will not result in direct life threatening situation for people within the Tretorn-area. In case of fire a public announcement should be made telling the people to stay inside, close their windows, stop the ventilation etc.

4.3 Transportation

Included in the transportation objects are the road system and the railroad system, which includes the City tunnel, the Shunting yard and Dan link and the roads for transportation of dangerous goods.

Based on the transported amount year 1976 of hazardous chemicals [KEK] and assuming that the same proportions apply today, the percentage can be viewed in Table 4.2.

Chemical	Percentage of transport
Sulphuric acid	52
Chlorine	19
Ammonia	12
Sulphur dioxide	8
Other Chemicals	9

Table 4.2: Percentage of transport of Hazardous Chemicals year 1976 [KEK].

4.3.1 The Shunting yard

Transportation of dangerous goods on the Shunting yard the years 1978 and 1992 as well as our own prediction for 1997 are shown in Table 4.3. The prediction for 1997 is based on the information from 1972 and 1992 assuming the same percentage increase in the transportation per year. In those cases no transportation took place in 1972, the same numerical increase in transported carriages is assumed.

Chemical	Loaded carriages 1978 (ton/year)	Loaded carriages 1992 (ton/year)	Prediction 1997 (ton/year)	Percentage 1997 transp.
Explosives	1524	6656	8489	4%
Gases	59721	41018	34338	15%
Fluid - danger to fire	8356	43687	56305	24%
Solid - danger to fire	0	5332	7236	3%
Oxidating Chemicals	2448	14225	18431	8%
Toxic Chemicals	1148	16938	22577	10%
Radio active Chemicals	0	899	1220	1%
Corroding Chemicals	4196	61184	81537	35%
	77393	189939	230134	100%

Table 4.3: Transportation of dangerous chemicals on the Shunting yard.

In Figure 4.1 the predicted number of loads carriages on the shunting yard is shown.

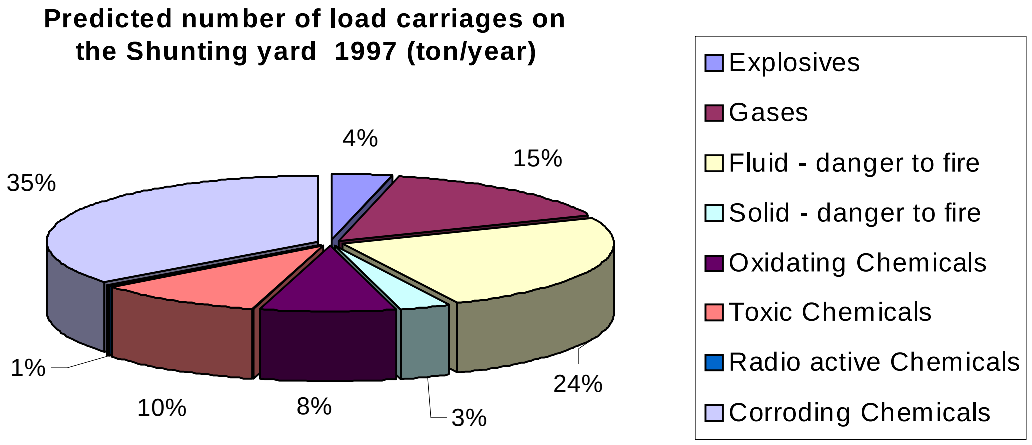


Figure 4.1: Percentage aggregation of different chemicals through the Shunting yard

The shunting itself does possess a danger as well as the transportation. It is important to realise the extent of both the number of shunting and how many dangerous chemicals are involved. The number of shunting is on the range 15-16 carriages per day or about 5820 carriages per year. The amount of dangerous goods involved is according to the 1997 prediction about 630 ton per day or 230,000 ton per year [JN].

Condensed gases are about 20-25 % of the total number of loaded carriages through the Shunting yard or about 1200 carriages per year.

4.3.2 Danlink

Danlink is a ferry connection to Copenhagen, Denmark and is responsible for both imports and exports of great deal of hazardous chemicals. The following Table shows the statistic for the year 1992.

	Chemical	Importation (Carriages/year)	Exportation (Carriages/year)
1	Explosives	78	182
2	Gases	351	572
3	Fluid possessing a danger of fire	1040	65
4	Solid possessing a danger of fire	104	13
5	Oxidating Chemicals	78	208
6	Toxic Chemicals	260	39
7	Corroding Chemicals	247	637
8	Other Chemicals	143	26
		2301	1742

Table 4.4: Imports and exports of dangerous chemicals through Danlink year 1992.

Condensed gases make up for about 15-20 % of the import of loaded carriages and 30-35% of the export with Danlink [JN].

5 Consequence Analysis

5.1 Introduction

We have chosen three different scenarios of probable incidents within the neighbourhood of the Tretorn-area.

The assumed scenarios are:

- Shunting incident involving ammonia (railroad).
- Switching incident involving chlorine (railroad).
- Fixed tank incident involving propane.

Comparison of railroads to ordinary roads reveals that there is a larger amount of hazardous goods transportation on the railroads. Therefore we have chosen to focus our attention on the railroad in our scenarios.

5.2 Assumptions for calculations

5.2.1 Weather conditions

The same weather conditions were assumed for all the three cases. Sensitivity analysis has shown a variation in temperature has little influence on the distance to critical concentration. It showed that a somewhat longer distance was obtained when the temperature was 20 ºC than when it was 0 ºC. On the basis of the above the temperature in the calculations was assumed to be 20 ºC.

Atmospheric stability is important factor for the dispersion of a chemical as it decides how fast diffusion in the lower air occurs. It is caused by a vertical temperature gradient in the atmosphere causing a buoyancy force on the dispersed chemical if there are differences in density between the chemical and the surrounding air. In this report the stability conditions have been chosen as "neutral" as the gases are assumed to have temperatures near the atmospheric, This means that there will be no extra upward force on the dispersion because of atmospheric stability.

The wind on the other hand is of great importance in the spread model as shown in Figure 5.1 and the design wind will be chosen in accordance with this analysis. Note that the sensitivity analysis was done for ammonia and it assumed that the same applies to the other chemicals.

If not otherwise specified the wind speed is assumed 3 m/s for the design cases. Note that for each dispersion calculation it is necessary to calculate the affected area by finding a suitable angle and length. By this way it is possible to calculate the number of such dispersions that make up for the whole circle and also the frequency for the whole area of this circle. The method for this analysis will be further explained in Chapter 7 "Risk Analysis".

5.2.2 Toxic effects

A vital instrument in the analysis of the individual risk, is the calculation of the probability that a certain effect influences on the individual. This effect will be "death" in our case. The probability that an individual will die, given a certain chemical dispersion, can be calculated with a probit-function (Pr) given the average concentration (mg/m^3), exposure time (min), breathing volume (l/min), and the place (outside/inside).

The probit-function and the factors of regression are obtained from [FOA].

$$Pr = \alpha + \beta_2 \ln(C^n t) \qquad \text{Equation 5.1}$$

$$n = \frac{\beta_1}{\beta_2}$$

where

Pr	Probit function	
C	Concentration	[mg/m^3]
t	Exposure time	[min]
α, β_1 and β_2	Factors of regression	

The method of calculation is to set a value on the probability of death, which gives a value for Pr and given the exposure time calculate the allowed concentration. This is of course done for each type of chemical, which gives different values of the regression factors.

The calculation will be carried out for probability of death as 1, 33, 67 and 99 %.

The exposure time is chosen as 5 minutes and the breathing volume is chosen as 50 l/m in comparison to 15 l/m for low activity (for which the regression factors are given). This is done to simulate the increasing effect of stress and other hazard related factors.

The results for each calculation will be presented later in this Chapter and a summary of results can be viewed in Appendix B1.

5.2.3 Dispersion Analysis

For a railway incidents, there have been defined three different sizes of average mass flow rate. These are: Large, medium and small. The values for each of these are given in Table 5.1.

Size of dispersion	Average flow rate [kg/s]
Large	9.4
Medium	0.7
Small	0.08

Table 5.1: Definition of the dispersion size

In this Chapter, the distance to the defined probabilities of death, defined in Section 5.2.1, is calculated for each of the dispersion sizes given in Table 5.1.

Two different models have been used to calculate the dispersion; Continuous heavy gas, and Finite duration Gaussian. The Continuous heavy gas model assumes that the gas is heavier than air and the gas is evenly distributed in the plume. Finite duration Gaussian model on the other hand assumes a standard normal distribution in the plume.

5.3 Ammonia Dispersion

5.3.1 Ammonia

Ammonia, NH_3 is a gas at normal temperatures and pressures but can be liquefied when applying modest pressure or low temperature (240K). It is used is in industrial processes and in agriculture [HMSH].

Ammonia possesses a great danger to health both when persons are exposed to acute exposure to high concentrations or low concentrations over a longer period of time. The aim in this report will be on the former and the maximum allowed concentration is set in according to calculation in Section 5.3.2

The following table shows the consequences of different exposures to the health of a human being.

Concentration equal or greater than:		Physiologic response	Remarks
In ppm	In mg/m^3		
0.7	0.5	Odour detectable	Most sensitive people
5.0	3.5		Average threshold value
20.0	14.0		Complaint level
50.0	35.0	Hygienically set min value	Least sensitive people
100	70.0	Irritation in nose and eyes	
400	280	Immediate throat injury	
500	350	Serious coughs	
700	490	Irritation of eyes, coughing	
1700	1200	Coughing	
2400	1700	Life threatening after 30 min	
3000	2100	Dangerous to life	Design Concentration
5000-10,000	3500-7000	Rapidly fatal for short exp.	

Table 5.2: Symptoms to different concentrations of ammonia [HMSH] and [BA].

5.3.2 Toxic effects from Ammonia

With the aid of Equation 5.1 the Concentration of a certain probability of death can be calculated. The factors for ammonia can be viewed in Appendix B1 and the result of the calculation is shown in Table 5.3.

Percentage dead	Concentration [ppm]
99	31072
67	7918
33	4189
1	1068

Table 5.3: Concentration for a certain percentage of death

5.3.3 Assumed Scenario

The assumed scenario is that a pipe on an ammonia carriage ruptures after a shunting accident. The pipe is located close to the bottom of the tank indicating that a fluid flow will result.

Assumptions for the tank are as shown in Table 5.4 as well as the governing weather conditions.

Tank Specification			Unit
Size	Length	19.0	m
	Diameter	2.5	m
	Volume	93.3	m^3
Hole	Type	Sharp edges ⇒ $C_d = 0.62$	
Contents Mass		45500	ton
Contents Pressure		852,000	Pa
Contents Temperature		293	K

Table 5.4: Tank Specification.

The result from dispersion calculations gives the distance to the critical concentration. This length is given for different probabilities of death.

Dispersion size	Average flow [kg/s]	Equivalent hole diameter [mm]	Percentage dead	Length of effect zone [m]	
				Finite Duration Gaussian	Continuous heavy gas
Large	9.4	25.2	99	75	4
			67	195	28
			33	301	120
			1	741	554
Medium	0.7	6.8	99	18	16
			67	42	31
			33	61	43
			1	139	155
Small	0.08	0.75	99	5	6
			67	12	13
			33	18	32
			1	40	49

Table 5.5: Dispersion calculation for the Ammonia incident

The case for which further calculation will be based involves a wind speed of 3 m/s.

5.3.4 Sensitivity Analysis

To gain an understanding of the influence the wind has on the dispersion, a diagram has been constructed varying both hole sizes as well as the wind. The hole diameters analysed are 10, 30, 75, 120, 150, 200 mm and for each of these holes the wind have been varied from 0.1 m/s to 5 m/s. The dispersion will then be according to Figure 5.7.

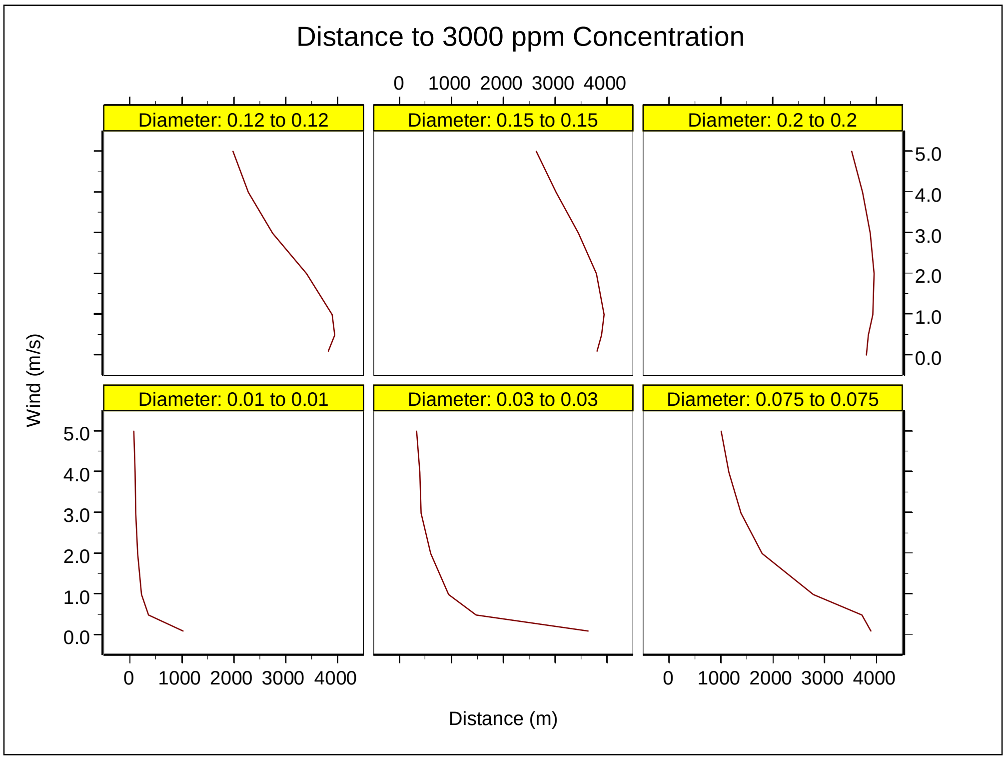


Figure 5.1: Distance to 3000 ppm Concentration for Ammonia discharge as a function of wind velocity and diameter of the hole.

Observe how the wind influence on the distance to the critical concentration. The wind increase has very little influence on the distance for small diameters but as soon as these are increased up to 12 mm and above, the increase in wind velocity will increase the distance to the critical concentration to similar one similar the maximum distance. Note that the maximum distance is though not increased by the increase in wind velocity but remains basically constant.

5.4 Chlorine Dispersion

5.4.1 Chlorine

Chlorine is a basic element and it usually is in the form of Cl_2 in the nature. The gas is 2.5 times heavier than air but is usually stored as liquid, under pressure.

Chlorine is highly toxic and only 100 ppm can be considered as dangerous to health. The influence of other concentrations can be seen in Table 5.6.

Concentration [ppm]	Physiologic response
0.5	Hygienically set min value
10.0	Detectable odour and Irritation in nose and eyes
15.0	Irritation of throat
30.0	Immediate serious coughs
100	Can be life threatening
1000	Life threatening after few breaths
10,000	Rapidly fatal

Table 5.6: Symptoms to different concentrations of ammonia [KH] and [BA].

5.4.2 Toxic effects from Chlorine

With the aid of Equation 5.1 the Concentration of a certain probability of death can be calculated. The factors for Ammonia can be viewed in Appendix B1 and the result of the calculation is shown in Table 5.7.

Percentage dead	Concentration [ppm]
99	969
67	432
33	296
1	132

Table 5.7: Concentration for a certain percentage of death

5.4.3 Assumed Scenario

An assumption is made that a switching accident happens on the railroad leading to the shunting yard. After the accident a pipe on the tank erupts, and results in a hole with diameter of 75 mm.

The tank specifications are as shown in Table 5.8 and are similar to the ammonia tank.

Tank Specification - Ammonia tank			Unit
Size	Length	19.0	m
	Diameter	2.5	m
	Volume	93.3	m^3
Hole	Type	Sharp edges ⇒ $C_d = 0.62$	
Contents Mass		45500	ton
Contents Pressure		852,000	Pa
Contents Temperature		293	K
Degree of filling		80	%

Table 5.8: Tank Specification

The result from dispersion calculations gives the distance to the critical concentration. This length is given for different probabilities of death. This is shown in Table 5.9.

Dispersion size	Average flow [kg/s]	Equivalent hole diameter [mm]	Percentage dead	Length of effect zone [m]	
				Finite Duration Gaussian	Continuous heavy gas
Large	9.4	20.3	99	316	103
			67	634	172
			33	682	240
			1	1140	1030
Medium	0.7	5.5	99	64	71
			67	99	108
			33	128	140
			1	217	242
Small	0.08	0.56	99	19	27
			67	30	42
			33	37	52
			1	58	79

Table 5.9: Calculation of the effect zone for chlorine dispersion

For chlorine the continuous heavy gas model is chosen because of chlorine weight.

5.5 Propane explosion

For fixed objects, other methods have to be applied when calculating probabilities for an accident than for accidents involving transportation. Here the object itself is of greatest interest and pipes and other connections will affect assumed scenario.

5.5.1 Propane

At normal temperatures and at atmospheric pressures propane is a gas, but at pressure and temperature relatively low it is in liquid form. It is usually transported under pressure and is under these conditions named LPG, Liquefied Petroleum Gas.

Propane is not toxic but can cause problems when it lowers the oxygen in the air. It is flammable in combination with air for concentrations between 2 and 10%. Propane is about 1.5 times heavier than air, which must be taken into account when dispersion takes place.

5.5.2 Criteria for Death

It is difficult to set a clear value for death from a radiation. The variation of the death criteria is very large within a population. It is easier to calculate effects as which degree of burning results from a certain radiation. The criterion for death in this report is set as a third degree burn. Hence, it is assumed that everyone within the zone where the radiation causes third degree burn dies and everyone outside this zone survive.

5.5.3 Assumed scenario

In this scenario a propane tank is assumed have a leakage and the maximum distance to where the mixture is flammable is taken as the critical distance. The propane tank in question is located between the Shunting yard and the harbour and not far away are tanks with flammable liquids.

Tank specification is shown in Table 5.5. Some assumptions regarding the tank have been done e.g. for filling percentage and design and breakage pressure.

Tank Specification			Unit
Size	Length	30	m
	Diameter	3.9	m
	Volume	360	m^3
Contents Mass		150,000	kg
Contents Pressure		800,000	Pa
Contents Temperature		293	K
Degree of filling		80	%

Table 5.10:Tank Specification for the Propane tank

For the tank given in Table 5.10 the following values for a BLEVE are given in Table 5.11.

BLEVE	Value	Unit
Mass out	146736.3	kg
Diameter of the fireball	309.5	m
Duration	18.2	s
Height over ground	232.15	m
Distance for broken tank parts	1800	m
Distance to 3rd degree burn	**938**	**m**
Distance to 2nd degree burn	1239	m
Distance to 1st degree burn	1937	m

Table 5.11: Information about the Propane BLEVE incident at the Oil Harbour.

The design criterion is marked with bold letters in Table 5.11.

6 Frequency Analysis

Probability analysis has been carried out for both fixed risks objects and for transportation.

Certain calculation methods have been used to judge the probability of failure for transportation but the judgement of how a tank failure happens is by far more complicated. Some engineering judgement has to be done in several cases.

6.1 Rail road accident

Statistical analysis of railroad accidents is done according to "Farligt Gods - Riskbedömning vid transport" published by "Räddiningsvärket" [RV]. In this method, factors like number of axles, rail quality, number of different crossings as well as number of transportation is used to calculate the risk for leakage per rail length. This can be done for different sorts of moving: shunting, switching or if the railroad has some interference with other traffic. The calculation is done for each rail road section so this risk will then have to be multiplied with it's length of the in order to obtain the section's risk. Type of failure can be of three kinds: Human, wagon or unknown.

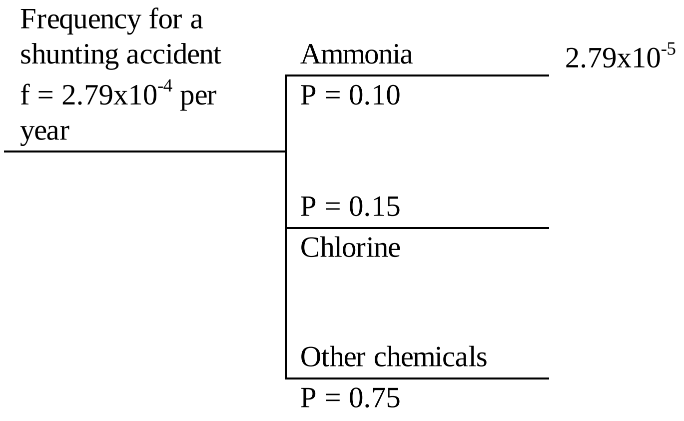
In this project a spreadsheet has been constructed in order to simplify the calculation of the railroad risk mentioned above and can be viewed in Appendix D1. This home-made spreadsheet makes it possible to calculate the probabilities for different accidents in a quick and simple way.

For each of the assumed mass flow rates in Chapter 5.2.3, a certain probability has been applied [FG]. The probabilities are 16.7 % for large flow rate.

6.1.1 Accident on the shunting yard - Ammonia

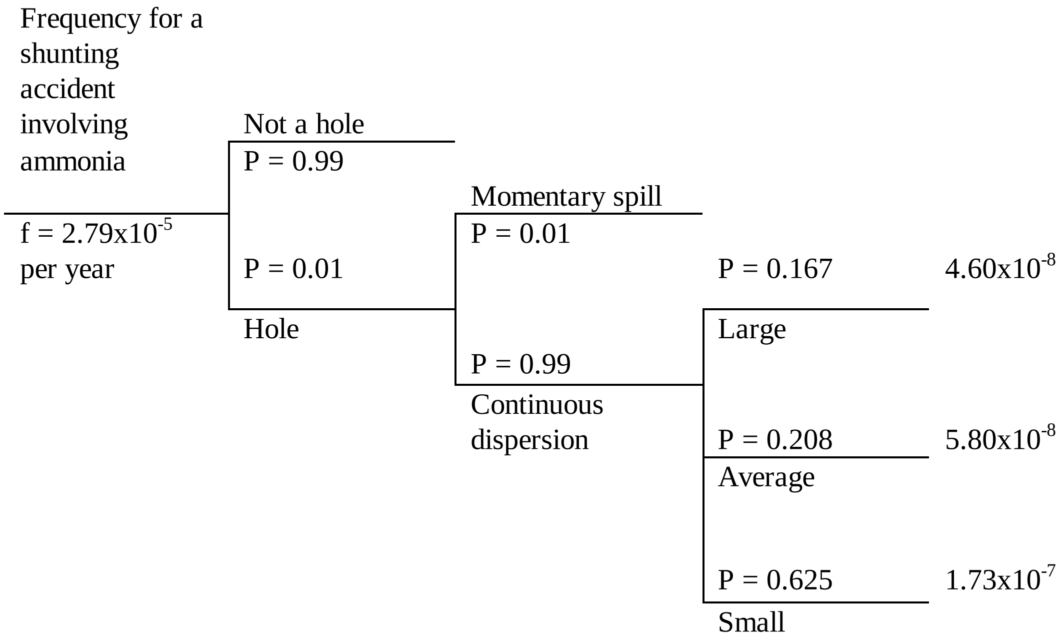
We assume that each wagon has four axles each. According to our spreadsheet program it will give a frequency for an accident of $4.8x10^{-8}$ per shunting (in this case it's four times the frequency $1.2x10^{-8}$ for each axle). Note that probability of shunting accident is not affected by path length and only by the number of axles on the wagon. About 5820 wagons loaded with hazardous chemicals are shunted each year on the shunting yard [JN], which makes the frequency for shunting accident to $2.79x10^{-4}$ per year.

We assume that hazardous chemicals are good for about 10% of the total shunting of the shunting yard. Of those hazardous chemicals condensed gases are about 20 - 25% (25% assumed) [JN]. According to Table 4.1 ammonia stands for about 12% and Chlorine about 19% of the total amount of transported hazardous goods and assuming that the chemicals are to 80% stored under pressure the percentage becomes 10 and 15% for Chlorine and Ammonia. Here it is assumed that the same proportions can be applied to carriages at the shunting yard.



Fault tree 6.1: Frequency for shunting accident, involving ammonia.

The case that we have chosen to analyse on the Shunting yard is an accident involving ammonia dispersion. We assume that a hole is made on the tank and the probability for that to happen is 1%. Further more we assume that in 99% percent of the cases we have continuous dispersion.



Fault tree 6.2: Frequency for Ammonia dispersion on the shunting yard.

6.1.2 Switching accident - Chlorine

For the switching accident an assumption is made regarding the length of the railroad in question. We assume that the length of the track is 1 km and it's placed close by the shunting yard. If the train consists of 29 carriages, each with 4 axles the total frequency for a switching accident is according to Table 6.1. For transportation of chemicals under pressure the tank is thick walled.

The properties of the wagon can be shown in Table 6.1.

Moment	Assumed number
Number of axles (H)	10
Number of axles (Total)	116
Rail quality	b
Number of gate crossing	0
Number of sounds and light crossing	1
Number of signposts or none	1
Number of H-transportation per year	5820

Table 6.1: Properties of rail wagons.

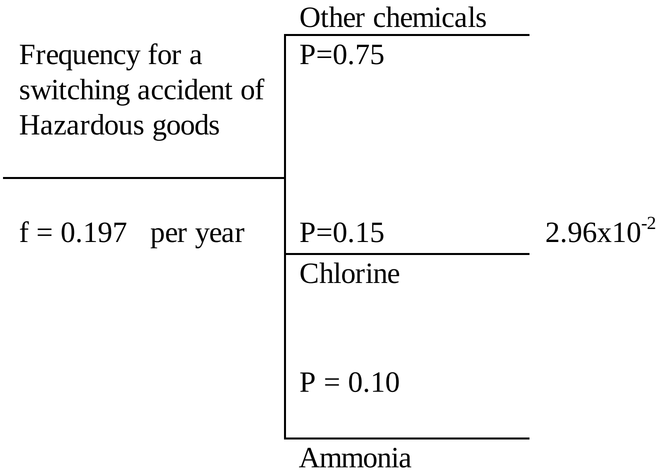
The resulting frequency is dependent up on the type of failure occurring and can be of three kinds. These types and the resulting frequency for accident are shown in Table 6.2.

Type of failure	Frequency
	Hazardous
Wagon	3.39×10^{-5}
Human	3.75×10^{-5}
Unknown	3.35×10^{-5}

Table 6.2: Frequency of different failures depending on different failure factors.

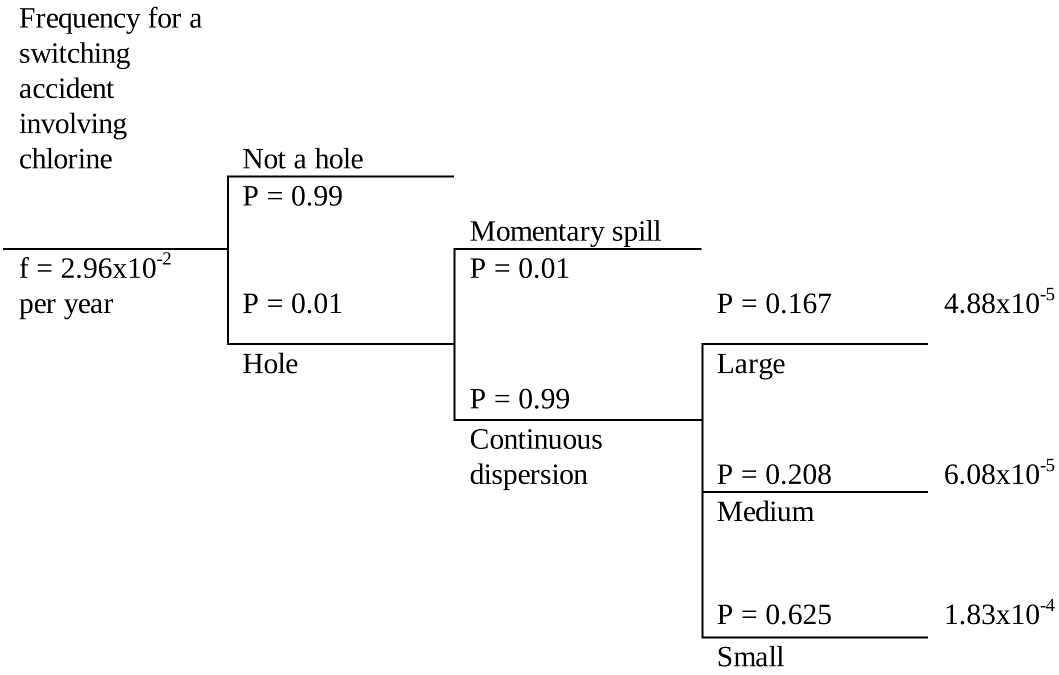
The frequency for wagon failure is chosen as 3.39×10^{-5}.

As the trains are only going to the shunting yard the same number of trains can be assumed to travel along this distance as the number of trains that are shunted each year or 5820. On the one kilometre track in question the frequency will then be $3.39 \times 10^{-5} * 5820*1$ km = 0.197.



Fault tree 6.3: Frequency for switching incident involving Chlorine.

For the switching accident the same assumptions are made as above for the chlorine accident. The fault tree for this happening is as shown in Fault tree 6.4.



Fault tree 6.4: Chlorine, frequency for dispersion.

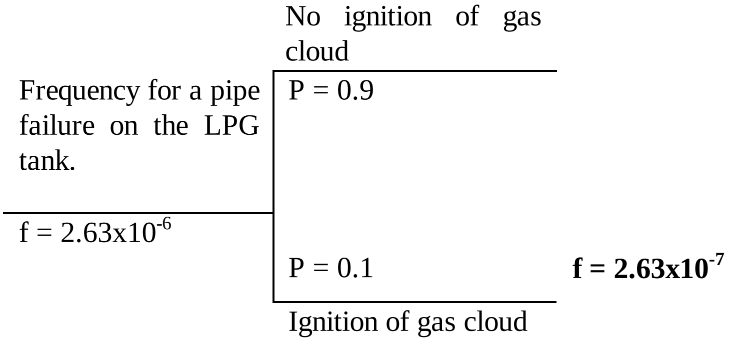
The values obtained in Fault tree 6.2 are for large, medium and small flows. As these are different incidents, all of the values will be used in Chapter 7.

6.2 Fixed Object Incident - Propane BLEVE

In this Chapter we will look at a propane incident from a fixed tank (see specifications in Chapter 5).

For a pipe rupturing of the propane tank the failure rate is set the same as for catastrophic failure for a pipework (diameter 150 mm): 3×10^{-10} per section and hour or 2.63×10^{-6} per section and year [RIJN]. Such a large leakage can be considered as momentan with the possibility for BLEVE (Boiling Liquid Expanding Vapour Explosion) to occur.

The LPG leakage is can be seen as large for which the probability of immediate ignition can be set as 0.1 [CHL]. The resulting frequency will therefore be as shown in Fault-tree 6.5.



Fault tree 6.5: LPG frequency for immediate ignition causing BLEVE.

As a result the frequency for BLEVE to occur in the fixed propane deposits is 2.63×10^{-7}.

7 Individual Risk

7.1 The CPQRA Method

The risk that will be calculated in this section is the individual risk (IR) that can be defined as "the risk to a person in a vicinity of a hazard" [CPQRA]. This risk is not affected by the density of the people within the zone of calculated risk.

7.1.1 Calculation Method

If frequency at any particular location is affected by the wind direction, that have to be accounted for by assigning an enclosed angle on which the dispersion applies. If the direction is not affecting the dispersion (e.g. BLEVE), the angle is set as 360 degrees.

The frequency can be calculated as:

$$f_{i,d} = f_i\ (\theta_i / 360\ ) \qquad 7.1$$

Where

$f_{i,d}$ = frequency at which the incident outcome case i affects a point in any particular direction assuming a uniform wind direction distribution [yr^{-1}]

f_i = estimated frequency of occurrence of incident outcome case *i* [yr^{-1}]

θ_i = the angle enclosed by the effect zone for incident outcome case *i* [degrees]

Individual risk contours are calculated by adding the individual risk of the next further risk contour or:

$$\mathrm{IRC}_i = f_{i,d} + \mathrm{IRC}_{i-1} \qquad 7.2$$

where

IRC_i = value of individual risk at the contour of the incident outcome case under consideration [yr^{-1}]

IRC_{i-1} = value of individual risk at the next further risk contour [yr^{-1}]

The procedure for individual risk contours calculation can be viewed in [CPQRA].

7.1.2 Assumptions

A simplified approach of calculating the individual risk is followed in this report and some assumptions made:

- All hazards originate at point sources.
- The wind distribution is uniform.
- A single wind speed and atmospheric stability class are used.
- No mitigation factors are considered.
- Contributions from different outcome cases are additive.

Further more is assumed that within the 33 % concentration boundary of ammonia, all persons are killed but outside the boundary everyone survive.

7.2 Ammonia Dispersion

The angle of enclosure for the ammonia dispersion is set as 15 degrees [CPQRA] and it is assumed that the wind is equally likely to blow in every direction. The dispersion model chosen is "Finite duration Gaussian".

In Table 7.2 the data for the ammonia dispersion at the shunting yard is summarised and the individual risk calculated according to Equation 7.1 and 7.2.

Size of dispersion	Deaths [%]	Effect zone [m]	f_i [year $^{-1}$]	$f_{i,d}$ (θ_i =15deg) [year^{-1}]	IRC$_i$ [year^{-1}]
Large	33	301	$4.66x10^{-6}$	$1.94x10^{-7}$	$1.94x10^{-7}$
Medium	33	61	$5.80x10^{-6}$	$2.42x10^{-7}$	$4.36x10^{-7}$
Small	33	18	$1.73x10^{-5}$	$7.2x10^{-7}$	$1.16x10^{-6}$

Table 7.1: Calculation of Individual Risk contours for Ammonia dispersion.

The individual risk contours (IRC) for the Ammonia incident are shown in Appendix A1.

7.3 Chlorine Dispersion

As before the angle of enclosure (θ_i) for the ammonia dispersion is set as 15 degrees [CPQRA] and it is assumed that the wind is equally likely to blow in every direction. The dispersion model chosen is "continuous heavy gas".

In Table 7.3 the data for the ammonia dispersion at the shunting yard is summarised and the individual risk calculated according to Equation 7.1 and 7.2.

Size of dispersion	Deaths [%]	Effect zone [m]	f_i [year $^{-1}$]	$f_{i,d}$ (θ_i =15deg) [year^{-1}]	IRC$_i$ [year^{-1}]
Large	33	240	4.88x10^{-5}	2.03x10^{-6}	2.03x10^{-6}
Medium	33	140	6.08x10^{-5}	2.53x10^{-6}	4.57x10^{-6}
Small	33	52	1.83x10^{-4}	7.63x10^{-6}	1.22x10^{-5}

Table 7.2: Calculation of Individual Risk contours for the Chlorine dispersion.

The individual risk contours (IRC) for the Chlorine incident are shown in Appendix A2.

7.4 Propane Incident

BLEVE is considered as independent of the wind direction and therefore the angle of enclosure (θ_i) is set as 360º. Note that the criterion for death was set as 3rd degree burn.

Table 7.3 shows the calculation of the Individual Risk Contours for the Propane BLEVE incident.

Death criteria	Effect zone [m]	$f_{i,d}$ [year $^{-1}$]	$f_{i,d}$ (θ_i =360º) [year^{-1}]	IRC$_i$ [year^{-1}]
3rd degree burn	938	2.63x10^{-6}	2.63x10^{-6}	2.63x10^{-6}

Table 7.3: Calculation of the Individual Risk Contours for the Propane BLEVE incident.

As BLEVE is independent of wind direction the values for the f_i and $f_{i,d}$ will be the same and as there is only one incident in this calculation, the IRC$_i$ will be the same as well.

The individual risk contour (IRC) for the Propane BLEVE incident is shown in Appendix A3.

8 Conclusions

Today's Helsingborg possesses many risks to the individual of the community. A great deal of attention must be paid to the closeness of risk objects to high-populated places, inclusive the Tretorn area in order to try to minimise those risks. The most important part of future plans is to separate the different risk factors from the residential areas and other areas where the "social risk" is high.

8.1 *"Better Place for Work"*

In 1995, a guidance was published from "Boverket" that should serve as a help or guidance in physical planning. This guidance is called "Better Place for Work". The effect zone is given as the minimum distance for different activities with respect to safety and health as well as the environment. The values are viewed in Table 8.1.

Activity	Distance to residential area. [m]
Great industrial areas	>1000
Wastewater cleaning	1000
Power plant	500
Shunting yard	500
Industry	500
Small industry	200
Hazardous goods transportation	>100

Table 8.1: Effect zones for different activities

It is important to notice that many factors are taken into consideration in "Better Place for Work" that has not been analysed in this report. The bad odour from a wastewater cleaning plant is unacceptable for residential areas but still does not possess much risk for health. However, there are some activities that can have a much larger effect zones than the ones given in the table.

A special investigation should be carried out for every case where hazardous goods are involved on a shunting yard or in an industry area. As demonstrated in Chapter 7, "Individual Risk" the effect zone can be several hundred meters for hazardous goods transportation areas.

Comparison between "Better Place for Work" and calculations carried out in this report can be viewed in Table 8.2.

Incident	Effect zone [m]	
	"Better Place for Work"	Calculation from Chapter 7
Shunting Yard (Shunting incident - Ammonia)	500	300
Hazardous goods transport. (Railway switching - Chlorine)	>100	240
Great industrial area (Fixed tank – Propane)	>1000	500

Table 8.2: Comparison of different effect zones from "Better Place to Work" and the calculation from Chapter 7.

Observe that the criteria for the calculated effect zones in this report is that within the zone 33 % of the population are expected to die within the boundary and outside every one will survive.

8.2 Acceptable Risk

There is a limited use for a calculated risk if there are no values to compare it to, i.e. what is acceptable. Acceptable risk level has been suggested as 10^{-5} - 10^{-6} [SEM]. These risk values are obtained for the railway incident involving Chlorine dispersion and the Propane BLEVE at the Oil Harbour. The Ammonia dispersion at the Shunting yard is at the upper limits of the acceptable limits mentioned.

The frequency values are based on coarse assumptions and it can be difficult to judge their connection to reality. The values on the other hand give some idea about the risks in the area.

The general results from the Chapter 7 "Risk Analysis" point in the direction that the risks posing the Tretorn area are quite large but a further analysis would have to be done in order to more closely map the total risk. The frequency for an accident should for example be analysed in more detail.

9 References

[CHL]	A.E. Cox, F.P. Lees, M.L. Ang, Classification of Hazardous Locations, Chem.
[CPQRA]	Guidelines for Chemical Process Quantitative Risk Analysis, Center for Chemical Process Safety of the American Institute of Chemical engineers, New York, 1989.
[HMSH]	Bennett G. et.al., Hazardous Materials Spills Handbook, Part 4, Ammonia, Chlorine.
[BS]	Berit Andersson, Expert opinion.
[KEK]	Berit Andersson, Karakteriska Kgenskaper hos Kemikalier, Lund 1988
[BPA]	Bättre plats for arbete, Planering av arbetsområden med hensyn till miljö, hälsa och säkerhet.
[FG]	"Farligt Gods, Riskbedömning vid transport" Statens Rddningsverk, Karlsstad 1996.
[FOA]	Fisher S et.al, "Vådautsläpp av brandfarliga och giftiga gaser och vätskor", FOA, Stockholm 1995.
[JN]	Jonas Nylén, Overheads
[KH]	Klorhandboken, AB Svenska Klorfabrikanter.
[PSK]	Paragrafer mot Stora Kemikalie olyckor, en vägledning för tillämpning. Arbetarskyddstyrelsen m.m. Stockholm and Karlstad 1995.
[RIJN]	Risk Analysis of Six Potentially Hazardous Industrial Objects in Rijnmond Area, a Pilot Study, D. Reidel Publishing Company.

A Individual Risk Contours

Figures not included

B Criteria for Death

B1 The Probit-function for toxicity

The probit-function and the factors of regression are obtained from [FOA].

$\mathrm{Pr} = \alpha + \beta_2 \ln(C^n\, t)$

$$n = \frac{\beta_1}{\beta_2}$$

Pr	Probit function	
C	Concentration	[mg/m^3]
t	Exposure time	[min]
α, β_1 and β_2	Regression factors	

For an increase in breathing frequency (*bf*) above the normal 15 l/m, the probit-function will have to be calculated as:

$$\mathrm{Pr} = \alpha + \beta_2 \ln\left[\left(C \cdot \frac{bf}{15}\right)^n \cdot t\right]$$

For chemicals ammonia and chlorine the following values are obtained:

Chemical	α (Death)	β_2	*n*
Ammonia	-14.70	0.96	1.44
Chlorine	-22.97	2.41	0.97

Percentage Death	Pr	Concentration [ppm]
99	2.33	31072
67	0.44	7918
33	-0.44	4189
1	-2.33	1068
99	2.33	969
67	0.44	432
33	-0.44	296
1	-2.33	132

C Computer calculation

C1 Ammonia dispersion from the Shunting yard

```
Pressurized liquid discharge model
Horizontal cylindrical tank

    Tank Diameter, (m) ........................................        2.5
    Tank Length, (m) ..........................................        19
    Hole Diameter, (m) ........................................     0.075
    Contents Temperature, ( K ) ................................       293
    Contents Pressure, (Pa) ...................................  8.52E+05
    Initial Liquid Volume, (m3) ...............................      74.6
    Initial Liquid Mass, (kg) .................................  4.55E+04
    Initial Liquid Height, (m) ................................      1.78
    Discharge Coefficient .....................................      0.62
    Entrance Effects: Circular holes with sharp edges
    Liquid density, (kg/m3) ...................................       609
    Tank capacity, (m3) .......................................      93.3
    Tank capacity, (kg) .......................................  5.68E+04
    Time to empty, (s) ........................................      545
    Average mass flow rate, (kg/s) .............................      83.4
    Average volumetric flow rate, (m3/s) .......................     0.137
    Discharge Velocity, (m/s) .................................        31

    2-Phase expansion/aerosolization model
Initial temperature, (K) ..................................       293
    Initial pressure, (Pa) ....................................  8.52E+05
    Nozzle vapor quality ( 0 to 0.99 ) .........................     0.001
    Nozzle diameter, (m) ......................................     0.075
    Two-phase mass flow rate, (kg/s) ...........................      83.4
    Final temperature, (K) ....................................       240
    Final pressure, (Pa) ......................................  1.01E+05
    Ambient temperature, (K) ..................................       293

    Initial vapor density, (kg/m3) ............................      6.46
    Initial liquid density, (kg/m3) ...........................       609
    Initial mixture density, (kg/m3) ...........................       557
    Initial mixture velocity, (m/s) ...........................      33.9
    Final vapor density, (kg/m3) ...............................     0.879
    Final liquid density, (kg/m3) .............................       681
    Final mixture density, (kg/m3) .............................      5.53
    Final mixture velocity, (m/s) .............................      73.6
    Isentropic flash fraction .................................     0.158
    Expanded diameter, (m) ....................................     0.511

    Superheat, (K) ............................................      53.3
    Total internal energy change, (J/kg) .......................    4.2E+04
    Work done on the atmosphere, (J/kg) ........................  1.81E+04
    Expansion Energy, (J/kg) ..................................  2.38E+04
    Mass fraction rained out ..................................  4.99E-11
    Vapor mass rate, (kg/s) ...................................      13.2
    Liquid aerosolization rate, (kg/s) .........................      70.2
    Liquid mass rainout rate, (kg/s) ...........................  4.16E-09
    Final vapor fraction ......................................     0.158
```

C3 Chlorine Dispersion

Pressurized liquid discharge model

Tank Diameter, (m)	2.5
Tank Length, (m)	19
Hole Diameter, (m)	0.075
Contents Temperature, (K)	293
Contents Pressure, (Pa)	8.52E+05
Initial Liquid Volume, (m3)	74.6
Initial Liquid Mass, (kg)	4.55E+04
Initial Liquid Height, (m)	1.78
Discharge Coefficient	0.62

Entrance Effects: Circular holes with sharp edges

Liquid density, (kg/m3)	609
Tank capacity, (m3)	93.3
Tank capacity, (kg)	5.68E+04
Time to empty, (s)	545
Average mass flow rate, (kg/s)	83.4
Average volumetric flow rate, (m3/s)	0.137
Discharge Velocity, (m/s)	31

2-Phase expansion/aerosolization model

Initial temperature, (K)	293
Initial pressure, (Pa)	8.52E+05
Nozzle vapor quality (0 to 0.99)	0.001
Nozzle diameter, (m)	0.075
Two-phase mass flow rate, (kg/s)	83.4
Final temperature, (K)	240
Final pressure, (Pa)	1.01E+05
Ambient temperature, (K)	293

Initial vapor density, (kg/m3)	6.46
Initial liquid density, (kg/m3)	609
Initial mixture density, (kg/m3)	557
Initial mixture velocity, (m/s)	33.9
Final vapor density, (kg/m3)	0.879
Final liquid density, (kg/m3)	681
Final mixture density, (kg/m3)	5.53
Final mixture velocity, (m/s)	73.6
Isentropic flash fraction	0.158
Expanded diameter, (m)	0.511

Superheat, (K)	53.3
Total internal energy change, (J/kg)	4.2E+04
Work done on the atmosphere, (J/kg)	1.81E+04
Expansion Energy, (J/kg)	2.38E+04
Mass fraction rained out	4.99E-11
Vapor mass rate, (kg/s)	13.2
Liquid aerosolization rate, (kg/s)	70.2
Liquid mass rainout rate, (kg/s)	4.16E-09
Final vapor fraction	0.158

C3 Propane BLEVE from the Oil Harbour

Values from “GASOL”

Moment	Value	Unit

Storing		
Temperature		
Condensation		
Pressure		

Tank		
Form		
Diameter		
Length		
Degree of filling		
Weight, empty		
Design pressure		
Breakage pressure		

Weather conditions		
Air pressure		
Air temperature		
Relative moisture		
Wind velocity		
Reference height		
General weather cond.		

Environment		
Surface coarseness		
General description		

BLEVE		
Mass out		
Diameter of the fireball		
Duration		
Height over ground		
Distance for broken parts		
Distance to 3rd degree burn		
Distance to 2nd degree burn		
Distance to 1st degree burn		

D Frequency Calculation

D1 Spreadsheet for frequency calculation of railway incidents

Calculation of Hazardous Leakages caused by railroad accidents

Type of failure (x = occur - ONLY one failure)

Wagon	
Human	x
Unknown	

0	Part number			1	
1	Length of path	S	km	1	
2	Number of axles (H)	TAF	st	10	
3	Number of axles (Total)	TAV	st	116	
4	Rail Quality (a-d)	(i)		b	
5	Sort of moving (train, switching, shunting)			switching	
6	Derailment (H) Rail Quality	Utif		1.9E-09	
7	Derailment (N) Rail Quality	UTig		4.3E-09	
8	Derailment (H) No railfailure	UTOf		3.1E-09	
9	Derailment (N) No railfailure	UTOg		3.1E-09	
10	Expected # of collision Train vs. Train	FKT	st	6E-08	
12	Number of gate crossing	PK1	st	0	
13	Number of sound and light cross.	PK2	st	1	
14	Number of signposting or none	PK3	st	1	
15	Number H-transportations per year	AT	st	5820	
16A(H)	Damaged H-wagon by derailment (Only H)	F(1H)	st	0.000728	
16A(N)	Damaged H-wagon by derailment (Most N)	F(1N)	st	0.000728	
16B(H)	Damaged H-wagon by train collision (Only H)	F(2H)	st	0.001048	
16B(N)	Damaged H-wagon by train collision(Most N)	F(2N)	st	9.03E-06	
16C(H)	Damaged H-wagon by cross collision (Only H)	F(3H)	st	0.001979	
16C(N)	Damaged H-wagon by cross collision(Most N)	F(3N)	st	1.71E-05	
17	Damaged H-wagon by shunting	FR	st	0.000012	
18a	Leaks thin-wall tank (small leakage)			Hazardous	Normal
	Train and truck traffic		st	0.000938	0.000189
	Switching		st	0.000938	0.000189
	Shunting		st	1.2E-06	1.2E-06
18b	Leaks thin-wall tank (Medium leakage)				
	Train and truck traffic		st	0.00015	3.02E-05
	Switching		st	7.51E-05	1.51E-05
	Shunting		st	1.2E-07	1.2E-07
18c	Leaks thin-wall tank (Large leakage)				
	Train and truck traffic		st	3.75E-05	7.54E-06
	Switching		st	3.75E-05	7.54E-06
	Shunting		st	1.2E-07	1.2E-07
19a	Leaks thick-wall tank (alll leakages)				
	Train and truck traffic		st	3.75E-05	7.54E-06
	Switching		st	3.75E-05	7.54E-06
	Shunting		st	1.2E-07	1.2E-07