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Container Transport on the Rhine
MARGINAL COST CASE STUDY

Infrastructure, environmental- and accident costs for Rhine container shipping

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Chapter 1: Case study scope

1.1 Introduction

The Rhine Container Shipping study is an exceptional case in the UNITE case study framework as it covers three marginal cost subjects in one case study: environmental, accident and infrastructure marginal costs, with wherever possible a specific focus on container shipping.

The Rhine is the most important European waterway with respect to inland shipping. A long history with respect to freedom of transport has facilitated this development. In 1868 the **Convention of Mannheim** was signed, bringing about regulations, based upon the evolution of Rhine shipping and taking into account technical, economical and political developments. A number of the regulations are still in force today. The Mannheim convention ensured the freedom of transport where inland waterways transport on other waterways used to be regulated by 'Tour de Role'[1] systems until very recently. An interesting development of the last decades is the growth market of inland waterways container transport with scheduled services very much similar to the deeps sea container shipping market.

This introductory chapter describes the general geographical and topical aspects of the case study which are relevant to all marginal cost case studies and which give an idea of the main characteristics of Rhine container shipping. It provides an explanation of the geographical area, the topic of container transportation, the methods (ship descriptions) and patterns (container service descriptions and terminal facilities) of container transportation as well as some important operational and nautical aspects. Chapters 2,3 and 4 deal with respectively the marginal infrastructure, environmental and accident costs methodology and calculations and can each be read in isolation from the other.

1.2 Lower- and Middle Rhine shipping area

The study area comprises the areas along the lower and middle Rhine, from the seaport of Rotterdam to the inland port of Mannheim. The justification for this stretch of river lies in the scale of inland shipping operations. On the River Rhine, the largest vessels can proceed up to Mannheim. Beyond Mannheim, navigation constraints will increase and downgrade both ship size and total transported volumes.

The area contains numerous densely populated cities in both the Netherlands (Rotterdam, Dordrecht, Tiel and Nijmegen) and Germany (Emmerich, Duisburg, Düsseldorf, Cologne, Bonn and Mainz and Mannheim).

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[1] In the 'Tour de Role' system all demand for transport has to be reported at a central location and barge owners await their turn for their employment.

The River Rhine also provides a central corridor for containerised traffic to and from Eastern Europe, following the River Main, the Rhine-Main-Danube Canal onto the River Danube as far as to the Black Sea. Through the Rhine other river destinations can be reached, such as Saarbrücken (via the Saar and Mosel), Frankfurt (through the River Main) and Stuttgart (via the Neckar).

Figure 1.1 Map of the River Rhine and important container terminals

Based on the selected route Rotterdam-Mannheim and the selected terminals, it is possible to differentiate the route into three main sections.

Table 1.1 Regional differentiation and distances

Region	Origin-destination	Distance in km
Lower Rhine	Rotterdam-Nijmegen	105
Lower Rhine	Nijmegen-Duisburg	116
Middle Rhine	Duisburg-Mannheim	369
Total		590

Source: Mitteleuropaische Wasserstrassen, Binnenschiffahrts-verlag, Duisburg.

These three sections are roughly identical to the operational areas within container transporting operations, with the exception of the Dutch domestic section, which can be further segmented.

1.3 Ship size classes in Rhine container transport

Ship size is considered to be an important cost driver in the UNITE guidelines. Ship size classes are usually connected to waterway characteristics. The CEMT[2]-class indicator is the usual parameter to establish the size (width and depth) of a navigable waterway. The CEMT-classification consists of 5 main levels:

Table 1.2 Ship size classification

Classification	**Type of ship**	**Length** (m.)	**Beam** (m.)	**Draught** (m.)	**Height** (m.)	**Capacity** (tons)
CEMT-class I	Spits	38,5	5	1,8-2,2	3.55	<250
CEMT-class II	Kempenaar	50	6,6	2,5	4,2	<600
CEMT-class III	Dortmunder	67	8,2	2,5	3,95	<1,000
CEMT-class IV	Rhein-Herne	85	9,5-11,4	2,5	4,4	1,750-1,950
	Pushbarge	95-105	11,4	2,5	4.4	2,400-2,700
	Europa	172-185	11,4	2,5	4.4	3,320
CEMT-class V	Container	110	11,5	3,2	6,7	>3,000
	Pushbarge	175-190	22,8	3,2	6,7	>3,000

Source: CEMT Waterway classification, 1961.

Based on the scale of container operations on the River Rhine today, the top-levels of this classification, the classes IV and V are relevant for this case study. More ship details of class IV and V levels are included in Annex 1. Restriction to the class IV: the Rhein-Herne type of vessel is in the container operator’s opinion often too small to be operated on the Rhine.

It is important to note that most container transport (contrary to sea shipping practices) takes place with ships that are not specifically built for container transport and can also

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[2] CEMT means Conseil Européenne du Ministres des Transports (Council of the European Ministers of Transport).

be used for bulk transports. This makes segmentation to container transport especially difficult in the accident case study.

1.4 Ship movements

In 1998 the total number of ship movements at the border between The Netherlands and Germany (Lobith) was 166.282. Of these ship movements, approximately 6.200 were related to container transport. Specific statistics on movements of container ships on each Rhine segment are unfortunately not available.

In 1998 a total of 893.000 TEU (9,4 million tons) were transported on the total case study stretch. Table 1.3 shows an overview of origins and destinations. The content of the containers is unknown. Annex 2 however gives an overview of types, purposes and sizes of common containers.

Table 1.3 Ship movements containerships and other from and to the Netherlands (1998)

Transport relation	Total ships	Of which loaded with cargo
Inbound		
Germany-Netherlands	50.632	25.591
France-Netherlands	3.977	3.146
Luxembourg-Netherlands	186	83
Switzerland-Netherlands	1.706	404
Other-Netherlands	421	381
Through transport	22.259	16.684
Outbound		
Netherlands-Germany	61.233	51.628
Netherlands-France	2.744	2.714
Netherlands-Luxembourg	224	215
Netherlands-Switzerland	2.919	2.897
Netherlands-Other	1.031	1.010
Netherlands-Through transport	18.950	17.264
Total	166.282	122.017

Source: Rijkswaterstaat, Adviesdienst Verkeer en Vervoer, Scheepvaartverkeer 1998.

1.5 Container terminals

The coverage of marginal accident, infrastructure and environmental marginal costs also includes where applicable the container terminal areas alongside the Rhine.

A total of 35 container terminals are situated along the case study stretch of the Rhine. Of these terminals, 22 are located within the port of Rotterdam of which the **Delta Terminal complex** in Rotterdam is the only deep-sea terminal. This state-of-the-art terminal is the largest in Europe and plays an important role in the throughput of containers from world-wide origins and destinations to the German hinterland. One other Dutch terminal exists en route to Germany; this one is located in Nijmegen. This terminal (**Nijmegen Container Terminal**) was the first operational inland waterway terminal in Holland and is located closest to Germany.

The largest inland terminal of Germany is located in Duisburg and is also able to accommodate smaller coastal sea-river ships. The **Duisburger Container Terminal** (DeCeTe) is one of few inland terminals containing a railway connection and therefore holds a strategic position within the hinterland of Rotterdam. Germany's second largest inland waterway terminal is **Rhenania Intermodal Terminal**, located in Mannheim. This is the southernmost point where the largest of the inland waterway vessels can load or discharge.

Table 1.4 Main terminal characteristics of selected terminals

Terminal name	**Rotterdam**	**Duisburg**	**Mannheim**	**Nijmegen**
Served modes	inland/road/rail/sea	inland/road/rail/sea	inland/road/rail/sea	inland/roadsea
# served inland barge operators	24	5	3	4
# ship to shore cranes	8	2	2	2
Crane lifting capacity (tons)	67.0	50.0	35.0	n/a
Yard equipment lifting capacity (tons)	55.0	41.0	12.0	42.0
Container storage (TEU)	n/a	15.000	3.500	2.500
Storage of reefer containers (TEU)	882	20	10	N/a
Quay Length (m.)	1.650	600	320	175
Water depth (m.)	16.6	5	4,5	5
Size (m2)	920.000	80.000	40.000	25.000
Annual throughput (TEU)	3.220.000 (1999)	150.000 (1998)	80.000 (1999)	70.000 (1999)

n/a = not available information
Source: Various commercial terminal brochures

Within the terminal outline, as illustrated in the above table, the Rotterdam terminal stands out in both size and terminal equipment, since this is the only terminal within the selection that handles intercontinental ships. Some containers loaded or discharged at Duisburg and Mannheim may have been transported by roll-on/roll-off vessels, which can be received at these terminals. However, on an annual basis, the share of roll-on/roll-off containers will not exceed one percent of the total amounts of handled containers.

All mentioned terminals are privately owned terminals but, also from the point of view of externality of costs, a distinction has to be made where terminal investments are concerned. A terminal both uses **public** and **private** funding. Public funding is usually based upon investments of harbour authorities or (regional) governments in the port basin and quays. Public investment is limited to the construction of quay walls, pavement of the terminal area, the construction of access roads (or rails) and the dredging of the terminal approach. Private funding is usually on account of the terminal operator. The operators invest in the **superstructure**, which means all terminal equipment, maintenance buildings, offices, communication lines, etc.

1.6 Container shipping services

The shipping companies active with Rhine container shipping provide an extensive range of services, both on an individual basis as well as on the basis of strategic alliances with competitors.

Shuttle services

Some container lines (the in-house shipping companies of the container terminals) only provide sailings from Rotterdam to their 'home' terminals, on a point-to-point basis. These services are called shuttles, and usually do not call at any other (intermediate) terminal. In table 1.5, shuttles are included for Rotterdam-Nijmegen v.v. and Rotterdam-Duisburg v.v. (Lower Rhine sphere). Another shuttle exists on the Rotterdam-Germersheim-route v.v. (Middle Rhine sphere).

String services

Other container lines prefer to operate their services through strings of intermediate terminals en-route to their destinations. Theoretically all terminals along the Rhine can be connected, however, the current operations show that most operators adopted dedicated strings.

The exception to the regionally dedicated string service is initiated by economical motives. If load factors for specific trips are unsatisfactory, unorthodox route patterns may appear. Another complicating factor may be the non-availability of cargo for a specific destination. Occasional lack of cargo for a specific terminal may lead to the omission of a terminal on a particular voyage.

Offered frequencies and capacities

The selected terminals are connected through a series of container services, which are performed almost on a daily basis. The following table shows how the selected terminals are connected to each other and what the allocated ship capacity is in terms of TEU. The overview is based on the publications of the indicated operators. Annex 3 provides additional information on the utilisation rates per ship type.

Table 1.5 Offered services and their frequencies and capacities (May 2000 situation)

OFFERED CONTAINER SERVICES BETWEEN SELECTED TERMINALS (in 2000)

Upstream container supply

From	To	Frequency/ week	Frequency/ year	Capacity (TEU)	Capacity per week (TEU)	Capacity per year (TEU)
Duisburg	Mannheim	0	0	0	0	0
Nijmegen	Duisburg	0	0	0	0	0
Nijmegen	Mannheim	0	0	0	0	0
Rotterdam	Duisburg	16	832	779	12.464	648.128
Rotterdam	Mannheim	5	260	358	1.790	93.080
Rotterdam	Nijmegen	5	260	100	500	26.000
Total		**26**	**1.352**	**1.237**	**14.754**	**767.208**

Downstream container supply

From	To	Frequency/ week	Frequency/ year	Capacity (TEU)	Capacity per week (TEU)	Capacity per year (TEU)
Duisburg	Nijmegen	0	0	0	0	0
Duisburg	Rotterdam	17	884	779	13.243	688.636
Mannheim	Duisburg	0	0	0	0	0
Mannheim	Nijmegen	0	0	0	0	0
Mannheim	Rotterdam	5	260	358	1.790	93.080
Nijmegen	Rotterdam	5	260	100	500	26.000
Total		**27**	**1.404**	**1.237**	**15.533**	**807.716**

Checked operators: CCS, CTN, Danser, DeCeTe, Haeger&Schmidt, Haniel, Rhinecontainer

Total offered capacity between the selected terminals

From	To	Frequency/ week	Frequency/ year	Capacity (TEU)	Capacity per week (TEU)	Capacity per year (TEU)
Upstream		26	1.352	1.237	14.754	767.208
Downstream		27	1.404	1.237	15.533	807.716
Grand Total		**53**	**2.756**	**2.474**	**30.287**	**1.574.924**

1.7 General marginal cost methodology issues

The case study is worked out with the help of the earlier developed UNITE guidelines on marginal cost calculation, specifically for accident costs, environmental costs and infrastructure costs. General conventions that apply to all three case studies are indicated below.

Valuation conventions

All estimates are calculated for 1998 and presented in Euro. Costs have been indicated at factor costs, which means that no indirect taxation or subsidies have been taken into account. No adjustments were necessary for infrastructure costs. For accident costs (with the exception of health care) and environmental costs no final consumers were involved in the calculation so division by $(1+\tau)$ was not necessary.

Cost drivers

Underlying each individual cost category is a number of cost drivers. The four main cost drivers as indicated in UNITE, Deliverable 3 are:

- Vehicle type

- Infrastructure type
- Traffic type
- Location type

In this case study, the vehicle type is determined by the choice for container barge transport and can be segmented by CEMT class IV and V. The Rhine is in principle one type of infrastructure, though variations exist in water velocity and embankment types. Where possible and relevant, a segmentation will be made according to embankment type. The Rhine has a lot of overcapacity which implies that a segmentation according to traffic level is not relevant. The implications of the distinction between rural and urban location type will be further detailed with respect to accident and environmental costs.

Chapter 2: Marginal infrastructure costs

2.1 General

Infrastructure costs in inland shipping are mainly borne by national and regional governmental bodies. An important complication in calculating the infrastructure costs of inland shipping is that not all costs related to investments and maintenance and management of inland waterways are related to inland shipping. Costs (approximately 30% of all annual expenditure of inland water infrastructure costs[3]) with respect to water management, flood protection, soil pollution prevention, recreational facilities on the embankments, etc. can't be attributed to inland shipping.

Waterways infrastructure costs related to inland shipping are the following:

- Maintenance costs of the waterway: dredging of the waterways and maintenance of embankments for nautical reasons.
- Costs of nautical operation of the waterway: of locks, bridges and of upholding waterway regulations.
- Costs of investments in the waterway: in embankments (for nautical reasons), locks bridges and waterway navigation aids.
- Costs of investment and maintenance of terminal quays.

2.2 Objectives of the marginal infrastructure costs case study

Very little information is available about the marginal costs of infrastructure in inland waterways, no cost function study exists in this area. As the UNITE guideline states, this may be the result of missing interest in the area. On the other hand, this lack of cost function may also be the result of marginal infrastructure costs referring to cost elements such as maintenance and repair, which usually vary with traffic volume. These elements have little importance for waterborne transport.

The aim of this marginal infrastructure case study with respect to inland waterways is to further explore the possibilities of a cost function for inland waterways. It must be remarked that very little research was available on the subject and that as a result of this, the following information is largely based on expert opinions. A list of consulted experts is included in the reference list. The source of information for the mentioned infrastructure characteristics for the Dutch part is the publication "Vaarwegkenmerken in Nederland" (Ministerie van Verkeer en Waterstaat, Adviesdienst Verkeer en Vervoer, 2001). For the German part the information is from the Central Rhine Commission and the Statistisches Bundesamt.

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[3] Source: Fourth National document on Water Management Government decision, Netherlands Directorate-General for Public works and Water Management, 1998.

Within the scope of marginal cost analysis are all infrastructure costs, which can be identified to vary with traffic volume. Given the fact that marginal costs have to be derived from variable costs, all costs identified to vary with use of infrastructure will form the starting point for the estimation procedure.

The case study focuses on marginal infrastructure costs on the Rhine waterway stretch itself, also including a number of terminals, as the case study focuses on container transport these terminals are by definition multi-modal.

As asset costs which relate to supplier operating costs (recovered with charges to users) are not included and in addition to this, intermodal freight terminals are not taken into account, only the costs relating to investments in quay walls and the port basin will be further researched with respect to terminal infrastructure costs.

2.3 Rhine infrastructure characteristics

Determining infrastructure construction characteristics for rivers are:

- Type of embankments
- Locks
- Bridges
- Ferries

In the following an overview is given of the main aspects for the Rhine.

Type of embankments

1. Dyke-embankments

The core of the infrastructure along the River Rhine consists of dykes, sometimes strengthened by breakwaters. When taking into consideration that the distance of the total route from Rotterdam to Mannheim is about 590 kilometres, the minimum length of embankment is theoretically at least twice this length, being 1.180 kilometres (assuming an equal split between the left bank and right bank).

However, usually the embankment is not located close to the rivers’ fairway (the navigable centre of the river), so the distance from the centre of the river may vary according to the shape of the river (narrow, broad, tight of long curves, number of meanders, number of tributaries, number of dead-end tributaries, etc.). This means that the number of kilometres of embankments is significantly higher than just the length of the river itself.

The embankments are adapted to contain water levels throughout the year. In general, the composition of the dykes must be doubled in almost all stretches of river, since two types of dykes exist. Two sets of dykes protect the surrounding land from flooding during summer and winter periods. The water levels during the winter and spring are much higher than during the summer and autumn, due to melting water coming from the

Alps and from tributary rivers. This results in winter dykes being twice as high as the summer dykes and are usually located twice the distance from the river as summer dykes, to contain the surplus river water during winter and spring time. It is fair to assume that at least 70% of the river length has been equipped with double dykes, equivalent to 826 kilometres, with the remaining 30% of embankment consisting of quay walls. The total length of the dykes comes to 2.006 kilometres within the Rotterdam-Mannheim route. The current trend is that the summer dykes are likely to disappear, since much emphasis is put on winter dykes only.

With the continuing rise of water levels, temperatures and the risks of floods, Dutch and German authorities are increasing the widths and heights of the winter dykes considerably, without too much affecting the length of the dykes. Other projects, such as increasing the width of the riverbed through the deliberate flooding of ‘polders’, may change the length of the dyke system considerably. Since quite some projects of this nature are still in the designing phase, it is not possible to estimate the changes in length of the dykes upon completion of the projects. In Germany some 12 projects for “Deichrückverlegung” (dyke withdrawal) are examined through feasibility studies and two projects in the Netherlands are being examined.

From the above it can be concluded that investment in dykes result from environmental and safety considerations rather than for navigational purposes. Costs of investment in infrastructure are not only dependent on inland shipping considerations, but also on flood and environmental protection schemes.

2. Quay walls

Another type of embankment consists of quay walls, to facilitate the mooring of ships. The quay walls cover 30% of the total river length, equivalent to 117 kilometres. The majority of this number is to be found along riverbanks within cities. In addition to this, there are the (terminal) quay walls within harbour basins.

These walls, regardless of their use, are generally made of concrete, embedded in reinforcing corrugated iron shells. The use of the quay walls determines the strength and composition of the structures. Quay walls designed along waterways within cities (used as promenades) are usually destined for the mooring of ships, without cargo handling. Quay walls within ports or outside city areas are extra reinforced to withstand the high weights of cargo handling equipment and the operational vibrations produced by heavy machinery during the loading and discharging process of the barges.

3. Other embankment reinforcements

Other means of reinforcing the banks of the river are related to the use of dykes. To decrease the current velocity, **breakwaters** are placed along the riverbanks. This has advantages to both the infrastructure itself, as well to the navigability of the waterway. When the velocity of the current is decreased, the water will slow down in pace and is less likely to cause any damage to the infrastructure or ships.

Large tree trunks can cause damage to the hull of ships when ships are sailing upstream, where a tree trunk is floated downstream at considerable speed. It is also possible that floating debris or garbage clog drainage installations along the rivers, causing problems to the outlet of surplus water from the land side. By using breakwaters, there is a chance that floating garbage can be "captured" between two breakwaters and be subsequently washed ashore by the redirected water current.

Advantage to the navigation is the fact, that navigational lights can be put at the tips of the breakwaters, much closer to the fairway of the river, thereby ensuring safety during everyday sailing operations.

Often dykes and breakwaters are themselves protected by large **basalt blocks**, which is a very hard stone and therefore is less susceptible to fluvial erosion than other stone types. Where basalt rocks are not used, often **sandy beaches** between breakwaters exist.

Locks

The River Rhine is a river, which contains no locks. The hang of the terrain is such, that no ascending or descending areas have to be passed. For the ships this means that their voyages can proceed without major obstacles and delays. From the point of view of infrastructure costs, it means that there are no variable costs resulting from lock operation.

Bridges

Bridges are located within cities or metropolitan areas. Most of the bridges can be found in German metropolitan areas: Duisburg (8 bridges), Cologne (6), Bonn (5), Andernach (4) and Mainz (5). En route from Rotterdam, the following numbers and types of bridges have to be passed.

Table 2.1 Bridges on the Rotterdam-Mannheim route

Country	**Type of bridge**	**Shipping constraint**	**Number**
Netherlands	Road bridge	No, on normal water levels	9
Netherlands	Railway bridge	No, on normal water levels	3
Germany	Road bridge	No, on normal water levels	29
Germany	Railway bridge	No, on normal water levels	12

Source: Mitteleuropaische Wasserstrassen, Binnenschiffahrts-verlag, Duisburg.

Despite the fact that 53 bridges span the River Rhine none of them pose problems to the ships at normal water levels. All of the bridges have a height of at least 6 meters. Although more than 80% of the road bridges facilitate highways and have no mechanisms to let ships pass in high-water conditions, shipping is not hindered. The remaining 20% of the bridges are located in city areas and are substantially lower, around 4 meters. The railway bridges create no constraints under normal circumstances.

Only in extreme water level conditions, the road- and railway bridges in the centre of Cologne have caused obstructions. It must be noted that by the time these conditions were reached in the past, all shipping normally is prohibited.

Ferries

The number of bridges is low, compared to the distance of 590 kilometres on the route in general. The number of bridges versus the total distance equals one bridge in every 11,1 kilometres. This figure is for the Netherlands: one bridge in every 9,5 kilometres, for Germany: one bridge in every 9,1 kilometres. As mentioned in the previous paragraph, all bridges are located within cities. This means that other necessary means to cross the river are ferries. These can be found in abundance along the Rhine. The average ferry coverage in the Netherlands is one ferry in every 10,4 kilometres. For Germany this ratio is approximately one ferry every 15,8 kilometres.

Table 2.2 Ferry services across the River Rhine

Country	**Number of Ferries**
Netherlands	11
Germany	30

Source: Mitteleuropaische Wasserstrassen, Binnenschiffahrts-verlag, Duisburg.

Ferry services on the Rhine have a special position. Although they are part of the navigational aspect on the River Rhine, they pose a potential threat to the shipping on the river, since they cross-navigate the Rhine’s fairways. Infrastructure costs related to the presence of ferries are however not related to the number of inland ships.

2.4 Infrastructure cost drivers

To identify a functional relationship between cost behaviour, traffic volume and impact factors, rather than input factors, there is a necessity to identify all factors having an impact on cost behaviour, the so-called cost drivers.

The identified potential cost drivers for this case study consist of the following:
- Climate conditions.
- Geographical conditions.
- Vessel speed, size and draught.

2.4.1 Climate conditions

Climate conditions which can be considered as cost drivers of infrastructure costs related to two items, water level and water velocity. Both the water level and water velocity determines the necessary quality and characteristics of maintenance and investments in infrastructure.

Water level

Rhine shipping has only one natural constraint, the weather and its implications for the water level. Extremely high water levels may cause difficulties in passing bridges. The depths of river usually reach their peak levels early spring, around March and April, when temperatures in the Swiss, Austrian and German Alps start to increase, causing floods of melting water. Since this is no biological law, monitoring services have to be in place to carefully monitor and forecast water levels.

In Germany, water levels are monitored on a continuous basis, to ensure shipping safety throughout the year. Water levels are monitored around the clock. This is achieved by using 15 German monitoring stations on the Rhine, of which 13 are of interest within this paragraph. The German section of the Rhine is split in two sections: Middle Rhine area (represented by Mannheim) and the Lower Rhine area (represented by Ruhrort).

Table 2.3 Water levels and critical conditions during 2000 in Germany, in metres

Name station	Average	Low	High	Max I (restrictions imposed to shipping)	Max II (shipping prohibited)
Mannheim	3,85	2,20	5,50	6,50	7,60
Ruhrort	8,71	4,40	6,72	9,30	11,30

Source: Zentralkommission fur die Rheinschiffahrt.

Table 2.1 shows the average water levels for Mannheim and Ruhrort (Duisburg). Max I is **High Water Mark I**, at which restrictions are imposed on use of the fairways on the river, on both upstream and downstream voyages. Also the ships' speed must be reduced to 20 kilometres/hour, measured upon the passing speed of the riverbanks. Max II is **High Water Mark II**, at which all shipping traffic is prohibited, with the exception of ferry traffic.

Water monitoring systems in the Netherlands are similarly organised as their German counterparts. A total of 11 monitoring stations are operational along the Dutch section of the route.

Table 2.4 Water levels and critical conditions during 2000 in the Netherlands, in metres

Name station	Average	Low	High
Nijmegen	7,93	6,64	11,76
Rotterdam	0,31 + NAP	1 -NAP	2,31 + NAP

NAP= Nieuw Amsterdams Peil (approx. sea level)
Source: Schuttevaer weekly, 2000

Table 2.4 shows the water levels for the year 2000 in the Netherlands. The standard N.A.P. means Nieuw Amsterdams Peil, which actually is the sea level.

The tidal influence on water levels in Rotterdam is significant (3.31 metres). For Rotterdam goes, that no shipping restrictions exist, since the port of Rotterdam has an average depth of 7 metres, where dredged about 15 metres. Quay walls are about 7 metres height, which allows inland-shipping operations at all times. Shipping prohibitions based on water levels are not operational in the Netherlands. Only once shipping was prohibited following high water levels, not in order to guarantee shipping safety, but by request of the polder-board, which feared the waves of the ships would cause damage to the dykes.

Water velocity

Next to water level, the water current velocity is a climate factor that determines infrastructure costs. Since the water velocity differs greatly under influence of every single depth-width ratio of the river, water current velocity is a difficult item to deal with. In addition to depth-width ratios, water velocity can vary within the hour, dependent upon the amount of water flowing downstream.

Along the Rhine, average water current velocity can be listed per monitoring station as follows.

Table 2.5 Current velocity per monitoring station

Monitoring station	Water current velocity m/sec.
Mannheim	
Bingen	
Ruhrort	
Lobith	1,3
Rotterdam*	0,9

Water current velocity varies extra due to tide influence. Below average during rising tide, above average on outgoing tide.
Source: Schuttevaer weekly, 2000

From the above it can be concluded that shipping is very much influenced by water depth and velocity conditions but, the other way around, ships have no impact on infrastructure costs via water depth or velocity. Rather than having additional ships cause damage to embankments at high water levels, the traffic is put to a halt. A relationship between additional ships, water speed, and infrastructure costs seems non-existent.

2.4.2 Geographical conditions

The river Rhine flows through two landscape types. The majority of the flow is situated in a **lowland type** of countryside, with little ascending terrain. This applies to the entire

Lower Rhine region. The river within this type of landscape is usually wide and can absorb large quantities of surplus water. Given the width and depth of the river in lowland terrain, current velocity is relatively low, compared to the Middle Rhine area.

The Middle Rhine section is situated in the **low mountain range**-region. This type of landscape includes sloped terrain, below 500 metres above sea level. Given the hills on either side of the river, it has a natural boundary and in time of surplus water the river has less power of absorbing the water. This also implies that the water current velocity is much higher than in the Lower Rhine area.

No relationships can be observed between number of ships, geographical aspects and infrastructure costs.

2.4.3 Vessel speed, size and draught

From a theoretical point of view, the presence of ships has an influence on the deposition of sediments in the Rhine. Ships may have a scouring impact at particular segments which may result in additional sediments on other segments or in just a general dispersion of light sediments. The effect results from a combination of vessel speed, size, number of vessels but especially the draught of the vessel. The nearer the bottom of a ship is to the riverbed, the bigger the scouring impact. An extensive search has been made for available literature (both economics related but also engineering-based) in this field but no studies were found which provided any more explanation or evidence. It is not known if the impact of additional ships is positive or negative, and what the magnitude of the impact is.

As no literature could be found on the subject, experts in the field were contacted to provide their opinion or suggestions. Most experts (see reference list) assume that the scouring impact has either a small positive effect or no effect at all on dredging costs but no-one was able to quantify this effect. This marginal effect can therefore not be further quantified.

In addition to this, the speed and size of vessels is expected to impact on the maintenance costs of quays and embankments. If the speed of the vessel is too high or if a large ship passes too close to the embankment, damage is caused to the embankment. These types of costs are however related to the improper use of the waterways and must be regarded as a breach of shipping rules. With normal use of the waterways, no additional costs of embankment maintenance occur on the case study stretch as a result of additional ships.

With respect to infrastructure costs it is important to note that there is a great difference between canals and free flowing rivers. For canal embankments there exists a causal relationship between the use of the canal and maintenance costs. The stern and bow waves of ships cause damage to the embankments. Around 1970 there have been done a number of studies on the issue in West Europe and the US, but these seem to have evaporated in the libraries since then. There is also a relation between maintenance costs of river training works and traffic, but this is often negligible as most maintenance has to do with seasonally varying currents and waves.

2.4.2 Infrastructure cost calculation

2.5.1 Total infrastructure costs

Starting point for an estimation of marginal infrastructure costs is the consideration of a cost function approach. As stated in the UNITE guidelines, cost functions for infrastructure can be derived either with econometric methods or with engineering approaches. The outset of this case study has been to take an econometric approach, by looking top-down at the case study, starting with the actual occurring total costs and then looking for a relationship between total costs and marginal costs.

The total infrastructure costs ($TC_{infrastructure}$) are a function of climate conditions, geographical conditions, vessel dimension and infrastructure characteristics such as type of embankment and number of bridges.

$$\mathbf{TC_{infrastructure} = f(C,G,V,I)}$$

Where
C = climate conditions
G= geographical conditions
V = vessel dimension (velocity, size and frequency)
I = infrastructure characteristics (type of embankment, no. of constructional works)

Contrary to expectations it has proven impossible to specify the costs of infrastructure investments and maintenance for the Rhine case study stretch specifically, mainly because there is no obligation to publish the governmental justification of costs on this level. The below table shows the estimation for the Netherlands as a whole and for the German Rhine stretch, where a segmentation according to type of cost (the figures include maintenance, protection investment, labour costs) was stated to be impossible.

Table 2.6 Waterways infrastructure expenditure for the Netherlands, in million €

Year	Investments	Maintenance	Capital costs (interest paid on loans)	Total
1992	125	227	15	367
1993	133	246	15	394
1994	132	259	15	405
1995	137	270	15	422
1996	117	290	16	422
1997	132	334	16	482
1998	163	361	17	541

Source: Dutch Central Bureau of Statistics, Governmental expenditures for roads and waterways, Voorburg 2001

The share of the Dutch Rhine segment in the total kilometres of main shipping network in the Netherlands is approximately 15%. It is unknown if the costs of infrastructure are proportional to waterway length.

Table 2.7 Waterways infrastructure expenditure for German Rhine segments, in million €

Year	Baden-Wurtemberg	Hessen	Rheinland Pfalz	Total
1995	21,9	1,2	3,7	26,8
1996	4,0	0,2	7,4	11,6
1997	4,6	0,2	4,3	9,1
1998	6,4	0,2	5,1	11,7
1999	8,5	0,6	6,4	15,5
2000	13,0	0,1	6,7	19,8

Source: Wasser- und Schifffahrtsdirektion Südwest

2.5.2 Marginal infrastructure costs

In order to arrive from total infrastructure costs to marginal infrastructure costs, the quantification with the help of a Translog function would provide the best basis. Its advantages are that it is a systematic and flexible approach allowing for specialising the function from a general case stepwise to further detail.

However, there is no need to develop such a function because for the specific circumstances of this case study, no costs have been identified that vary with the number of ships. As will be explained below, from the assembled qualitative information it can be concluded that the relationship between additional inland ship movements and infrastructure costs is virtually non-existent, thus that the marginal infrastructure costs for the Rhine case study stretch are 0.

The starting point of the analysis that only infrastructure cost that may be variable in proportion to the number of ships should be taken into account. This rules out the investment costs in infrastructure of embankments, constructions and of ports and terminals. What remained to be researched was weather the number of vessels would have a direct impact on maintenance and operational costs or an indirect impact via infrastructure cost drivers.

Maintenance costs of embankments and quays

Additional ships may have an impact on the maintenance costs of embankments as large ships or ships with a (too) high speed may cause damage to the embankments. Damage could also happen in case the water level is too high. The former condition does apply to smaller waterways but not to the Rhine shipping conditions. The latter condition could appear on any natural river, but shipping traffic is constrained or forbidden in those conditions and thus do not lead to maintenance costs. For the quays investments and maintenance no costs of additional ships can be identified. It can therefore be concluded that for the Rhine case study, no additional maintenance costs for embankments do exist.

Maintenance costs of river depth

A very weak relationship may be existent with respect to the costs of maintenance of infrastructure. Dredging amounts may be influenced by differentiation in sediment patterns, which may have different outcomes depending on traffic volumes. It is however unknown if additional ships would have a positive or negative impact on the amounts necessary to be dredged. The common opinion of experts (which unfortunately could not be quantified) is that additional ships might somewhat increase the scouring effect of the waterway, allowing for a very small marginal external benefit.

Operational costs of bridges and locks

The operation of locks and bridges may result in marginal costs as a result of the energy used for closing and opening a bridge or a lock and the personnel needed for operation. For the Rhine case study, there is no situation with locks. Under normal conditions, bridges do not need to be opened for passing ships and even over 80% of the bridges can’t be opened at all. However, in the access to some terminals are bridges that would need to be opened. For the operation of bridges it is assumed that this takes place with permanently employed staff and that energy costs for an additional bridge opening are negligible.

The conclusion from the above, that there are little or (in case of the Rhine case study) no marginal costs involved with inland waterways infrastructure costs is supported by the research study “Paying our Way” (US Transportation Research Board, Special report 246, Washington DC, 1996). Marginal costs here are defined as the change in the cost to the government of operating the system. Physical durability of the waterway structure and maintenance dredging costs are assumed to be independent of the rate of use and the only marginal costs assumed to be present are operating and maintenance costs of locks.

2.6 Conclusion and generalisation issues

Conclusion

"Unlike the other cost categories such as accidents and environmental costs which deal with non-monetary values and consequently have to deal with input parameters which influence substantially the whole cost estimation, the weakness of the proposed marginal cost estimation method could arise from an oversimplified function, insufficient data and possibly extreme values". This conclusion from the UNITE guideline on marginal infrastructure costs has been demonstrated in this case study. Investment and infrastructure operating costs seem not identifiable for the case study stretch specifically, therefore not enough data could be found to make a reasonable approach to a Translog function.

An additional complicating factor in all infrastructure calculations is that the costs of embankment for rivers are not specifically for inland ships. Water management and protection against flooding are major issues along the whole length of the case study stretch of Rhine. For the construction of embankments, considerations in the area of flood protection may be even of higher importance than the necessities for inland shipping.

For the case study these complications had no consequences as from the inventarisation of cost drivers the conclusion was drawn that a relationship between number of inland ships and infrastructure costs for the Rhine case study stretch is virtually non-existent. The situation could be somewhat different if locks would be necessary in the Rhine. In that particular situation, some labour and energy costs would prove to be variable and also other waterways users would incur some costs as each additional lock handling would cause some delay to other ships in opposite directions. This should also be taken into account when generalising the conclusions from case study level. Other infrastructure situations or geographical situations may result in a different (non-zero) relationship between ships and marginal costs.

Rather than the development of a Translog function for an estimation of marginal infrastructure costs in inland waterways transport, this case study has developed insights in the cost drivers of waterways infrastructure upon which it has become clear that for the case study stretch of Rhine specifically, no marginal infrastructure costs do exist.

Generalisation issues

In order to allow for a generalisation of the case study results to other inland waterways stretches the specific characteristics of the inventarised inland waterways infrastructure cost-drivers will need to be re-examined. As indicated before, the occurrence of locks on the waterways stretch can be expected to result in some marginal costs. Also the presence of bridges needing to be opened for every ship passage would entail marginal costs.

Compared to other modes of transport, the inland waterways sector has a special position because marginal costs are virtually non-existent and other modes of transport always will incur some additional costs per additional vehicle. The results of this case study can therefore not be generalised to other modes of transport.

Chapter 3: Marginal environmental costs

3.1 General

Inland waterways transport has a reputation for environmentally friendly transport as it has very little impact on landscape, pollution of water is small and air emission per tonne kilometre is low compared to road transport given the current applied technologies.

The most important type of pollution by barges is air pollution and global warming related, and is fully dependent on fuel use. Barge owners are of course very much motivated to achieve the highest possible utilisation rate (see also Annex 3 on container ship utilisation rates), decreasing the average consumption of fuel per loaded ton. The higher the ships utilisation rate, the more effective the use of fuel and the less the environmental pollution per tonne kilometre.

Since the majority of the Rhine river stretch flows through rural areas, most of the pollution will occur in those areas. However, the wind may cause pollutants to end up in city areas, as will the rivers' water current transport waste deposits through city areas, or wash the garbage ashore in city areas.

3.2 Objectives of the marginal environmental cost case study

In this case study on Rhine inland waterway transport the objective is to apply the UNITE preferred methodology for environmental marginal costs, the Impact Pathway Approach, to the specific situation of inland waterways transport.

The Impact Pathway Approach starts with a quantification of the emission of a burden and of this impact on various receptors. This amount is finally valued in monetary terms.

The methodology is applied to the *use* of a vehicle (in this case barges), marginal environmental costs due to vehicle *maintenance, building* and *infrastructure provision* are expected to be very small. Where possible a categorisation will be made according to vessel type (barge/tug), small, large), engine type class and range and type of pollutants. Also an explanation will be given about the main cost drivers of inland waterways environmental pollution.

3.3 Environmental pollution by (container) barges

Environmental pollution in inland waterways may occur on the aspects of air pollution, global warming, noise, water and soil pollution and nuclear risks.

Barges make use of internal combustion engines as means of traction. Vehicles with this type of combustion represent line emission sources, emitting continuously along a route. With this type of propulsion, **air pollution** and **global warming** impacts do occur. The marginal environmental costs of these two items will be further quantified in the following paragraphs.

Noise impacts of barge shipping are minimal. The actual noise emission is low and very little habitation is located close to inland waterways. The main noise emissions result from container handling at terminals and for this it may be argued that this is not specifically related to inland waterways, but to transhipment activity. External costs of noise for this inland waterways case study are therefore considered to be negligible.

Marginal costs due to impacts on **water quality** and **soil** are existent but small. There is always a risk of accidents causing unintended water pollution (see also marginal accident costs). During 1998, in accidents within the Netherlands only one case of oil pollution was recorded within the port of Rotterdam. In five other cases the environmental damage is unknown. Data on environmental pollution within German waters is not available. It is estimated that the total number of environmental accidents per year is 10 with an average cost of € 10,000. In case an oil slick is resulting from a collision between two ships, the oil will pose a direct threat to the nearby embankments. Intended pollution of the water also happens, by throwing garbage into the river. Although this is prohibited and stiff penalties are imposed on this behaviour, quite some waste is dumped overboard on an annual basis. Law enforcing bodies are patrolling the rivers on a daily basis, in order to prevent pollution or apprehend the perpetrators. Also the garbage put overboard is washed upon the embankments, causing an array of tin cans, broken plastic buckets, mooring ropes, etc. This ecological pollution disturb the local wildlife or even cause some deaths of animals when swallowing waste.

Nuclear risks are not associated with barge transport as no use is being made of electrical propulsion (generated by nuclear power production) and neither of nuclear propulsion systems.

3.4 Air pollution and global warming cost drivers

Air pollution and global warming impact of inland barges is dependent on the number of ship kilometres and the corresponding (average) fuel use per kilometre. The fuel use per kilometre is influenced by the following aspects:

- Ships master skill and style;
- Speed adjustments;
- Technological developments.

3.4.1 Behaviour of the ships' master

Fuel consumption is closely related to the way the ship is operated and the way it is operated depends on the skills and style of the ships master. When ships sail within schedules, it is assumed that the ships try to race to their destinations as fast as possible. Reality shows a different picture, since the speeds, which are encountered upstream, prove to be a counter-acting force. The higher the speed, the more fuel is consumed. As mentioned in paragraph 4.3, the type of cargo in the containers consists of non-perishable goods, so the urgency of always achieving the highest speed can be neglected.

3.4.2 Speed adjustments

Adjustments in speed or ships' engine capacity use and thus fuel use can be categorised in six types of situations:

1) Upstream or downstream;
2) Dense traffic flows;
3) Dangerous crossings and junctions of waterways;
4) Tight curves in the river;
5) Port situations;
6) Other.

Upstream or downstream

First of all, due to the downstream current, the consumption of fuel in upstream direction would be higher than that downstream and the emissions would follow exactly the same pattern. However, the differentiation takes place in speed per hour. The upstream ship velocity is 12 kilometres per hour, the downstream velocity is 18-22 kilometres per hour. An upstream velocity of 12 kilometres can be achieved by any containership, despite the encountered velocity of the downstream current, with increased use of engine capacity.

Very dense traffic flows

When looking at the density of traffic on the Rhine, the highest level of traffic occurs in the region from Rotterdam to Duisburg. At the ship counting station at Lobith 166.282 ships have passed the Dutch-German border in 1998, equivalent to approximately 500 ships a day and 21 per hour. The Duisburg-Rotterdam route has one of the highest traffic densities of inland ships anywhere on earth. In those dense traffic flows, ships have to overtake others frequently. Often extra power is required to overtake other ships, especially upstream. When generating extra power from the engine, extra pollutants will be inserted in the air. Therefore one can conclude that the higher the traffic density, the higher the number of overtaking actions, the higher the air pollution.

Dangerous crossings and junctions of waterways

En route from Rotterdam to Mannheim, eight difficult waterway crossings have to be passed, which are the following:

- Within the Netherlands: **Dordrecht-area** (crossing with Oude Maas, Noord and Dordtse Kil), **Gorinchem-area** (junction Nieuwe Merwede and Beneden Merwede), **Tiel-area** (crossing Waal and Amsterdam-Rhine Canal), **Nijmegen-area** (junction Waal and Maas-Waal Canal), **Millingen-area** (junction Waal, Boven-Rhine and Pannerdensch Canal).
- Within Germany: **Duisburg-area** (junction Rhine and Wesel Datteln Canal, junction Rhine and Ruhr-Herne Canal and junction Rhine-Duisburg port entrance), **Koblenz-area** (crossing Rhine, Mosel and Lahn) and the **Mainz-area** (junction Rhine and Main).

On all junctions and crossings traffic control systems are in place. Traffic control decides which ships may overtake, where and when and which have to slow down to let incutting traffic enter the fairways from the tributaries. This is never decided by the ships' masters, as they only can make requests whether of not it is allowed by traffic control to overtake at a specific location. Here the masters have no decisive vote in the speed of the ships. As soon as the dangerous crossings have been passed, ships will increase speed again, until the next obstacle. Therefore, where ships increase speed, extra power is generated from the engine, causing extra exhaust fumes, including emissions.

Tight curves in the river

Only one tight curve in the route is difficult for the ships to pass. This is the Lorelei-gorge in the Drachenfels-mountain range near Bingen. Here the river is at its narrowest, with current velocity being the highest. Also a 45^0-turn is located in this stretch of river. This requires especially careful navigation, at slow speed for upstream traffic. Any mistake may cause collisions with either the river bank or other vessels. When upstream traffic slows down, it still has to make progress against the opposing current. The slower the vessel sails against the current, the more engine power is needed to keep the ship in forward motion. Although there is less traffic at the Lorelei than in the Duisburg range, pollution may be much higher due to the fact that half of the passing ships in upstream direction make use of their engines at more than 80% of the engines' capacity, against approximately 70% in the lower Rhine area.

Downstream vessels are less affected. Because they float on the strong downstream current, they have difficulties in braking their speed, so they have right of way. Additional speed may be gained for downstream traffic, having their engines run on half-capacity. This way, emissions are reduced compared to full-capacity engine use.

Port manoeuvring

When manoeuvring in ports a ships engine has to be used on peak capacity. Under normal circumstances, ships are loading and discharging within port basins, where water movements are less heavy. However, when a ship is fully loaded with containers, the wind direction plays an important role. When containers are stacked three or four-tiers high, a large surface is created which will influence the ships motion when swinging in port basins.

This will sometimes lead to almost full use of the engines' capacity to prevent the ship from drifting and colliding with the quay wall. In this instance, exhaust fumes will be generated, so it can be assumed that within port areas annual pollution will be significantly higher than under normal circumstances on the river, depending on the number of ships calling at a specific port every year.

Other occasions where air pollution may occur

Other areas where risks of air pollution occur are of relative minor importance. The first of them being seasonal variations in water levels (climate conditions). In some stretches of river applies the rule that the higher the water levels are, the stronger the water current velocity. This can not be quantified, since water depths and water levels vary on a day-to-day basis. However, under high-water circumstances, some bends in the river require extra engine power when sailing upstream. One of these bends is situated near Nijmegen, where the river follows a W-shaped pattern. Especially larger ships will need extra power to pass through this stretch of river.

Another, yet even less important, location of emission is a shipyard. Wherever ships are being built and repaired, test procedures of the engines have to take place sometimes. In this occasion ships are moored to a test site on the shipyard, where the engine is tested at full capacity. This will generate more pollution than under normal operating circumstances. This type of pollution is however outside the scope of this case study.

3.4.3 Technological developments

Ships are designed more efficiently than ever before, although the exterior of the ship may not reflect this. Most of the innovations are not visible from the outside. This concerns mostly the underwater hull shape, which has been optimised to new hydrodynamic standards, in order the enable more water to flow past the ships propellers, to create more effective propulsion. Secondly, optimised propeller blades enable more thrusting power than previous designs, thereby cutting fuel consumption considerably. Finally, new engine designs are also based upon decreasing the fuel consumption. In all, the entire propulsion system of modern inland vessels has been thoroughly upgraded compared to the vessels delivered earlier. As this case study is static in the sense that only one year (1998) specifically is taken into account, the impact of technological developments cannot be taken into account. However, estimations on future emissions per engine type do exist.

Also from a water pollution point of view, the ships have increased in quality by having onboard receptor tanks for bilge water, oil residues, chemical waste (paints and lubricants) and human waste. No garbage therefore has to be dumped overboard anymore, since the ships can deposit garbage at special waste collecting facilities in the ports.

3.5 Marginal environmental cost calculation

Inputs to the Impact Path Assessment model relate to the air pollution and global warming emissions (paragraph 3.5.1) and the valuation of their costs (paragraph 3.5.2)

It should be stressed that all mentioned quantified information is a best estimate, as there is a lot of uncertainty in the value of emission output and the monetary value of the environmental impact.

3.5.1 Air pollution and global warming emission statistics

No specific information on the actual emissions of barge ships on the Rhine case study stretch is existent. However, the study “Inland shipping emission factors” (Dorland c.s., 2000) makes calculations for a number of ship types and situations from which the relevant information for ship types operating on the Rhine can be deduced. The study also discriminates between steady state operation and non-steady state operation, which include docking, undocking, passing a lock (not applicable to this case study) and docked ‘hotel’ stage. The below emission factors are given for 2000, it is assumed that this is representative for the situation in 1998.

Steady state operation

In order to know the emission factors per type of pollutant for specific ship types, it is necessary to calculate the fuel use per ton kilometre. This is the factor based on the tonnage of the ship. The emission factor on the basis of the cargo carried results by multiplying the factor by the vessel’s average load factor. Both figures are given in the table below. In the tables after 3.1. only the factors based on cargo carried are given. It may be clear that one easily can switch from one factor to the other by applying the average load factor.

Table 3.1 Engine capacity, fuel use per ship size class

Ship size class (tonnes)	Average load capacity (tonnes)	Design engine capacity (kW)	Maximum speed at 95% of maximum capacity (MCR), 100% load factor (KW/tonne)	Fuel use, 100% load factor (kg/ktonne-kilometre) Basis: vessel tonnage	Load factor (%)	Fuel use, corrected for load factor (kg/ktonne-kilometre) Basis: cargo tonnage
A. 251-450	350	350	10	22,8	74	30,8
B. 451-650	550	248	10	10,3	74	13,9
C. 651-850	750	338	12	8,6	91	9,4
D. 851-1050	950	428	12	8,6	91	9,4
E. 1051-1250	1.150	575	14	8,1	74	11
F. 1251-1800	1.550	775	14	8,1	74	11
G. > 1800	2250	1.125	14	8,1	74	11
H. Push tug (2)	5.400	2.160	13,9	6,8	74	9,1
I. Push tug (4)	10.800	3.312	12,6	5,5	74	7,5

Source: Dorland c.s., Inland shipping emission factors, 2000

Information on emission in grams per ton kilometre is available for three ship types, class B (451-650 tons), for class F (1251-1800 tons) and class H (push tugs). Class F is a little below the average size of a container transporting ship. Class H is representative for only a limited number of Rhine container transports. It is assumed that the emission for a representative container transporting ship on the Rhine is halfway between the emissions for class F and H.

Table 3.2 Emissions per ship size class, at an average load factor of 74% with 95% MCR, 2000

Emission type (g per ktonne km)	Ship class B. (451-650 tons)	Ship class F. (1251-1800 tons)	H. Ship class Push tug (2)	Approximation Rhine container ship (3300 tons)
Air pollution				
NO_x (Nitrogen oxides)	650	516	428	472
PM_{10} (Respirable fraction particles)	13	10	9	9,5
SO_2 (Sulphur dioxide)	44	35	29	32
HC	13	10	9	9,5
NMHC	12	10	8	9
CO (Carbon monoxide)	35	28	23	25,5
Global warming				
CO_2 (Carbon dioxide)	40.685	32.289	26.788	29.539

Based on: Dorland c.s., Inland shipping emission factors, 2000

The above figures are for an engine capacity use of 95, 50 and 25%, at an average load factor of 74%. If it would be necessary to maintain the same velocity, the fuel usage in Rhine upstream direction is much higher compared to the downstream direction. In fact, the engine capacity use is different for upstream and downstream, and for the segment of the waterways as a result of water current velocity. The below table shows the engine capacity use estimations per Rhine segment, and the corresponding estimations of outputs of pollutants in g/kiloton kilometre, for application in the Impact Pathway Approach model.

Table 3.3 Steady-state emissions per containership on Rhine, specified for case study stretch segments (g/tonkm)

Rhine segment	Direction	Engine capacity use	Air pollution						Global warming
			NOx	PM10	SO2	HC	NMHC	CO	CO2
Rotterdam-Nijmegen	Upstream	60%	313	6	20	7	6	20	18.462
	Downstream	50%	267	5	17	6	5	18	15.297
Nijmegen-Duisburg	Upstream	65%	336	7	22	7	7	21	20.044
	Downstream	45%	245	5	15	5	5	17	13.714
Duisburg-Mannheim	Upstream	70%	358	7	23	7	7	21	21.627
	Downstream	48%	258	5	16	5	5	18	14.664

In combination with the number of ton kilometres of barge transport on the case study stretch of the Rhine, the below quantities of emission where reached in 1998 during steady-state operation.

Table 3.4 Total emissions 1998 for containers transport on Rhine case study stretch in steady state operation

Emission type (g per ktonne km)	Emission in kg
Air pollution	
NO_x (Nitrogen oxides)	416.823
PM_{10} (Respirable fraction particles)	7.953
SO_2 (Sulphur dioxide)	26.476
HC	8.694
NMHC	8.372
CO (Carbon monoxide)	26.747
Global warming	
CO_2 (Carbon dioxide)	24.439.670

Non-steady state operation

Only for class B type of ships the emissions are calculated for non-steady state operations such as hoteling, docking, undocking etc. With the assumption that the ratio of emissions between class B and the approximated Rhine container class would be comparable for the steady state and non-steady state, the emissions for the Rhine container class in non-steady state operation are calculated.

Table 3.5 Non-steady state emissions for ship size class B (2000)

Emission type (g per ktonne km)	Hotel (g/ktonne)	Docking approach (g/ktonkm)	Docking manoeuvring (g/ktonne)	Undocking manoeuvring (g/ktonne)	Undocking depart (g/ktonkm)
Air pollution					
NO_x (Nitrogen oxides)	111	469	1.877	512	469
PM_{10} (Respirable fraction particles)	2,2	8,5	50	14	8,5
SO_2 (Sulphur dioxide)	7,5	27	142	39	27
HC	2,2	9,8	63	17	9,8
NMHC	2,1	9,4	60	16	9,4
CO (Carbon monoxide)	6,0	32	432	118	32
Global warming					
CO_2 (Carbon dioxide)	6.921	25.195	130.530	35.599	25.195

Source: Dorland c.s., Inland shipping emission factors, 2000

Table 3.6 Non-steady state emissions for Rhine container class (2000)

Emission type (g per ktonne km)	Hotel (g/ktonne)	Docking approach (g/ktonkm)	Docking manoeuvring (g/ktonne)	Undocking manoeuvring (g/ktonne)	Undocking depart (g/ktonkm)
Air pollution					
NO_x (Nitrogen oxides)	65	275	1.099	300	275
PM_{10} (Respirable fraction particles)	1	5	28	8	5
SO_2 (Sulphur dioxide)	5	17	87	24	17
HC	1	5	35	9	5
NMHC	1	6	37	10	6
CO (Carbon monoxide)	3	19	250	68	19
Global warming					
CO_2 (Carbon dioxide)	4.057	14.770	76.518	20.868	14.770

In order to calculate the emissions in 1998 during the non-steady state operation, it is necessary to make assumptions on the number of docking/undocking manoeuvring activities take place. It is assumed that during one trip, docking and undocking takes place twice. Hotelling emissions are negligible.

With this assumption, the emissions on the Rhine case study stretch by container ships during non-steady operation are as indicated in the second column table 3.7. The table also shows the total emission in 1998 including steady and non-steady state operation, under the assumption that during steady state operation, vessels on average operate on 50% of their engine capacity.

Table 3.7 Emissions 1998 for containers transport on Rhine case study stretch, with 50% capacity use in steady state

Emission type (g per ktonne km)	Emission in kg in non-steady state	Emission in kg in steady state	Total emission 1998 in kg
Air pollution			
NO_x (Nitrogen oxides)	36.517	416.823	453.339
PM_{10} (Respirable fraction particles)	854	7.953	8.807
SO_2 (Sulphur dioxide)	2.693	26.476	29.169
HC	1.027	8.694	9.721
NMHC	1.086	8.372	9.459
CO (Carbon monoxide)	6.657	26.747	33.404
Global warming			-
CO_2 (Carbon dioxide)	2.380.227	24.439.670	26.819.896

3.5.2 Monetary valuation of air pollution and global warming

Air pollution

NO_x and SO_2 are important factors in local air pollution and acidulation. Both prevention cost calculations and damage cost calculation are available for SO_2 and NO_x. The damage costs calculations are based on the elements of human health and morbidity, damage to materials and the impact on crops. The prevention cost calculations result from estimations of the cost-effectiveness of reduction measures. The below table indicates the various options. The values selected for calculation are € 4,5 per kg for NO_x and € 3,4 per kg for SO_2. This selection is based on a conservative average of the estimations.

PM_{10} particles have negative health impact on local and national level. PM_{10} emission costs are available for urban and non-urban regions based on prevention cost calculations. In non-urban regions the monetary valuation ranges from €1 to € 20. For the selected value somewhat the average is taken at € 11,5.

Costs estimations on CO, HC and NMHC are not available. Given the extensive scan on (international) literature with no mention of these costs, it is assumed from economic point of view that these emission types are less important than the quantified emissions.

Global warming

The shadow price for one ton CO_2 reduction is defined as that price where the propensity to pay for one additional unit of healthy atmosphere as a result form 1 ton CO_2 reduction is equal to the additional costs to reduce this 1 ton CO_2 emission. It is concluded that both in an approach based on damage costs or in a prevention costs approach there is such an amount of uncertainty in calculations that a shadow price can not be realistically assessed. A choice is then being made for application of prevention costs because the range in results in this approach (€ 5-45 per ton, 1998) is somewhat lower than for the damage cost approach (€14-150 per ton, 1998). Given the assumption that future developments in technology will reduce the emission costs, a value of €20 per ton is selected for calculations.

3.5.3 Environmental accident costs

In addition to the costs of air pollution and global warming emissions, environmental costs result from the occurrence of accidents. During 1998, in accidents within the Netherlands only one case of oil pollution was recorded within the port of Rotterdam. In five other cases the environmental damage is unknown. Data on environmental pollution within German waters is not available. It is estimated that the total number of environmental accidents per year is 10 with an average cost of € 10.000.

3.6 Marginal environmental cost calculation

Marginal environmental costs

The above information will allow for a run with the Impact Pathway Approach model in order to calculate the marginal external costs. In the below table, the results of the Eco Sense model run by IER are presented for air pollution damages on the identified three Rhine segments. They are expressed as damage factors per unit of pollutant and are calculated as marginal increases based on a 1998 emission scenario. With the model run, the UNITE valuation conventions were applied.

Table 3.8 Marginal increase expressed in damage factor costs per unit of pollutant in kg

Emitted pollutants	NOX	PM2.5	SO2	CO	Benzene	NMVOC
Damaging pollutants	Nitrate+Ozone	PM2.5	SO2+Sulphates	CO	Benzene	Ozone
	€/kg	€/kg	€/kg	€/kg	€/kg	€/kg
Rotterdam-Nijmegen	3,1	145,6	9,1	0,0012	0,8	1,5
Nijmegen-Duisburg	2,5	69,2	6,5	0,0006	0,4	1,5
Duisburg-Mannheim	3,9	68,7	5,4	0,0006	0,4	1,8

Source: IER, 2000

As can be concluded, the Rotterdam-Nijmegen segment of Rhine causes much higher damages. This is the result of the high population density near Rotterdam. The other Rhine segments have quite similar results.

With an average capacity of 200 TEU's per ship and a utilisation rate of 80%, the marginal costs can be estimated at 1.8-1.2 eurocent per TEUkm, averaged for up- and down stream.

There is a lot of uncertainty in the estimation of the (marginal) external environmental costs. Emission outputs and emission costs are available in a range rather than for a specific value. As the UNITE guideline states, most of the uncertainties are attributable to an insufficient knowledge of the physical phenomena associated with the various impact chains, and do not reflect a deficiency in methodology. In order to show the impact of varying assumptions, it is therefore advised to do some alternative runs in order to perform a sensitivity analysis.

3.7 Conclusion and generalisation issues

With the help of the Ecosense model of IER, a calculation has been made of the marginal increase in damage factor per unit of pollutant for three specific Rhine segment. The Rotterdam-Nijmegen segment of Rhine seems to causes much higher damages compared to the other two segments. This is the result of the high population density near Rotterdam. The other Rhine segments have quite similar results. With an average capacity of 200 TEU's per ship and a utilisation rate of 80%, the marginal costs can be estimated at 1.8-1.2 eurocent per TEUkm, averaged for up- and down stream.

The EcoSense calculations shows that the proposed methodology is also applicable to inland waterways. Apart from the applied methodology, generalisable study elements include the inputs such as emission factors and economic unit values. The emissions for a specific ship type per used litre of fuel is applicable for use (for this particular shiptype) on any inland waterways.

The emissions will only change over time following innovations in the energy-effectiveness of the engines or of the fuel itself. Total annual emissions are dependent on the volume of ship movements.

Not to be generalised to other modes or situations are the infrastructure characteristics, vehicle speed, numbers of ship movements, tons transported, etc.

Chapter 4: Marginal accident costs

4.1 General

During the last decade, accident risks and safety in inland waterways transport has gained more attention than ever before. This was mainly the result of a series of accidents during the 1980's, when some collisions in Germany caused subsequent oil pollution. These collisions were caused by human errors onboard the tankers. To protect the environment from the consequences of accidents, regulations have been issued in which vessels transporting dangerous cargo should have a double hull. This double hull both acts as a impact zone in case of collisions and also prevents water from entering the hull after the collision took place and, more important, dangerous cargo from leaking out. The latest oil- and chemical tankers and containerships are equipped with a double hull.

Global Positioning Systems are being used by the various Traffic Control Centres along the Rhine, monitoring every ship closely and thus helping to avoid any accidents. This is accompanied by a vessel identification program, which enables even closer monitoring of vessels loaded with dangerous cargo, including most of the containerships. Lack of structural data entry and data submission already may cause uncertainty amongst rescue teams and fire fighters. Sometimes, even when all measures are in place, uncertainty can arise as to the exact content of containers, thereby, in case of fire, not knowing whether to use water, foam or do nothing at all. Lists of dangerous cargo onboard the containerships have to be submitted to the authorities, which enter the data into the vessel identification program. If accidents should occur to a vessel, the local authorities can immediately assess the risks.

4.2 Objectives of the marginal accident case study

The objective of this case study is to show the application of the marginal external accident costs methodology in the case of inland shipping, based on local information on accident risks and costs on the Rhine.

The total marginal external accident cost is the extra cost related to accident risks imposed by a user on all other users and the general public due to his travel decision. In this case study, the user is defined as the shipper.

A segmentation in results will be made according to the following categorisation elements:

- ▲ Rural/Urban: between accidents occurring during normal operations on open stretches of the Rhine ('rural') and accidents in cases of manoeuvring in ports (Urban);

- Cost category: administrative, material damage (both to infrastructure and ships, shippers injury or death, production loss, risk value, etc.);
- Victim/injurer;
- Inland barges/other.

4.3 Accidents causes

The reasons for occurrence of accidents on the Rhine are very diverse. Both German and Dutch shipping authorities keep records on all accidents. A study of these records reveals that the most important causes of accidents are:

- High waves;
- Human errors;
- Misnavigation;
- River conditions;
- Weather conditions;
- Technical failures.

The fact that only on the Rotterdam-Nijmegen route **high waves** exist, has its nature in the combination of ocean ships and inland ships within the port of Rotterdam. Often seagoing ships create high stern-waves, in extreme cases (when speeding) up to 1 meter, causing damage to the inland vessels and also causing sometimes stability problems.

Human errors and **misnavigation** in most cases go together. A ships' master may become inattentive when distracted from his work, taking the wrong decisions and causing accidents. The frequency of human errors on the Middle-Rhine specifically is high. This has mainly to do with disorderly situations in combination with the strong river current (the number of accidents caused by river conditions here is greater than anywhere else on the river).

River conditions in the Lower Rhine region are not causing much concern. On the Middle Rhine, a difficult stretch of the river is the area between Koblenz and Mannheim. Not only does the river include a powerful current, but also it has two 45^0 bends at Oberlahnstein and Bingen. Especially the bend at Bingen imposes a potential danger, since the current velocity of the Rhine is the largest. Here the Rhine forces itself through the Lorelei-gorge at great speed, in a situation were ships have to make a 45^0 turn. This is one of the narrowest stretches of river.

Weather conditions accidents may result from fog, icy conditions and wind but are almost entirely on account of *strong winds* in the Rotterdam area. Many masters underestimate the wind velocity and the impact it has on a mooring vessel. Depending on the wind direction (in relation to the position of the container cranes), loading or discharging of ships can become dangerous, due to swinging of the containers when hoisted or lowered. A swinging 20-ton container can cause serious damage to the crane, the ship and other containers. Depending on the stack height of containers on a ship, it may also have some difficulties during navigation. Side winds may cause drifting of the vessel. This may cause delays or accidents when the vessel is mooring or manoeuvring at terminals, or during the voyage. In only one case, *fog* was the cause of an accident. Fog occurs frequently along the Rhine. Operations at the seaside container terminals in Rotterdam are frequently disturbed by sea mist, which decreases visibility to almost zero metres. Also inland mist can occur, especially during the spring and autumn. In this case the mist is not as thick as sea mist, and terminal operations are usually not disturbed. *Icy conditions* on the Rhine are rare. This results mainly from the current velocity, which is too fast to create any ice formation. Occasionally this may occur on the banks of the river or in submerged river forelands in the Lower Rhine area, where current flows may be non-existent. Transport operations are seldom hindered by ice. Occasional ice patches may occur, but these are no threat to ships. If however threatening ice conditions may form, ice breaking tugs can make way for the inland vessels. In the past 25 years, ice formation of any significance was recorded in the fairways on the river in 1978-1979 and 1997.

Another major contributory to accidents on the Middle-Rhine is **technical malfunctioning**. This is in most cases (11) related to engine problems. Since the ships' engine runs almost at maximum capacity for a considerable time (up to six hours), overheating of the engine is possible and in some cases results subsequently in a total breakdown. Within the Rotterdam- and Duisburg-areas also a substantial frequency of this kind of accident exists, mainly due to manoeuvring in port areas. In Rotterdam an additional factor is the average level of the tidal influence, which affect the water current to a large extent. This means vessels require more power to manoeuvre than in most other ports, with possible subsequent breakdown.

4.4 Accident statistics and assumptions

4.4.1 Number of accidents

The following table contains a summary of all accidents on the Rhine within the Rotterdam-Mannheim route for **all inland shipping categories** and their causes in 1998. The severity of the accident ranges from just material damage to heavy injuries. As no details are available for container transporting ships specifically (there are very little dedicated container ships, most container transporting ships are equipped to transport bulk products as well) the below table applies to all ship types active on the Rhine.

Table 4.1 Accidents per type and waterway section (1998)

Cause	**Rotterdam-Nijmegen**	**Nijmegen-Border**	**Border-Duisburg**	**Duisburg-Mannheim**	**Total stretch**
High waves	7	0	0	0	7
Human error	10	5	48	131	194
Misnavigation	12	4	0	0	16
Overloaded or unbalanced cargo	1	0	1	6	8
River conditions	3	0	2	11	16
Speeding	1	0	0	0	1
Technical malfunction	8	2	18	22	50
Unknown	15	0	0	0	15
Weather conditions	8	0	17	17	42
Other	3	0	4	22	29
Total	**68**	**11**	**90**	**209**	**378**

Source: CBS ongevallendatabase Binnenvaart, 2001 and Statistisches Bundesamt, Binnenschiffahrtsunfalle der gewerblichen Binnenschiffahrt auf Bundeswasserstrassen 1998.

Of this total number of accidents, 57% took place in urban areas (ports) and the remaining 43% in situations of normal operation along the inland waterway stretch. On the assumption that the transport intensity on the other segments is comparable to the intensity at the border, the accident risk is 2,3 on every 1.000 trips.

4.4.2 Victim versus injurer

A segmentation can be made between accident involvement of barge ships (injurer) with other barges or other types of inland waterways users (victims) (for instance passenger ferries, recreational craft, governmental surveyance ships, etc.). In addition to this, the number of accidents between "Other types of inland waterways users" may be of importance. Table 4.2 gives an overview of the distribution of accident involvement on the case study stretch. It shows that most accidents take place between barges.

Table 4.2 Accident groups

	Barge	Other	Total
Barge	0,826	0,037	0,863
Other (governmental, recreational, ferries)	0,029	0,108	0,137
Total	0,855	0,145	1,00

Within the shipping accidents of inland waterways ships only, an astounding 57% of the accidents are single ship accidents: for instance the shipper (in this case injurer) runs his ship aground. Of the other 43%, it is assumed that 50% is related to the injuring party and 50% to the victim. With accidents between Barge and 'Other', it is assumed that

100% relates to the injurer. With accidents between 'Other' and Barge, the assumption is the other way around (0%). To calculate the distribution between barge victims and barge injurers, the share of accident groups is weighed with the assumed victim/injurer distribution. The group other/other will not be taken into account in this calculation.

The probability for a barge owner in an accident situation of being a victim is:

$\beta =$ 22,7%, consisting of 19,9 % victims resulting from incidents amongst barge shippers and 2,8% from accidents caused by 'others'.

The probability of being an injurer is:

$1- \beta = 77{,}3\%$

Where β = probability of being a victim in the total number of accidents

The total number of ship ton kilometres on the Rhine case study stretch in 1998 is 1.383 million. The accident risk π is then defined as follows:

$$\pi = A/Q$$

Where π = accident risk
Q = Number of ship ton kilometres
A = Number of accidents

The value of $\pi = 2{,}73E^{-7}$. If the accident risk would be calculated per ship movement instead of ton kilometre, approximately in two cases out of every 1.000 shipping movements, some kind of accident happened.

4.4.3 Risk elasticity assumptions

The risk elasticity, i.e. the relationship between the risk and the number of users is the key function, which finally determines the magnitude of the external cost of accidents. It is however a very difficult element to calculate and for other modalities than road simply no study on risk elasticity exists.

An attempt has been made to analyse ship accident statistics over the period 1993-1997 and to thus make an estimation of the increase in accident risk with additional ship movements. However, as a lot of safety measures were taken during this period the number of accidents dropped whereas ship movements increased. This makes a comparison totally unreliable.

As there is still a lot of spare capacity on the Rhine and therefore no reason to assume that congestion will cause marginal cost to rise, it is assumed that the relationship between average costs and marginal costs shows very little diversion. The elasticity is thus set at zero. The risk elasticity for injurers is expected to be identical to the risk elasticity for the victims.

Thus, **E=0**

Where E= Risk elasticity
$E_v=E_i=E$

4.5 Accident cost categories

Costs related to inland waterway accident include the costs of damage to ships, the costs of damage to infrastructure, costs resulting from human injury or death, environmental damage, operational damage and administrative costs.

4.5.1 Costs of damage to ships

On the Dutch sectors of the Rhine, damage to ships is usually superficial. Out of 79 accidents in the Dutch sectors, only two vessels sank. The other ships suffered mostly slight damage (broken windows, dents in the railings, etc.). In only two cases heavy damage was caused (dented hull plates or destroyed forepeak).

The range of damage repair costs was from € 4.000 up to € 44.000 (average: € 24.000) in accidents causing slight damage. The repair costs for the heavily damaged vessels is not known, but it is estimated at € 220.000 up to € 300.000 (average: € 260.000)(source: inland operators).

In the German sectors, only one ship sank following an accident (Lower Rhine-area). In the Lower- and Middle Rhine regions 27 and 45 respective ships were severely damaged. Details on repair costs are not known, but identical assumptions to the Dutch situation will apply. Slightly damaged vessels numbered 41 and 54 respectively. Here too, detailed costs estimations are not available, but it is believed to be around the € 4.000,- up to € 44.000,- range.

The below table shows the estimations of costs of damage to ships. However, as these costs are fully internalised, they will not be taken into account when applying the methodology.

Table 4.3 Costs of damage to ships (1998)

	Total damaged ships	Total costs (€)
Heavily damaged	74	19.240.000
Slightly damaged	174	4.176.000
Total	248	23.416.000

Average costs thus amount to about € 94.400 per accident.

4.5.2 Costs of damage to infrastructure

On the Rotterdam-Nijmegen section, only two out of 68 incidents caused damage to the quays. Details on repair costs are not available for these specific examples. Within the Nijmegen-Dutch border area no accidents concerning infrastructure were recorded in 1998. On the German section of the Lower Rhine, in 6 accidents damage was caused to quays and bridges. On the Middle Rhine this figure totals 54, again with no financial details.

The average repair costs on Dutch stretches are estimated at € 37.000 per incident with infrastructure damage. For Germany, it is assumed that the costs are comparable.

It should be noted that the costs of *protection* of infrastructure from accidents are included with infrastructure costs, in accordance with the marginal cost methodology guidelines.

Table 4.4 Costs of damage to infrastructure (1998)

	Total no. incidents with infrastructure damage	Total costs (€)
Rotterdam-Mannheim	62	2.294.000

4.5.3 Costs resulting from human injury or death

The costs resulting from human injury or death relate to the following categories:

- Value of Statistical life and risk value;
- Costs of production loss;
- Medical costs.

During 1998, on the two Dutch sectors no personal injuries or deaths were recorded. One accident was caused by a ships' master who had a coronary and fell forward on the ships' telegraph, which he accidentally put on "full speed ahead". No fatalities were recorded in 1998.

In the German sector a different image arises. On the Lower-Rhine section 23 people were wounded when a passenger cruise ship was rammed by a barge. Of this cruise ship, 20 passengers were injured and 3 of the crew. On the Middle-Rhine no injuries were recorded as were fatalities for the whole of the Lower- and Middle Rhine.

Value of statistical life (VOSL) has been derived from UNITE Valuation Conventions and are (per fatality) € 1,7 million for the Netherlands and € 1,62 million for Germany. Risk Values for severe injuries are estimated at 13% of the Risk Value of Fatalities (=VOSL), and for light injuries at 1% following the ECMT (1998) recommendations. Medical costs are calculated at € 23.000 per hospitalised person. Production loss is valued at € 83.000 per hospitalised person (Source: Dings et al, Efficiënte prijzen voor het verkeer, The Netherlands, 1999).

Under the assumption that 75% of the injured people had light injuries (with no hospitalisation) and 25% severe injuries, the following table shows the estimated costs in 1998 of fatalities, injuries and production loss related to fatalities and injuries on the case study stretch of the Rhine.

Table 4.5 Costs resulting from personal injuries and death (1998)

	Occurrence	Risk value (€)	Production loss (€)	Medical costs (€)
Fatalities	0	0	0	0
Severe Injuries	6	1.263.600	498.000	138.000
Slight Injuries	17	275.400	0	0
Total	23	1.539.000	498.000	138.000

Total risk value, production loss and medical costs are thus estimated to amount to € 2.175.000 for 1998. The average costs related to human injury and death on the case study stretch are thus € 94.565 per incident.

Estimation of liability insurance premium

In order to arrive at a calculation of external costs, it is necessary to subtract the costs of liability insurance premiums to cover for liability claims of victims. As no relevant data are available to calculate the amount spent on liability insurance for Rhine shippers, it is assumed that the total premium paid amounts to 50% of the injury and death costs for victims. The liability insurance premiums paid by the injurer (g) is then € 246.833.

4.5.4 Environmental damage

During 1998, in accidents within the Netherlands only one case of oil pollution was recorded within the port of Rotterdam. In five other cases the environmental damage is unknown. Data on environmental pollution within German waters is not available. It is estimated that the total number of environmental accidents per year is 10 with an average cost of € 10.000. In line with the marginal cost methodology guidelines, the costs of environmental damage will however be taken into account within the environmental cost case studies.

4.5.5 Operational damage

Due to accidents, sailing restrictions may occur which have an impact on shipping operations. In the Dutch sectors traffic was relatively undisturbed by accidents throughout 1998. In case of the two sunken vessels, traffic was delayed due to salvage operations, but could proceed. On the German part of the Lower-Rhine, shipping was hindered 5 times and impossible on one occasion. The time the blockades lasted was 7 hours at maximum. On the Middle Rhine the situation was worse. Here the shipping was hindered 10 times, while the river was completely blocked 12 times. The average duration of the blockade was also approximately 7 hours.

However, from a methodology point of view, congestion caused by accidents is considered out of scope for the marginal accident cost analysis and therefore not further analysed.

4.5.6 Administrative costs

The potential administrative costs of settlement of accidents (police, fire department, justice, etc.) could not be identified specifically for the Rhine case study stretch as these costs are within a total conglomerate of budgets for governmental bodies. An estimation of the average external costs of accident settlement per hospitalised person was assessed by Dings et al (Netherlands, 1999) at € 9.000.

4.6 Marginal external accident cost calculation

Total and average costs

The total annual costs of accidents ($TC_{accident}$) are the total number of accidents (A) multiplied by the total costs per accident (a+b+c)

$$\mathbf{TC_{accident} = A\,(a+b+c+d+e+f)}$$

Where
A = total number of accidents
a = value of statistical life & risk values
b = costs of production loss
c = medical costs
d = damage to ships
e = damage to infrastructure
f = administrative costs

The total accident costs for 1998 are:

$$\mathbf{TC_{accident\ 1998}} = € \ 27.939.000$$

The average costs per accident ($\mathbf{AC_{accident}}$) is:

$$\mathbf{AC_{accident} = TC_{accident} / A}$$

$$\mathbf{AC_{accident\ 1998}} = € \ 73.913$$

Internalized costs

In order to arrive at an estimation of total and marginal external costs it is necessary to calculate the amount of the total accident costs that are internalised.

Costs of injury of "injuring" barge shipper (1- β (a+b+c))	€ 1.681.334
Costs of ship damage (d)	€ 23.416.000
Liability insurance premiums (g)	€ 246.833
Total	€ 25.344.167

The ratio λ of internal costs to total accident costs is then 91%.

The marginal external cost per additional ton kilometre then follows with the use the following equation.

$$\mathbf{MC^{extern}} \quad = \quad \mathbf{(1-\lambda)\ \pi\ (1+E)\ ((a+b+c+d+f)/A)}$$

$$\mathbf{MC^{extern\ 1998}} \quad = \quad € \ 0{,}0018$$

Marginal external costs related to one additional vessel ton kilometre on the Rhine case study stretch are thus estimated to amount to approximately € 0,0018. Based on the basis of cargo carried the costs would be € 0,00243.

4.7 Conclusion and generalisation issues

Approximately 2 of every 1000 ships travelling along the Rhine segment studied meets with an accident. These accidents are usually very light with some damage to the ships and indeed in 1998 no fatalities were recorded on the case study stretch. A calculation has been made on the marginal external costs of inland shipping on the case study stretch, which amount to approximately € 0,0018 per additional ton kilometre of vessel movement and € 0,00243 per additional ton kilometre of cargo movement.

Statistics on actual inland waterways accident costs have proven to be less ready available than expected, whereas the accident occurrence information is very detailed. Statistics with respect to container transporting ship movements are not available per transport segment. Therefore it was not possible to make segmentation into rural/urban areas and into various stretches of river, to specify the information to container transporting ships only.

The outputs of the case study are transferable to other Western-European Inland waterways from the viewpoint of overall methodology, output functions and relationships. Non-transferable items are the economic unit values (specific for the studied Rhine stretch and the countries involved) and the actual accident risk. The marginal external cost has been calculated for the year 1998 but could also be used for other years with modification of the risk level, and an update of the economic unit values. Generalisable to other modalities are the overall methodology and the segmentation of cost components.

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ANNEXES

Annex 1
Detailed ship characteristics

The for Rhine container transport relevant ship types within the class IV and V levels are indicated below.

Table B.1 Container vessel characteristics

Vessel characteristics	**Europa type**	**Pushbarge**	**Purpose-built containership***
Built (year introduction)	1980	1980	1998
Deadweight (metric tons)	3.200	1.800	5.200
Length over all (m.)	110,00	76,00	135,50
Beam (m.)	11,40	11,40	16,84
Draught (m.)	3,20	3,20	3,20
Height (keel to deck (m.))	Approx. 4,50	Approx. 4,50	5,50
Engine (brand and type)	Deutz 528	Not self-propelled	3 x 3508 Caterpillar
Bhp	2,100	0	2,800
Speed (downstream)	Approx. 10 knots	0	12,4 knots
Bow thruster	1 on each side	None	2 on each side
Bhp	**	0	1,000
Capacity (TEU)	208	160	398 (4 tiers)/ 470 (5 tiers)
Reefer capacity (TEU)	None	None	None
Crew	3	0	5
Remarks	General cargo ship suitable for container transport		Double hulled container vessel

* the purpose-built containership illustrated here represents the latest generation of modern containerships, of which two vessels are currently in operation.

** bow thruster configuration varies from 500 bhp to 1.000 bhp, upon owners request.

The purpose built containerships referred to in the last column concerns the largest ship afloat in 2000. This type is also known as “Jowi”-type, given the name of the lead vessel in this series.

Various operational possibilities exist when the use of a pushbarge is concerned. Often a pushbarge is combined with a Europe-class vessel, creating a 368 TEU craft with the sum of the specifications of Europe-types and pushbarges mentioned in the table. Another possible mode of employment is a combination of two (up to four) pushbarges, propelled by a pushtug. In this case a 640 TEU ship is created, with a DWT of 7.200 tons. This requires a very powerful pushtug, usually engaged in coal or iron ore trades from Rotterdam to Germany. This particular type of ship is very slow, especially when sailing upstream. This option is not used often, also due to difficult manoeuvring with a fully loaded pushcombination in the strong currents on the River Rhine. Additional item is the time consuming event of combining pushbarges and pushboats or containerships to create one unit. This can be avoided when using purpose-built containerships.

Annex 2   Container cargo types

All container vessel types are suited for transport of containers within the size range of 20’ to 40’. Sizes of 20’ en 40’ are common sizes and containers with these dimensions outnumber any other size. Within the size range a number of containers can be used for specific types of cargo.

The following table shows which containers are most common and how they are used and in what sizes they are offered to customers.

Table B.2 Types, purposes and sizes of common containers

Container type	Intended cargo	Product type examples	Available sizes
Bulk	Dry cargo in bulk	Malt, sugar	20’
Fantainer	Agricultural products needing ventilation	Unions, potatoes	20’, 40’
Flatrack	Overgauged cargo	Helicopters, cars, trucks	20’, 40’
Half heights	High density cargo	Ingots, steelwork, drums	20’, 40’
High cube	Dry cargo	Any product	20’, 40’, 45’
High cube reefer	Cooled/frozen cargo	Fruit, vegetables, fish, ice	40’, 45’
Highly ventilated	Highly ventilated cargo	Cocoa, tobacco, seeds	20’
Open top	Overheight cargo	Construction materials	20’, 40’
Platform	Oversized cargo	Railway wagons	20’, 40’
Refrigerated	Cooled/frozen cargo	Fruit, vegetables, fish, ice	20’, 40’
Standard	Dry cargo	Any product	20’, 30’, 40’
Tank	(dangerous) liquids	Chemicals, orange juice	20’, 25’, 30’

Around 95% of all containerised cargo is transported in containers listed in the table above. All of these types can be transported by barge, but the barge operators’ preferences sometimes lead to non-acceptance of certain container types or sizes on inland barges.

The 25’ and 30’ containers are a new size of container and are increasing in numbers on cross-North Sea traffic (Continent to United Kingdom), in dry cargo and tank container versions. These also increase within barge transportation.

45’-containers are confined to Mærsk Sealand operations (the worlds’ largest deepsea container operator) and are not transported by barge, but by rail. This is mainly because the current container fleet of barges is not adapted to the size of the containers, in terms of effective stowage of the ships.

Stowage of inland ships can best be compared to putting a three-dimensional jig-saw puzzle together. Containers have to be put immediately aside and on top of each other, in order for a rectangular block to emerge. This block has nearly the same dimensions as the shape of the ships hold.

From safety point of views it is not possible to randomly stack containers on top of each other: two 20’ containers can be placed on top of 40’ container (if the weight allows so) or the other way round. It is not possible to place a 40’ container upon a 35’ container. This would lead to protrusion of the 40’ containers, thereby increasing the damage risk. The usual procedure is that equal sized containers are stacked upon each other, the heaviest weighing one below, the lightest one on top. Inconsistencies in container length or height may lead to loss of effective cargo space and thus loss of performance of a ship. Ship operators try to avoid this at any time.

Some barge operators refuse to take acceptance of refrigerated containers onboard their ships, simply because containers can not be reached by repair workers for repair in case their cooling/freezing mechanisms fail during the trip and the cargo defrosts or perishes.

Annex 3 Ship operating information

Transit times

The following table shows the transit times between the main terminals on the Rhine stretch under study.

Table B.3 Upstream and downstream transit times between the selected terminals

FROM	TO	TRANSIT TIME (days)	
		Upstream	Downstream
Rotterdam	Nijmegen	1	1
Rotterdam	Duisburg	2	1
Rotterdam	Mannheim	3	2
Nijmegen	Duisburg	1	1
Nijmegen	Mannheim	2	2
Duisburg	Mannheim	2	1

The transit times downstream are a day shorter compared to those upstream. The voyage duration within the Netherlands is calculated as one day, to keep it in line with the others. In fact, the upstream transit time is approximately 12 hours, the downstream times about 6 hours.

This results from the speed of the vessels. Upstream ship velocity is 6,5 knots, equal to 12 kilometres per hour, the downstream velocity is 9,7 to 11,8 knots or 18-22 kilometres per hour. An upstream velocity of 6,5 knots can be achieved by any containership, despite the encountered water velocity.

Given the speed of a ship, one ship can cover the following number of round trips per year on a specific route, if she sails that route throughout the year:

Table B.4 Number of round voyages and ship kilometres per year

Route	# voyages per year	Distance in km	Ship kilometres per year
Rotterdam-Nijmegen v.v.	150	105	15.750
Rotterdam-Duisburg v.v.	100	221	22.100
Rotterdam-Mannheim	50	590	29.500

During the low season (from Christmas to New Year) ships spend time repairing or dry docking. Only two weeks, under normal circumstances, the ships are inoperative.

Ship loading capacity and occupation rates

The average weight of an import container equals 9,1 tons, the weight of an export container is about 11,2 tons, excluding a tare weight of 2,2 tons for the container itself. Load factors of the ships have been obtained through container ship operators. The average load factor upstream is about 72%, the downstream load factor about 81%. A load factor of 72% upstream means that 72% of the ships possible deadweight has been utilised on upstream voyages. The operators also revealed that 70% of all upstream containers are empty. These are repositioned to depots in Germany, so shippers have access to containers when required.

The following table shows the capacity use of the ship types in upstream and downstream directions.

Table B.5 Slot utilisation per ship type and direction

Slot utilisation

Ship Type	**Direction**	**DWT**	**TEU**	**Load factor TEU**	**TEU**	**Empty TEU**	**Slots not used**
Barge	upstream	1.800	160	0,81	**130**	**0**	**30**
Barge	downstream	1.800	160	0,72	**115**	**81**	**45**
Europa	upstream	3.200	208	0,81	**168**	**0**	**40**
Europa	downstream	3.200	208	0,72	**150**	**105**	**58**
"Jowi"-type	upstream	5.200	470	0,81	**381**	**0**	**89**
"Jowi"-type	downstream	5.200	470	0,72	**338**	**237**	**132**

Table B.5 emerges when the use of ship capacity is calculating according to the load factors derived from the operators. The variable slots ‘not used’ indicates the physical slots. In terms of capacity the ship is loaded to the maximum allowed, according to safety regulations.

Table B.6 Weights of the loaded containers per ship type and direction.

Container weights

Ship Type	**Direction**	**onboard TEU**	**loaded TEU**	**Empty TEU**	**gross average TEU-weight (loaded)**	**TEU weight (empty)**	**total teu weight (loaded)**	**total teu weight (empty)**	**Total used DWT**
Barge	downstream	130	130	0	11,13	2,200	1.447	0	**1.447**
Barge	upstream	115	34	81	13,23	2,200	450	177	**627**
Europa	downstream	168	168	0	11,13	2,200	1.870	0	**1.870**
Europa	upstream	150	45	105	13,23	2,200	595	231	**826**
"Jowi"-type	downstream	381	381	0	11,13	2,200	4.241	0	**4.241**
"Jowi"-type	upstream	348	105	243	13,23	2,200	1.389	535	**1.924**

Table B.6 shows the weights of the onboard containers. The average weights for loaded and empty containers on import and export legs were derived from a number of deep-sea operators and container leasing companies.

Combining table B.5 and B.6, utilisation rates per ship type can be calculated.

Table B.7 Utilisation rates per ship type and direction

Ship type	**Direction**	**Utilisation rate**
Barge	Upstream	1,25
	Downstream	1,07
Europa-type	Upstream	1,71
	Downstream	1,46
“Jowi”-class containership	Upstream	1,23
	Downstream	1,05

All upstream vessels have a low utilisation rate, due to imbalance of loaded containers. Downstream vessels have a much higher rate, approaching the optimum value of 1. This is due to the high average figure for loaded export containers. On both occasions however, vessels of the “Europa”-type are being operated less economically than the others. Purpose built containerships of the “Jowi-type” have the best ratings. On export routes they approach the optimum value nearest and thus can be operated most efficient.