9 OUTFLOW MODEL

Pollution of the environment is the most severe damage for the community. Two types of pollutions are distinguished, pollution by operational spills and pollution by calamitous spills. Operational spills can be further distinguished in spills that have a continuously character as emissions and deliberated spills. Emissions are for example emissions of exhaust gases to the air and leaching substances from the hull paintings to the water, during normal operation. Deliberated spills are discharges of wasted volumes somewhere at sea. Calamitous spills can occur after the ship is involved in an incident.

Operational spills can be quantified by linking the shipping miles with the emission factors per mile. In case of deliberated spills the geographical position in relation to the coast can play a role.
In some applications a number of ship related rules are applied for a better description of the emissions.

The total amount per year of operational oil spills is much more than the average yearly amount of oil spilt by calamities. However, operational spills are small volumes that have minor impacts, while a calamitous spill can have a large impact. For this reason the probability and the size of a calamitous spill plays a prominent role in environmental impact analyses.

9.1 Operational spills

The modelling of operational spills is simple. The probability and volume of an operational spill is directly related to the number of miles travelled, or time at sea. The behaviour of the crew can be modelled by using different probabilities for areas near the coast and sea areas further away from the coast. Also the volume of the spill can be modelled by expected volumes for different ship type and size classes. The determination of this type of spill depends completely on the assumptions because very scarce data is available.

All types of processes directly linked to ship miles can be modelled in this way. In the last years the emissions to air from exhaust gases and to water from antifouling paintings have been determined with SAMSON. For these projects the emission factors for each individual ship (detailed) or for an averaged ship of each cell of the ship matrix (globally) was determined. The spatial emission could be determined by applying these factors on the routes of the ships.

The SAMSON-model offers the possibility to apply the global approach. For the detailed approach, the detailed databases of the shipping characteristics and the voyage database are required. These detailed databases could not be included in the delivery of the SAMSON-model because these databases are acquired under condition of restricted use by MARIN only. MARIN is allowed to use the data for projects for the Dutch Authorities

9.2 Calamitous spills

A calamitous spill is an outflow of substance as a consequence of a casualty. For each type of casualty the probability and the expected volume of outflow is modelled. Only the outflow of substances carried as liquids in bulk are modelled. This means that the loose or dry cargo or containers are not modelled. The outflow of bunker oil from fuel tanks is included and can be determined in a similar way.

The outflow model follows the chain from the casualty to a possible outflow. An outflow occurs only when;

1. The damage takes place in the cargo part of the ship. A damage in front of the collision bulkhead (for example a colliding ship) or in the aft part of the ship will not result in an outflow. Of course the structural damage can be severe, but there will be no direct threat to the environment.
2. The cargo tank is penetrated. In case of a single hull ship the wing tank is penetrated when the ship hull is penetrated. In case of a double hull tanker more energy is required to penetrate the inner hull, being the hull of the cargo tank.
3. The penetrated cargo tank is loaded. The cargo tank that is penetrated can be a ballast tank or empty.
4. The amount of outflow depends on the location of the hole and the size of the penetrated tank.

The type of cargo that flows out depends on the substance carried by the ship. For the impact on the environment one can define the substances for which the outflow has to be calculated. This has been implemented in an flexible way in which the user defines a collection of substances for which the calculations have to be executed. After a new selection of substances, the program DETFLO calculates the probability of an outflow and the amount of outflow for each type of casualty. The results are stored in a sub directory of DETFLO with the name given to the selection of substances. The results are applied in the calculations with SAMSON by choosing this name of the selection in the calculations.

The finals result of DETFLO, stored in the files are:

$pflo_{ijk}$ probability of an outflow for each ship type i and ship size j for outflow class k
$xflo_{ijk}$ amount of outflow for each ship type i and ship size j for outflow class k
$uitkl_k$ the limits of the outflow class

The files (COLCARGO.ALL etc) also contain the base variables as the selection of dangerous goods and the weighing factors for which the files are composed.

9.3 DAMAGE models

The damage in case of a collision or grounding depends on a large number of parameters in which static parameters as dimensions and structures of the ships and operational parameters as speeds, drafts and collision angle. Even the structure is not completely static because it deteriorates with the age of the ship. It is nearly impossible to describe the damage as a function of all these parameters

Results of studies for IMO

In the period SAMSON was developed, different studies [10] and [11] were carried out for the IMO dealing with the possible damage after a collision or grounding. The results of these studies are implemented in SAMSON.

Some paragraphs and figures about the damage statistics are copied from the “explanatory notes to the SOLAS regulations on subdivision and damage stability of cargo of ship of 100 meters in length and above” [12]. These statistics have formed the base for the damage functions in SAMSON.

The IMO have collected 811 damage cards of casualties reported to the IMO that are used in many studies. There were 296 cases of rammed ships containing information about, the ship length (L), ship breadth (B), damage location (x), damage length (y) and penetration (z).

The principal factors affecting damage are:

1. structural characteristics of the rammed ship;
2. structural characteristics of the ramming ship;
3. mass of he rammed ship at the time of collision;
4. mass of the ramming ship at the time of collision;
5. speed of the rammed ship at the time of collision;
6. speed of the ramming ship at the time of collision;
7. the shape of the bow of the ramming ship;
8. relative course angle between rammed and ramming ship;
9. location of damage relative to the ship’s length and depth;

It was not possible to distinguish all factors in the distribution function, for reason that some values of the factors were not known, and in case they should have been known, the number of variables should have been too much.

Side step

All the principal factors mentioned above are used in the MARCOL (MARritime COLlisions)-model [13]. MARCOL has been developed to determine the probability of a hole from the other side, by varying the principal factors and next determining for each case whether or not the cargo tank should have been penetrated. In addition, the size of the hole and the location of the hole below or above the waterline could be delivered. This new development started within the safety studies for LNG transport to a port (Rotterdam, Eemshaven, Le Verdon (France), Goldboro (Canada) and Zeebrugge). It was felt that a better approach for the probability of a hole was required because the base for the probability functions delivered by the IMO is small. Further the IMO data is taken from the period that most tankers were single hull while many have double hull nowadays. The MARCOL-model offers also the possibility to calculate the effect of the structural design on the probability of a hole and the effect of external measures such as speed reduction.

Thus additional use of MARCOL offers possibilities that are not included in SAMSON.

The number of factors was reduced by eliminating all characteristics of the ramming ship. This means that they are considered as randomly distributed. The characteristics of the rammed ship are most important because this ship will be damaged most severely and can cause an outflow.

It was found that:

- the damage length did not depend significantly on the place where it occurred on the ship;
- the distribution of the ratio damage length to ship length y/L is more or less independent of the ship length.
- the distribution of the ratio penetration damage to ship breadth z/B is more or less independent of the ship length.

Based on different studies, as for example [10] and [11], IMO has provided a number of distribution functions that describe the damage functions in case of a collision and grounding. These distribution functions were derived from a large number of damage descriptions of ships involved in collisions and groundings. The functions were provided in a dimensionless shape. This is not exactly what is expected, because the probability of penetrating a large ship with 50% of the breadth will be less likely than penetrating a smaller ship with 50% of the breadth.

However, it was the best data that was available at that time. The distribution functions provided by IMO were used, but some changes were added to make the damage patterns more realistic. Later, when the worldwide statistics of casualties became available and were analyzed, changes were made to improve the fit between the calculated probability of a hole and the observed probability. That is described in Chapter 9.7 after the theoretical approach.

Distribution of damage length

The collection of the observed the damage length divided by the ship length is given in Figure 9-1. The distribution function for the dimensionless damage length of Figure 9-3 with the corresponding density distribution of Figure 9-2 are derived from these data points.

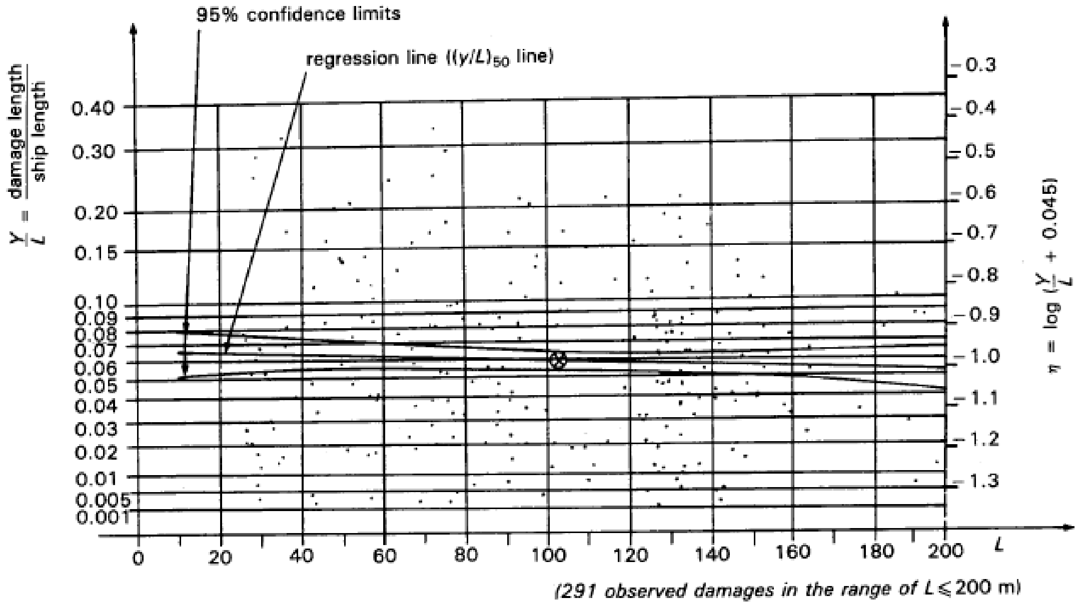

Figure 9-1 Regression of dimensionless damage length on ship length

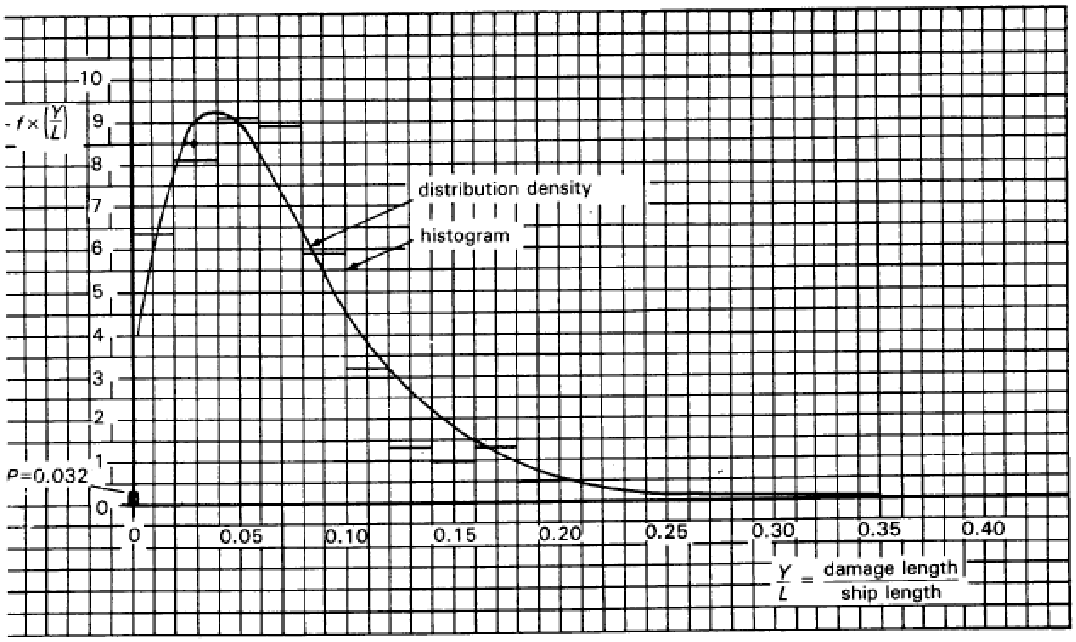

Figure 9-2 Distribution density of dimensionless damage length y/L

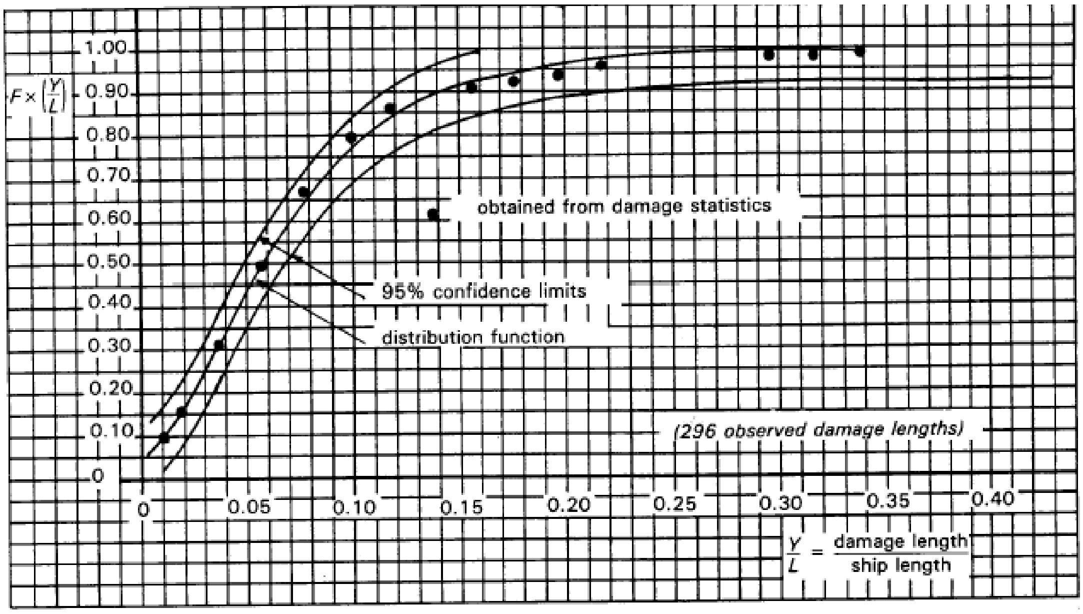

Figure 9-3 Distribution function of dimensionless damage length y/L

Distribution of damage location

From the collected data it seemed that collided ships are more frequently struck at the aft part of the ship, which is presumably caused by last minute actions. The derived distribution density for the damage location is presented in Figure 9-4 with the corresponding distribution function in Figure 9-4

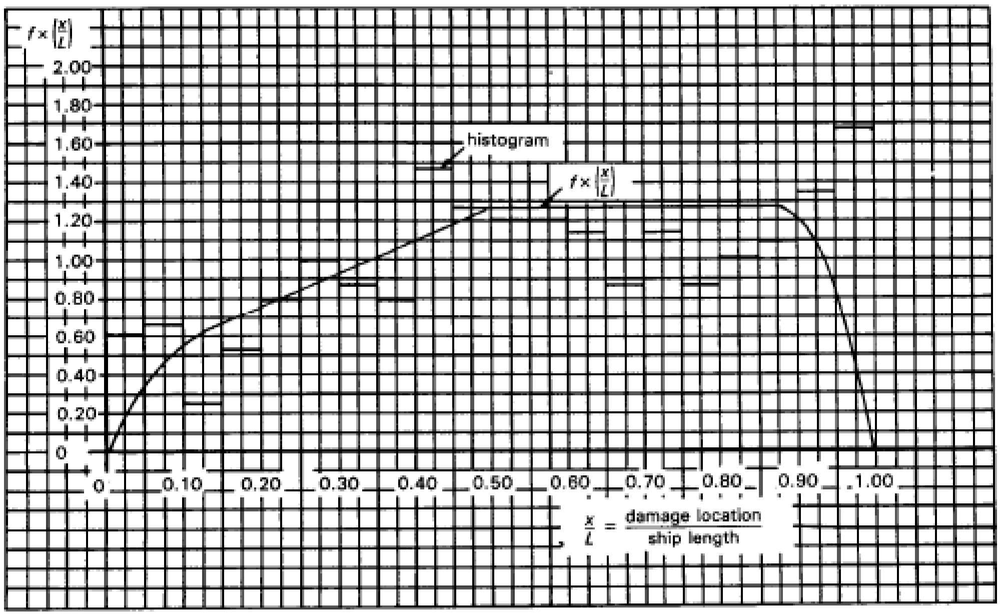

Figure 9-4 Distribution density of dimensionless damage location

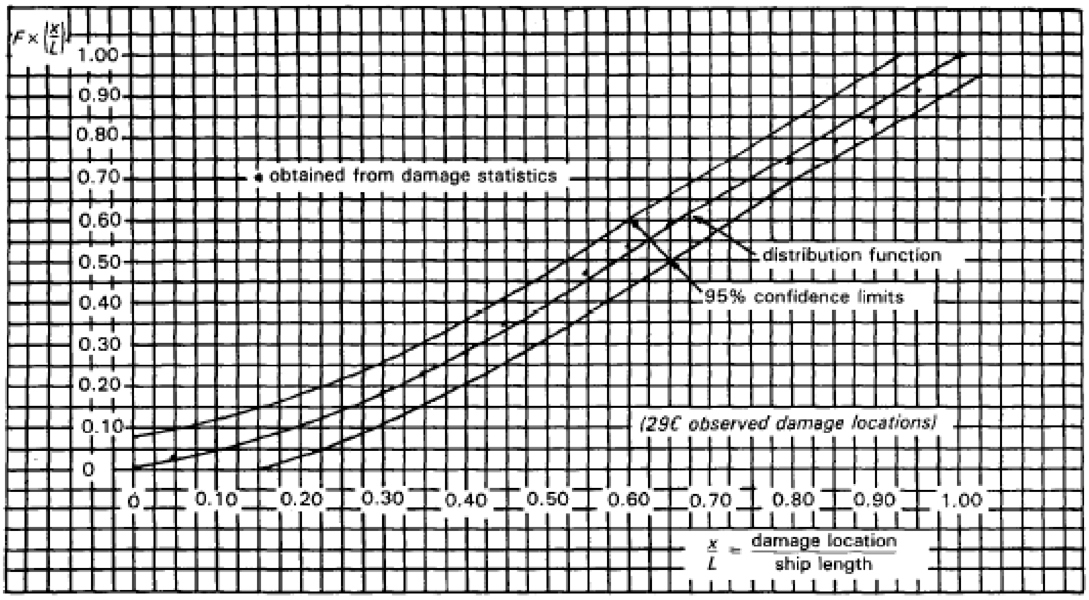

Figure 9-5 Distribution function of dimensionless damage location

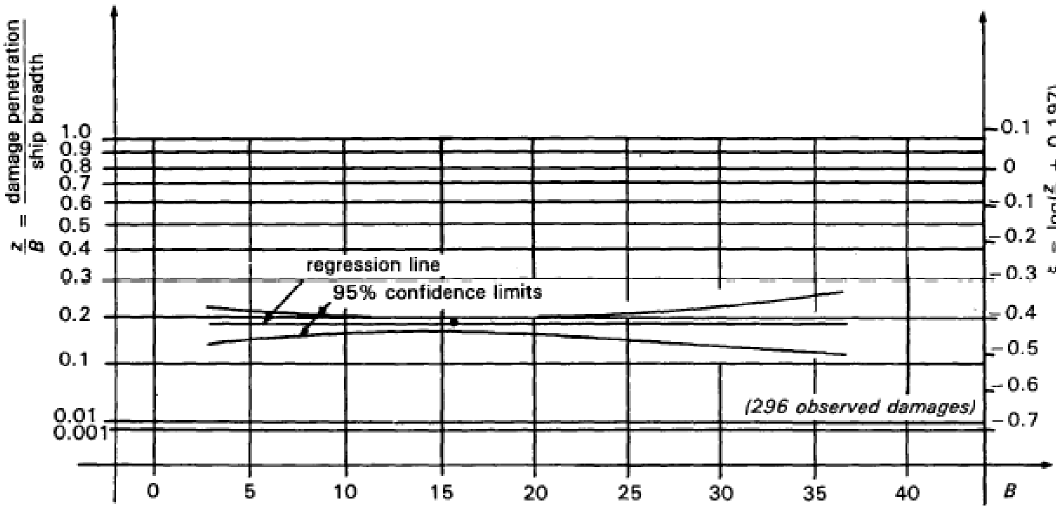

Figure 9-6 Regression of dimensionless damage penetration on ship breadth

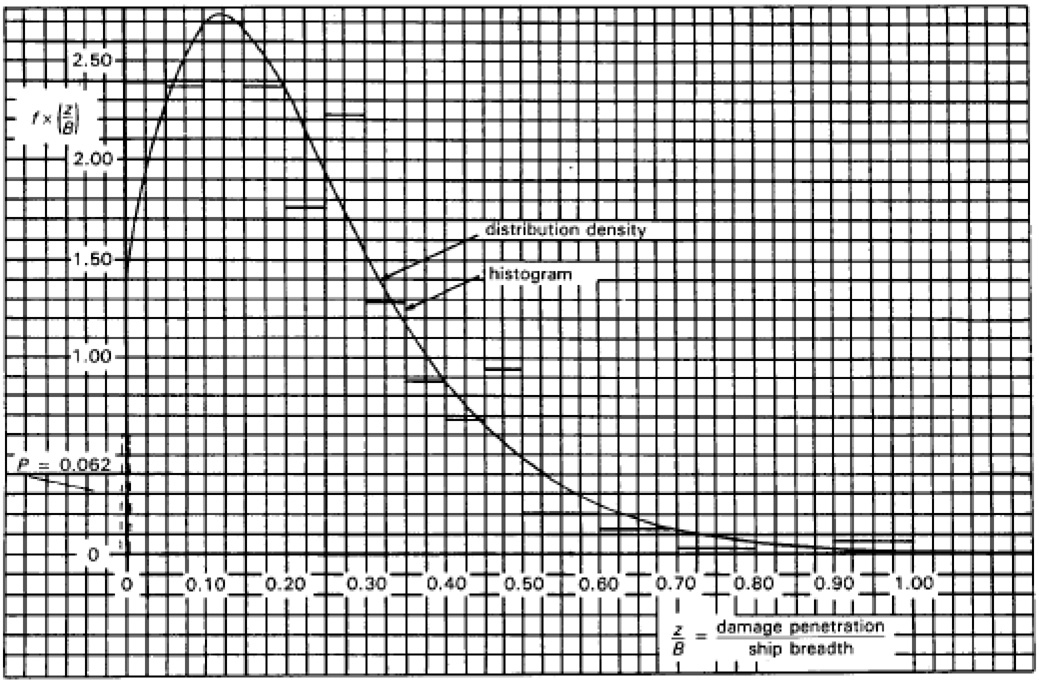

Figure 9-7 Distribution density of dimensionless damage penetration

The dimensionless damage penetration is also lognormal distributed. However, a general description of the damage penetration cannot be considered independent of the damage length. A large penetration is only possible combined with a large damage length. This is illustrated in Figure 9-8.

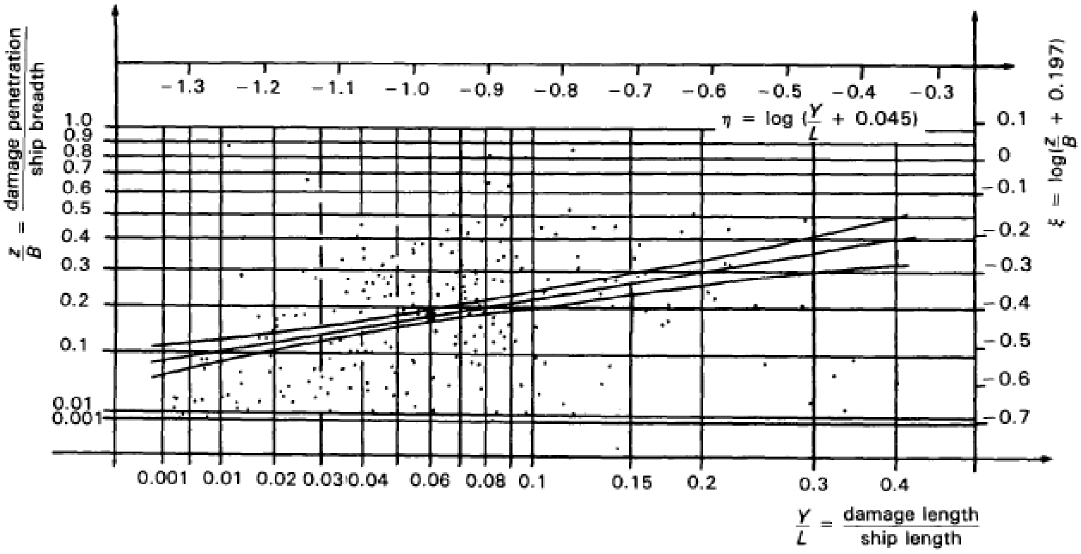

Figure 9-8 Dimensionless damage penetration versus dimensionless damage penetration

The above figures and distributions have resulted in the following description of the density function for the damage to a ship after a collision:

$$p(\frac{x}{L},\frac{z}{D},\frac{l_s}{L},\frac{b_s}{B},\frac{d_s}{D}) = p_x(\frac{x}{L})\, p_z(\frac{z}{D})\, p_l(\frac{l_s}{L})\, p_b(\frac{b_s}{B}|\frac{l_s}{L})\, p_d(\frac{d_s}{D})$$

In which:

L	length of the ship
D	depth of the ship
B	breadth of the ship
T	draught of the ship
x	position of the damage measured from the Fore Peak Perpendicular (FPP)
z	position of the damage measured from the base
l_s	length of the damage
d_s	height of the damage
b_s	penetration depth of the damage
p_x	probability distribution in length direction
p_z	probability distribution in vertical direction
p_l	probability distribution of the length of the damage
p_d	probability distribution for the height of the damage
p_b	the conditional distribution of the penetration when the damage length is given

Figure 9-9 shows some of parameters.

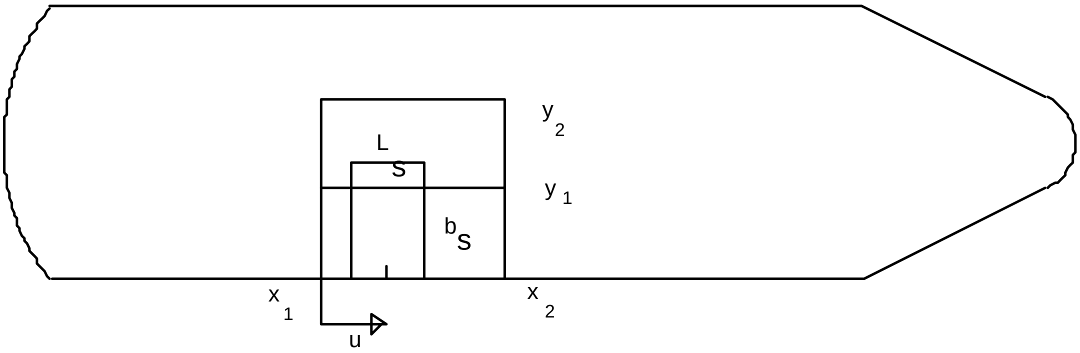

Figure 9-9 Explanation of variables used

The density functions for the damage length (l_s/L), the penetration depth (b_s/B) damage location (x/L) are taken from the IMO-distributions. The density functions of the damage location in the height direction (z/D), and the damage length in height direction (d/D) are added to the IMO density functions. The position of the damage location in the height direction is important to determine whether the hole in the cargo tank will occur above or below the waterline. The damage length in height direction is of minor importance because it is more or less implicitly included in the damage length l_s/L and the penetration depth b_s/B. Figure 9-10 shows that the operational draught, bow and bulb shape of the colliding ship and the operational draught and size of the collided ship are very important to determine where the cargo tank is penetrated.

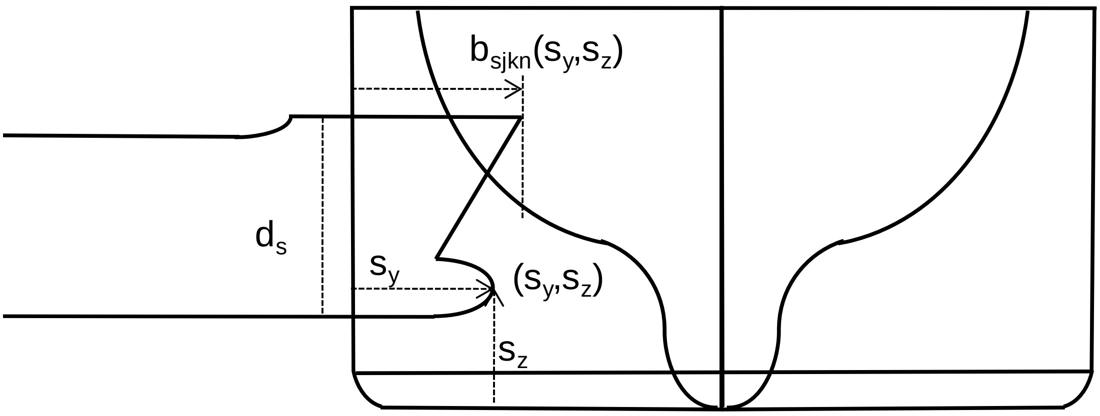

Figure 9-10 Penetration of hull of collided ship

For this reason further research was carried out to improve the damage distribution function. Chapter 9.3.1 describes the classification in ship types that is used to determine where the damage in the height direction can be expected. Chapter 9.3.2 contains the different operational draughts that are considered and Chapter 9.3.3 describes how the damage distribution functions are made dependent on the ship size class.

9.3.1 Bow types of the ships

The bow type, or more precisely the bow and bulb of the colliding ships are the most stiff parts of the ship that will cause the most damage. Which one, bow or bulb will cause the most damage will depend on the shape of the colliding ship and the shape of the collided ship. The bow shape is analyzed from 166 ship descriptions. It was found that seven basic shapes were sufficient to characterize all bow types. These seven bow types are presented in Figure 9-11.

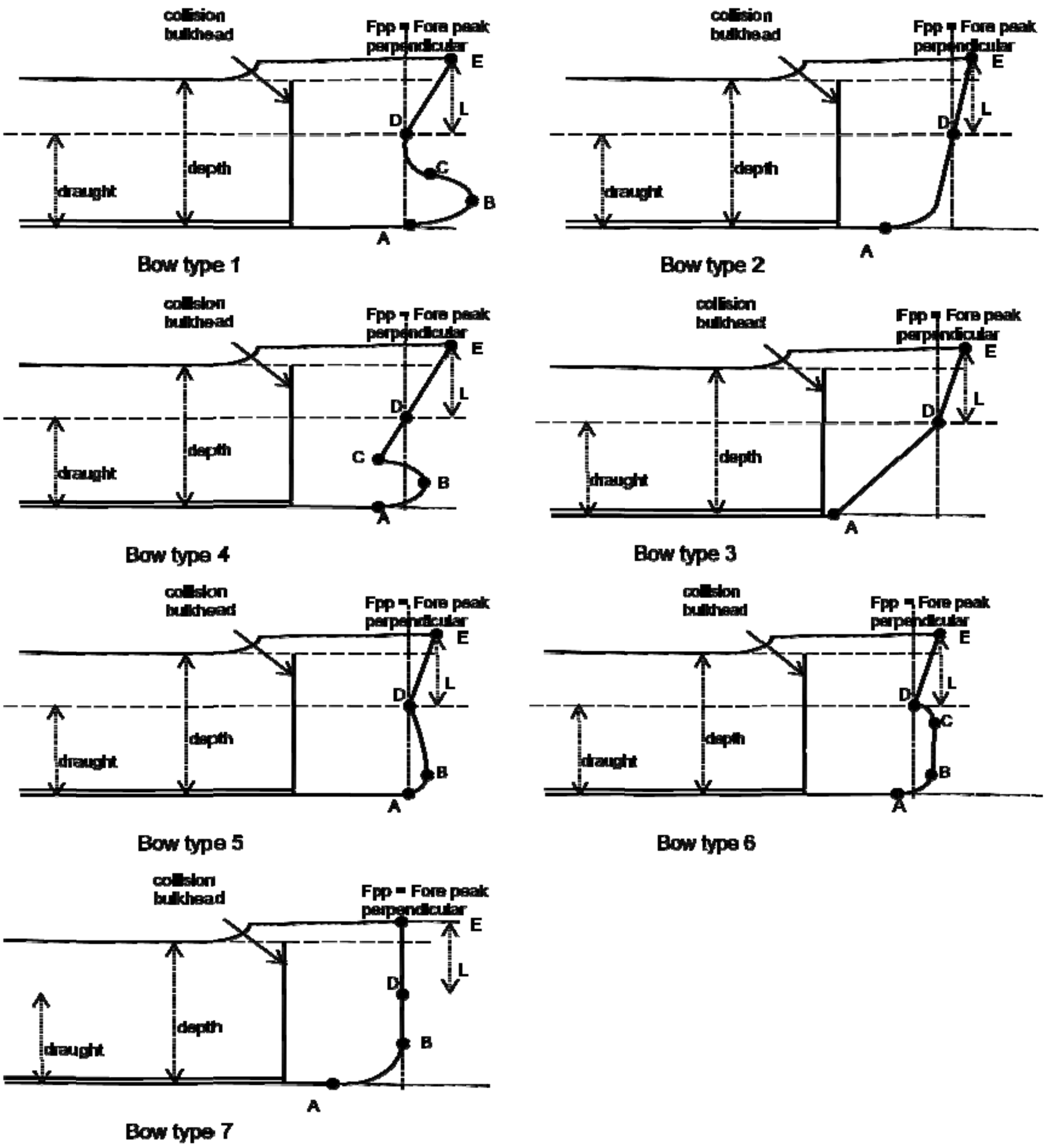

Figure 9-11 The seven bow types

The average positions, made dimensionless by dividing the vertical position by the depth and the horizontal position by the length, are determined for each bow type. The distribution over the seven bow types is not the same for each cell of the ship matrix. It was found that the bow type distribution depends mainly on the ship size class. The distribution found, given in Table 9-1, is used for the relation between the ship matrix and the bow types. The ships are divided in ships with bulb and ships without a bulb. The fraction of ships with a bulb increases from 40% for size class 1 with the smallest ships to 90% for size class 8 with the largest ships. The distribution over the different bow types composed for each size class are given in Table 9-2.

Table 9-1 Classification of bow and bulb shape of the 160 ship layouts

Bow type	SAMSON GT classes								Total	% of bulb	% no bulb
	1	2	3	4	5	6	7	8			
1	1	2	4	18	22	14	5	3	69	51%	
2	3	3	4	2	3	0	0	0	15	11%	
3	0	0	1	1	3	0	0	0	5		16%
4	1	0	5	11	11	9	1	0	38	28%	
5	0	2	2	1	6	0	0	1	12		39%
6	0	0	0	1	1	6	4	4	16	12%	
7	0	0	3	1	0	3	3	1	11		35%
Total	5	7	19	35	46	32	13	9	166	100%	100%
with bulb (1, 4, 5 and 6)	2	4	11	31	40	29	10	8	135		
in %	40%	57%	58%	89%	87%	91%	77%	89%	81%		
Used distribution in calculations	0.4	0.6	0.7	0.8	0.85	0.9	0.9	1			

Table 9-2 Distribution of bow types

Bow type	SAMSON GT classes							
	1	2	3	4	5	6	7	8
1	0.215	0.309	0.343	0.417	0.434	0.456	0.448	0.500
2	0.047	0.067	0.075	0.091	0.094	0.099	0.097	0.109
3	0.102	0.068	0.056	0.030	0.024	0.016	0.018	0.000
4	0.118	0.170	0.189	0.230	0.239	0.251	0.247	0.275
5	0.244	0.164	0.135	0.071	0.057	0.038	0.044	0.000
6	0.050	0.072	0.080	0.097	0.101	0.106	0.104	0.116
7	0.224	0.150	0.123	0.065	0.052	0.035	0.040	0.000
total	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

9.3.2 Distribution of operational draught

The dimensions of both ships are important for the determination of the first contact point. Also the loading conditions of both ships are important parameters for the determination of the first contact point. For some ships, as dry cargo and container ships, the draught varies not much. However, in case of tankers the variation in draught is considerable because they are loaded or sail in ballast condition. The distribution of the draught is derived from the data of arriving and departing ships of the Port of Rotterdam. Three different draughts are distinguished, a low, average and high value. The percentages of the draught related to the summer draught of the ship are given in Table 9-3 and the fractions of the ships with the corresponding draught are given in Table 9-4.

Table 9-3 Draught as percentage of maximum summer draught of the ship

Draught	SAMSON GT classes							
	1	2	3	4	5	6	7	8
Ballast	76%	86%	67%	76%	72%	62%	60%	55%
Average	88%	89%	88%	85%	82%	83%	77%	80%
Full	100%	95%	94%	88%	87%	88%	92%	95%

Table 9-4 **Fraction of ships with the distinguished draughts**

Draught	SAMSON GT classes							
	1	2	3	4	5	6	7	8
Ballast	0.00	0.06	0.08	0.10	0.20	0.40	0.50	0.50
Average	1.00	0.88	0.84	0.80	0.60	0.20	0.00	0.00
Full	0.00	0.06	0.08	0.10	0.20	0.40	0.50	0.50

9.3.3 Distribution of the penetration for each size class

The distribution of the penetration depth is the most essential for determing whether or not a cargo tank is penetrated. This distribution originally described by IMO was a dimensionless function of the penetration divided by the breadth of the ship. The first improvement was to describe the penetration depth as a conditional distribution given a damage length.

The objective of this chapter is to describe the shape of the distribution function of the damage location in the height direction. The position is strongly dependent on the size of the colliding ship. A small ship that collides against a large ship will do that with the bow or bulb depending on the bow type. However a large ship that collides against a small ship will do that always at the deck or bottom. Further the penetration depth will also depend on the colliding ship. It is not assumable that the penetration when collided by a small ship will be the same as when collided by a large ship. For this reason the dimensionless distribution function is arbitrarily split up into 8 different dimensionless distribution functions, namely one for each size class of the colliding ships.
Because no real data is available, this split up is based on the assumption that the penetration volume is linearly related with the absorbed energy (relation also found in publications). Thus with:

$$\frac{1}{2} m\, v^2 = c\, d_s\, l_s\, b_s$$

in which

- m mass of the colliding ship
- v speed of colliding ship
- d_s height of the damage
- b_s penetration depth of the damage
- l_s length of the damage

The size of the damage length l_s and the location of the damage d_s depend both on the size of the colliding ships, proportional with the length of the colliding ship (L_c). Because the mass of the colliding ship is proportional with L_c^3 it follows from above relationship that the penetration depth b_s is proportional with $L_c v^2$. This proportionality is used to derive the distribution for the dimensionless penetration for each size class from the only known distribution summarized over all size classes. This new distribution, may not be correct for 100% but gives a better approach of the probability of the penetration depth.

9.3.4 Probability of the penetration in a cargo tank

The results of 9.3.1, 9.3.2 and 9.3.3 have resulted in adapted damage functions of IMO that are used. The damage probability functions are used to determine if a tank in the ship is penetrated. Figure 9-12 shows a tank between x_1 to x_2 from the bottom to the deck, at a distance from z_{min} to z_{max} from the hull of the ship.

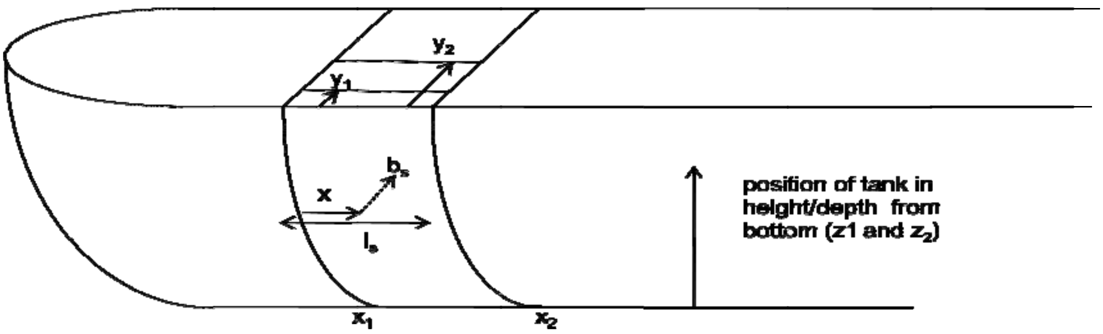

Figure 9-12 Location of tank

Four cases are distinguished in the modelling.
The first probability is determined for the case that only this tank is penetrated and not neighbourhood tanks, thus damage between x_1 and x_2. The damage routine determines the probability exactly for the given block. This means that when the centre point of the damage x is close to x_1, the damage length is limited to 2x, because otherwise the damage will stretch outside the range x_1 to x_2. For this reason the integration over the damage length is limited to 2x.

$$P_1 = 2\int_{z_1}^{z_2} \int_0^{(x_2-x_1)/2} \int_0^{2x} \int_{y_1}^{1} p_x(\frac{x+x_1}{L})\, p_z(\frac{z}{D})\, p_l(\frac{l_s}{L})\, p_b(\frac{b_s}{B}|\frac{l_s}{L})\, p_d(\frac{d_s}{D})\, db_s\; dl_s\; dx\; dz$$

A second probability is for the case that the centre of the damage lies between x1 and x2 but also the area lower than x1 or above x2 is damaged. This requires a damage length of at least 2x.

$$P_2 = 2\int_{z_1}^{z_2} \int_0^{(x_2-x_1)/2} \int_{2x}^{l s\max} \int_{y_1}^{1} p_x(\frac{x+x_1}{L})\, p_z(\frac{z}{D})\, p_l(\frac{l_s}{L})\, p_b(\frac{b_s}{B}|\frac{l_s}{L})\, p_d(\frac{d_s}{D})\, db_s\; dl_s\; dx\; dz$$

A third probability is determined for the case that the centre of the damage is on the aft side of the tank, but with a damage length that reaches above x1, thus larger than 2x (z taken aft wards from x1).

$$P_3 = \int_{z_1}^{z_2} \int_0^{\max(x_1, l_{s\max})} \int_{2x}^{l_{s\max}} \int_{y_1}^{1} p_x(\frac{x_1-x}{L})\, p_z(\frac{z}{D})\, p_l(\frac{l_s}{L})\, p_b(\frac{b_s}{B}|\frac{l_s}{L})\, p_d(\frac{d_s}{D})\, db_s\; dl_s\; dx\; dz$$

The fourth probability is determined for the case that the centre of the damage is on the fore side of the tank, but with a damage length that reaches to under x2, thus larger than 2x (x taken forwards from x2).

$$P_4 = \int_{z_1}^{z_2} \int_{0}^{\max(1-x_2, l_{s\max})} \int_{2x}^{l_{s\max}} \int_{y_1}^{1} p_x\left(\frac{x+x_2}{L}\right) p_z\left(\frac{z}{D}\right) p_l\left(\frac{l_s}{L}\right) p_b\left(\frac{b_s}{B} \middle| \frac{l_s}{L}\right) p_d\left(\frac{d_s}{D}\right) db_s \, dl_s \, dx \, dz$$

Because the density function in the z direction is not dependent on the others this integral is solved separately. The density function p_x in the x-direction does not change too much and local penetrations are considered, this function can be considered as a constant value for the location of the tank. This simplifies the solution of P_1 through P_4.

These four cases are used in the calculations to determine the probability that 1, 2, 3 etc. tanks are penetrated. For bunker tankers it is assumed that only one fuel tank will be penetrated. For cargo tanks the tank layout is used to determine how many tanks will be penetrated.

The probability of penetration is multiplied with the probability that the tank is loaded with the substances that are selected, thus bunker oil or a collection of UN-numbers, see 9.4.

9.4 Substances on board

9.4.1 Background

An enormous variety of goods are transported by ships. Some goods are not harmful for the environment when they come into the environment (sea) after an accident while others can be very harmful. The transport of goods is regulated to minimize the risk of the transport for people and the environment.

Each chemical substance has given a unique number by the United Nations Sub-Committee of Experts on the Transport of Dangerous Goods (UNSCETDG). The number of four digits is called the UN-number and is used for the classification for dangerous goods

Before a ship enters a port, the list of dangerous goods on board has to be provided to the national maritime authority in order to get permission to enter the port. Also a list with dangerous goods have to be provided when leaving the port. This means that the port authority (executive organisation for the national maritime authority) knows exactly what type of cargo is on board when the ship enters and leaves the port. In the first period of the development of SAMSON this was all paperwork. Nowadays most reports are provided digitally.

The information about the transport of dangerous goods is dealt with as confidential information that is not provided to others. At this moment (2009) each ship/port has to send a message to the SSN (Safe Sea Net)-database of the EMSA. The SSN-database is a so-called index-database, thus without the detailed information about the dangerous goods, but with only a reference where the information can be found. Only in case of an accident the maritime authority can ask for the detailed information of the transported dangerous goods of the passing ship.

9.4.2 Expected amount of substances on board

This short description makes clear that it is not easy to predict the type of substances and the amount of substances that can be spilt to sea in case of an accident. Because for example crude oil will be transported by large crude tankers, refined oils by product tankers and chemicals by chemical tankers it was assumed that some relations exist between UN-number and the ship type and size. This relation is used to described the

$$\mathrm{expon}_{ijk} = \mathrm{f}_{cel} * (\mathrm{wn}_{ijk} / \mathrm{n}_{ij}) + \mathrm{f}_{tot} * \left(\sum_j \mathrm{wn}_{ijk} / \sum_j \mathrm{n}_{ij}\right)$$

substances on board of a ship involved in an accident. The cargo on board can be considered as the average cargo for the ship. The average cargo is determined in two steps. Firstly, it is determined which part of the ships carries substance ki (is $expon_{ijk}$).
In which:

$expon_{ijk}$	expected fraction of ships of type i size j carrying substance k
f_{cel}	weighing ship type/size
f_{tot}	weighing total
wn_{ijk}	reported ships type i size j carrying substance k
n_{ij}	number of ships type i size j calling the ports of the inventory

Secondly the average amount of substance i on board is determined when is known that the ship carries this substance.

$$expod_{ijk} = f_{cel} * (wa_{ijk}/GT_{ij}) + f_{tot} * (\sum_j wa_{ijk} / \sum_j GT_{ij})$$

$$expod_{ijkt} = f_{cel} * (wa_{ijkt}/GT_{ij}) + f_{tot} * (\sum_j wa_{ijkt} / \sum_j GT_{ij})$$

In which:

$expod_{ijk}$	expected amount of substance k carried by a ship of type i size j carrying substance k per GT
$expod_{ijkt}$	expected amount of substance k carried in tank type t by a ship of type i size j per GT
f_{cel}	weighing ship type/size
f_{tot}	weighing total
wa_{ijk}	reported amount of substance k carried by type i size j
wa_{ijkt}	reported amount of substance k carried in tank type t by type i size j
GT_{ij}	sum of GT of ships type i size j calling the ports of the inventory

The formulas describe how the expected amount for substance i on board is determined by extrapolation based on the reports. It is assumed that each ship of a type i and type j carries on average the same cargo on the North Sea. For each ship the probability that it carries substance k is $expon_{ijk}$ and in case she is carrying substance k then the average amount is $expod_{ijk}$ GT_{ship}, in which GT_{ship} is the GT-value of the ship that can deviate of the average value of the ship type and size class.

Tank type t is added because some extra conditions have to be fulfilled for carrying some substances. The extra conditions are mentioned in Table 9-5 and the parameters are explained in Figure 9-13.

Table 9-5 Conditions on ship carrying dangerous goods

Condition for ships with tank type	Chemical tanker	Gas tanker
1	d_{SLL} > min (B/5,11.5 m) d_{bottom} > min (B/15,6 m) d_{hull} >0.76 m	d_{SLL} > min (B/5,11.5 m) d_{bottom} > min (B/15,2 m) d_{hull} >0.76 m
2	d_{bottom} > min (B/15,6 m) d_{hull} >0.76 m	d_{bottom} > min (B/15,2 m) d_{hull} >0.76 m

3	No condition	No condition

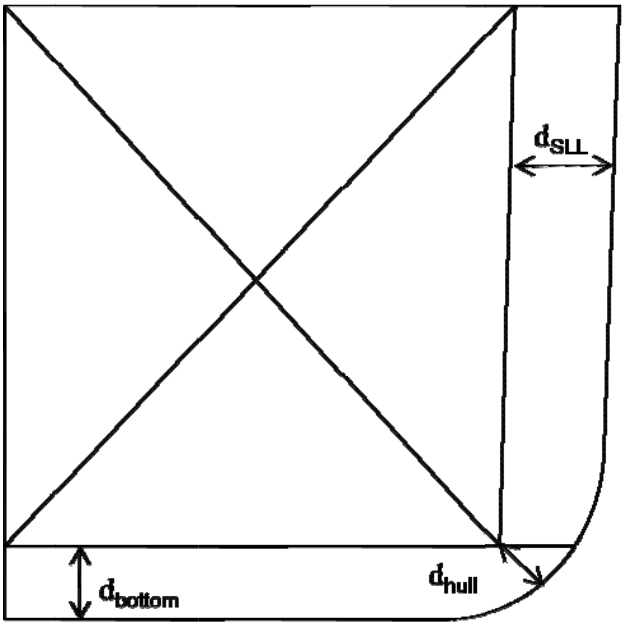

Figure 9-13 Parameter for the classification of the tank type

This assumption is reasonable for oil products, but less valid for chemical tankers, where the mix of substances carried will depend more on the chemical industry in the region considered. But it is the best that can be achieved. Only in case the SSN-database will change from an index database to a digital database containing all records with dangerous goods reported by ships crossing the North Sea this approach can be improved.

The base for the extrapolation requires that an inventory (as large as possible) of the reports with dangerous goods is executed. Until now the following inventories have been performed:

- 10% of the reports of dangerous goods in bulk for Rotterdam in 1982;
- 100% of the reports of dangerous goods in bulk and 5% of the report dealing with dry cargo for Rotterdam in 1987;
- 100% of the reports of dangerous goods in bulk for Rotterdam in 1998;
- 100% of the reports dangerous goods in bulk for all Dutch ports in 2000 [14];
- an international inventory of the transport of oil within the framework of the European project SAS.

The inventory has been performed several times to keep track of the changes in the transport of dangerous goods. Each time the inventory was more extensive. But the way of using the data was not changed.

In each inventory the records of all reports were collected in a file.

Each record contains the following information:

- The registration number of the report, unique for one call to a port;
- The SAMSON type number of the ship;
- The SAMSON size number of the ship;
- Main type of ship;
- Action in port
    - LO (lossen), unloading of the cargo, thus only on the arrival trip
    - LA (laden), loading of the cargo, thus only on departure trip
    - DO (doorvoer), transit cargo thus on arrival and departure trip
- Amount carried;
- Unit of amount;
- UN-number of the substance of the record;
- GT of the ship
- DWT of the ship
- Flag of the ship
- IMO number of the ship

The total file contains all reports of one port area (for example Rijnmond). The collected data is converted with the program CRDGFI.EXE to three random access files, namely:

1. BLKLNREG.RAN with the reference to the link numbers belonging to a certain registration;
2. BLKMELDD.RAN with the main characteristics of the ship of the report;
3. BLKMELDI.RAN with the records containing the carried substances.

The first file with the set of link numbers and registration numbers was used in the first period of SAMSON to determine the flows of reported dangerous goods to and from the ports in the inventory. The result was that the ships with an origin and destination not belonging to the ports of the inventory were dealt with as empty ships. This was not useful for predictions of spills of dangerous goods in the middle of the North Sea.

For this reason the extrapolation was introduced, which means that only the incoming and outgoing links to the port were important.

The formulas contain two weighing factors f_{cel} and f_{tot}. The use of f_{cel}=1 (and f_{tot}=1-f_{cel}=0) means that the extrapolation is only applied based on the ship type and ship size. The use of f_{tot}=1 (and f_{cel}=1-f_{tot}=0) means that the extrapolation is applied on all ships of one ship type, thus summarized over all size classes. Because some substances are more often carried by larger ships, the use of f_{cel}=1 was the best option, which is fixed in the program, but a different weighing can be made operationally easily.

9.4.3 Selection of dangerous goods

In 9.4.2 it is described how the amount of substances on board of a ship is extrapolated from the inventoried reports with dangerous goods. The dangerous goods were continuously indicated with substance i. Substance i represents a collection of UN-numbers that is considered as one group, because they have the same or nearly the same properties. The collection of UN-numbers that fall under “substance i” can be composed in SAMSON and assigned to a name of which the first four characters have to be unique. These four first characters are used in filenames generated by SAMSON. These files are used in all calculations in which this collection of UN-numbers is selected. All UN-numbers that existed in the inventories are presented in SAMSON for a selection by the user. They are read from the file VNNUMMER.RAN that contains some characteristics for each UN-number. The columns with the meaning under the used Annex 6 classification are:

- Column C: A, B, C, D or 3 for the pollution category. A is most pollutant;
- Column D: Reason why included. S is for Safety, P is for pollution, * for both;
- Column E: Ship type, 1,2 or 3 (physical protection, requirements for cargo tanks)
- Column F Tank type, 1 (independent tank), 2 (integral tank), G (gravity tank), P (pressure tank);
- Column G: Tank vents, O (open), C (controlled)
- Column H: Tank environmental control

After the selection of the UN-numbers, all records of all reports dealing with these UN-numbers are taken into account for the extrapolation. In SAMSON the selection of UN-numbers can be defined for the calculation of the outflow probabilities and volumes.

9.4.4 Layout of the ships

Cargo tank
The tank layout is important for the determination of the amount of outflow of substances after an accident. Figure 9-14 contains the layout for a tanker with two longitudinal bulkheads, 4 tanker rows and 1 ballast tank on each side. The tank layout of all tankers is described in the file CARTNKLO.DAT. Each record of this file describes the tank layout of one tanker, see Table 9-9.

Table 9-9 Record of CARTNKLO.DAT

1.	Type name of the ship	
2.	SAMSON type number	
3.	SAMSON size class	
4.	L_{oa} of the ship	
5.	L_{pp} of the ship	
6.	Breadth of the ship	
7.	Draught of the ship	
8.	Depth of the ship	
9.	Number of longitudinal bulkheads	
10.	Number of ballast tanks on each side	
11.	Number of tank rows	
12.	Capacity of wing tank	
13.	Capacity of centre tank (If 0 then 2 times capacity wing tank)	
14.	x_1	distance first tank bulkhead from aft perpendicular / Lpp
15.	x_2	distance second tank bulkhead from aft perpendicular / Lpp
16.	x_3	distance third tank bulkhead from aft perpendicular / Lpp
17.	x_4	distance fourth tank bulkhead from aft perpendicular / Lpp
18.	x_5	distance fifth tank bulkhead from aft perpendicular / Lpp
19.	x_6	distance sixth tank bulkhead from aft perpendicular / Lpp
20.	x_7	distance seventh tank bulkhead from aft perpendicular / Lpp
21.	x_8	distance eighth tank bulkhead from aft perpendicular / Lpp
22.	Ctobo	capacity of centre tank of an OBO
23.	Pship	fraction of ships in type size cell that is represented by this layout
24.	Dhull	witdh of double hull in meter

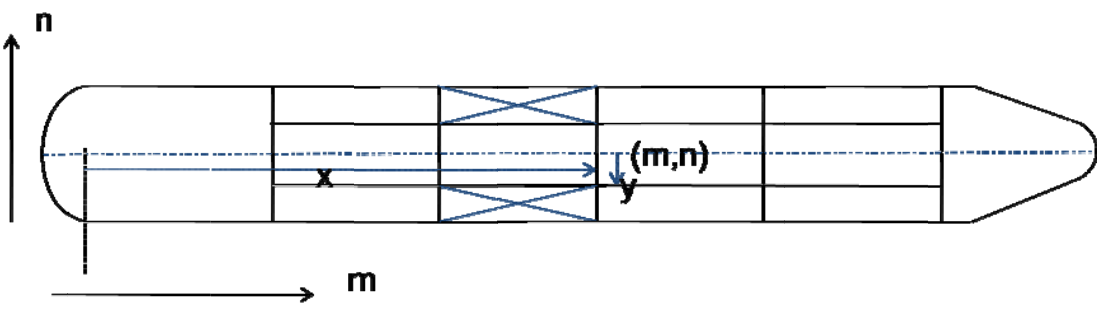

Figure 9-14 Tank layout of ship

For the tanker of Figure 9-14 only x_1 to x_5 have values between 0 and 1, x_6, x_7 and x_8 do not exist and are filled with 0.

The variable pship makes it possible to define different layouts for one type and size class. The user has to take care that the sum of the pship-values over the layouts of one ship type and size class is exactly equal to 1. In case of an accident the possible outflow for all layouts is considered and the probability of the accident is multiplied with Pship.

Bunker tanks

Each ship has one or more fuel tanks (= bunker tanks) filled with oil for the engines. In case of large ships these fuel tanks contain a considerable amount of bunker oil. The probability and amount of outflow of bunker oil is also calculated by SAMSON. The outflow depends on where the fuel tanks are located in the ship. This is described in the file BNKTNKLO.DAT. Each record of this file describes the position of one fuel tank for a ship, see Table 9-10.

Table 9-10 Record of BNKTNKLO.DAT

1. Type name of the ship
2. SAMSON type number
3. SAMSON size class
4. L_{oa} of the ship
5. L_{pp} of the ship
6. Breadth of the ship
7. Draught of the ship
8. Depth of the ship
9. Name of the tank
10. Capacity of the tank (tons)
11. Start of tank x_1=x/L_{pp} (x from APP, thus x/L_{pp} from 0 to 1)
12. End of tank x_2=x/L_{pp} (x from APP, thus x/L_{pp} from 0 to 1)
13. Start of tank y_1=y/B (y from centre, thus y/B from -0.5 to 0.5)
14. End of tank y_2=y/B (y from centre, thus y/B from -0.5 to 0.5)
15. Start of tank z_1=z/D (z from bottom, thus y/B from 0 to 1)
16. End of tank z_2=z/D (z from bottom, thus y/b from 0 to 1)

A ship can have more than one fuel tank, but not more than one ship can be described per ship type and size class. Thus no different layouts of ships as for the tank layout file can be defined.

9.5 Probability and amount of outflow

The impact of a spillage depends strongly on the amount of outflow. Therefore the probability and volume of the outflow is determined for a number of volume classes. Within SAMSON the user can define 8 different volume classes for which the outflow is calculated. The volume classes are linked to the selection of dangerous goods. For the outflow of cargo oil the classes can be defined larger than for a group of chemicals or bunker oil.

The following steps are executed to determine the probability and volume of the outflow for bunker oil:

1. A record is read from the BNKTNKLO.DAT. This describes the dimensionless position of the tank in the ship and the capacity. It is assumed that a fuel tank is loaded 50% of the time for 100%.

2. The routine DAMAGE is called for a tank (x_1,x_2,y_1+0.5,1,z_1,z_2) (of Table 9-10) that determines the probability that the penetration, between x_1 and x_2 in the length directions and between z_1 and z_2 in the height direction, will be larger than y_1+0.5. The "+0.5" because the penetration depth is calculated from the hull (starboard side) of the ship. The limit y_2 is not used, because all penetrations above 0.5+y_2 have to be counted because in these cases both tank hulls are penetrated (thus the upper value is 1).
3. Two models for outflow can be chosen, namely:
   a. The hole tank flows out. This means that an outflow of the capacity (cap) of the fuel tank will occur with a probability of damage_prob/2 (50% loaded). The outflow volume class k can be determined for the amount cap of the outflow. Thereafter the probability ($pflo_{ijk}$) and amount of outflow ($xflo_{ijk}$) are increased with these values.
   b. Only the fuel oil above the underside of the hole flows out. Based on the distribution of the hole in height direction the probability and outflow is described in more detail. For n=1,nout it delivers the probability pout(n) and fraction of the outflow xout(n). For each of these nout outflow classes the corresponding outflow class k is determined for the outflow xout(n)*cap and next the probability ($pflo_{ijk}$) and amount of outflow ($xflo_{ijk}$) are increased with respectively damage_prob/2*pout(n) and xout(n)*cap.

The process is described from the starboard side (see point 2), which means that the probability that a tank on portside is penetrated is nearly zero. In most ship designs the fuel tanks are located symmetrically with respect to the centre line. A ship that has collided on port side will have the same (calculated) outflow distribution.

9.6 Ecological Risk Indicator (ERI)

The objective of the Ecological Risk Indicator (ERI) is developed to have a tool for assessing the impact of a tactic on the risk involved in carrying dangerous goods on a water system like the North Sea. There were some detailed models available that could describe the effect of some substances, but no model existed that could describe the effect of the more than 200 substances that were inventoried. The ERI fulfilled the need to have a method to compare the results of different cases.

The Ecological Risk model does not indicate the impact in absolute terms. It is a qualitative model that indicates how serious the impact of a spill of a certain substance on the ecological system of the North Sea will be. Therefore each possible chemical spill is ranked on a scale from one to five, in words from "Very Large Ecological Risk" to "Negligible Ecological Risk". The scaling was done by using Expert Choice. A ranking tool that is based on the principles of the AHP (the Analytic Hierarchy Process) method developed by Thomas L. Saaty.

Available data:
Each ship that carries dangerous goods has to report this to the port of calling. For about 200 substances (or more precisely UN-numbers), the amount carried and the ships carrying were known. Based on this inventory the probability and size of a spill of a

certain substance can be assessed. The Ecological Risk Indicator classifies the risk of such a spill.

The ERI is built based on above mentioned available data. The impact of a certain spill for each of these 200 substances is assessed. The method is described in more detail in [15]. The basic idea is that dangerous goods are first of all dangerous because of their chemical characteristics, their impact on human health and risk for casualties. On top of that they can become a large ecological risk once they are spilled into a water body like the North Sea. Some substances, however, might be dangerous to ship and crew but might have no impact on the ecological system or the opposite way. The ERI contains three main risk items (D, E and S) which are separately assessed.

D stands for danger and is based on three types of data.

- GESAMP pollution categories that are used to rank the intrinsic danger of a substance for the environment;
- POW value of a substance in the water determines whether the substance is dangerous for animal like birds. The substance will glue to their feathers;
- Physical behaviour of a substance in the water. On basis of the SEBC classes, it is determined whether a substance is floating, sinking or dispersing and therefore causing more threat to the ecosystem.

Several databases, like GESIS, SISTER, ELSA were used for collecting data for the 200 UN-numbers that are dealt with. For each UN-number the danger class from I to V is determined. For each of these classes a separate selection of dangerous goods is made. The probability of an outflow and the volume of the outflow is calculated with DETFLO.

E stands for Environmental territory or area. Different classes are made to estimate the ecological similarity for different areas in the North Sea. A range of five classes are made ranking from unique conservation area or national park to high sea with no special ecological qualifications. The classification of sensitive regions of the North Sea made for the MANS project is applied for the calculation of the ERI. The classification of 16 sea areas into five sensitive classes is given in Table 9-11.

S stands for Spill. It is understandable that larger spills have a different effect on the environment than small spills. For this reason the eight spill sizes of Table 9-12 are distinguished in the determination of the ERI. Model calculations are made on basis of this classification.

Table 9-11 Sensitivity of areas in the North Sea

Sea area	Sensitivity class
Southern N. Sea	V
South England	II
North England	II
Oystergrounds	III
Central N. Sea	V
German Bight	II
Eastern N. Sea	V
North N. Sea	V
English Channel	IV
Flemish banks	II
Voordelta	I
Dutch Coast	II
Wadden Coast	I
German Coast	II
Frisian Front	III
Dogger Bank	III

Table 9-12 Outflow volume classes

Volume class	range
I	> 30 000 ton
II	10 000 - 30 000 ton
III	1000 - 10 000 ton
IV	500 - 1000 ton
V	300 - 500 ton
VI	100 - 300 ton
VII	10 - 100 ton
VIII	0 - 10 ton

For each chemical spill the Ecological Risk Indicator is assessed based on the **D**anger, the **E**nvironmental territory and the **S**ize of the spill as classified above. The process is as follows:

- SAMSON calculates the probability of an incident in each grid cell;
- The probability of an outflow of chemicals for each of the 5 danger classes is determined for that grid cell (D);
- The expected volume of the spill gives the outflow volume class of Table 9-12 (S);
- The sea area in which the grid cells is located, gives the sensitivity for the area of the grid cell (E);
- The combination of D, E and S value together with the assignment statements of ECOLRISK.INP delivers the Ecological Risk Indicator Table 9-13.

Table 9-13 Ecological Risk Indicator

Nr	Classification	Impact of spill in this classification
1	Very Large Ecological Risk	Threat to immediate death for most life forms on the waters as well as in the water and on the seabed floor.
2	Large Ecological Risk	Either (1) the most sensitive life forms will be threatened with immediate death, or (2) a part of the ecosystem (e.g., life on the seabed floor (benthos)) will be threatened.
3	Medium Ecological Risk	Parts of the ecosystem will be threatened.
4	Low Ecological Risk	Parts of the ecosystem will notice some difference in their environment.
5	Negligible Ecological Risk	No negative effects will occur.

The conversion of the D, E and S classes to the final ERI class is defined in the input file ECOLRISK.INP that is composed by experts. The first records

Table 9-14 First records of ECOLRISK.INP

```
5
5
8
1  1  1  6   1
2  1  1  5   1
3  1  1  4   1
4  1  1  3   1

1  2  1  6   1
2  2  1  5   1
3  2  1  4   1
4  2  1  3   1
```

The first three records contain:

number of danger classes
number of environment sensitivity classes
number of spill size classes

All next records contain in free format the danger class, the sensitivity class, the first size class, the last size class and the ERI. All size class from the first to the last class get the same ERI. The roman digits of Table 9-11 and Table 9-12 are converted to normal digits.

9.7 Validation of the probability of an outflow

The probability of a serious outflow is difficult to check because little accidents with outflow happen. For the validation of the absolute probability level the worldwide casualty database of Lloyds Register Fairplay has been used. Based on this comparison some changes were implemented. The penetration distribution always gives a penetration, thus a leak in a cargo tank of a single hull ship. This is not realistic because within a considerable part of the collisions their only will be minor damage without a penetration of one of the ships. The fraction of ships with only minor damage is determined from the worldwide database. This fraction is given in a ship type size matrix NODAMAGE.MAT.

Another point not covered by the damage distribution is the case that the damaged ship sinks after the casualty, immediately or after some time. In this case the hole cargo will flow out after some time. The fraction of the ships that will sink after a casualty is extracted from the worldwide database and put in a second matrix TOTALLOS.MAT.

The program DETFLO reads the files NODAMAGE.MAT and TOTALLOS.MAT and will include the zero outflow and all cargo outflow in the calculated outflow profile for each ship type and size.

9.8 Model RAMFOS

The oil spreading model RAMFOS, based on the formulae of Fay, describes how the slick, as result of the outflow after an accident, evolutes in the time. The initial position, the substance and size of the spill are the main parameters for the succeeding process. The slick area increases in the time and the slick amount decreases by evaporation, emulsification and dispersion.

The slick can also be decreased by processes initiated by the oil combatant organization. The most used method in the Netherlands is sweeping of the slick. This process is modelled and becomes active if the response time is past. Several types of combatant ships with sweeping parameters can be defined and located at different geographical positions.

This model is developed by Delft Hydraulics (now Deltares) used in the nineteen eighties for the MANS-project (Management Analysis North Sea), but it is not maintained and is not applied in projects within the last 10 years. It is mentioned here because some calls are still available within SAMSON.