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ACCIDENTS IN EUROPEAN PORTS INVOLVING CHEMICAL SUBSTANCES: CHARACTERISTICS AND TRENDS

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Abstract

It is widely acknowledged that ports play a crucial role in the economic development of any coastal country. However, ports are not exempt from suffering accidents as a result of the transportation and manipulation of dangerous goods within their boundaries. Consequently, the environmental, social and economic impacts of these accidents should not be ignored.

In this work, accidents occurred in European ports since the beginning of 20th century until now have been compiled. The main characteristic of all these accidents is that they involve chemical substances with their consequent risk for society and environment. The survey has been performed by using mainly accidents databases.

Once all the accidents have been gathered, some results and conclusions have been drawn. All these results have been compared with previous studies on port accidents and with a specific research also conducted in this project for recent accidents (from 1990 until now). This has allowed to find differences and similitudes, and to establish trends.

Most of the accidents have occurred in the last decades, being France (29.9%) the country with the higher percentage of accidents followed by UK (25.8%). The most common type of substance involved in the accidents is oil or derivates (56.8%) and most of the accidents involved a release of material (61.0%), being this one the type of accident that has increased the most in the last years. The origin is mainly transport (41.7%) and transfer (31.5%), typical port operations, and the most common cause of accidents in ports has involved impacts (45.1%).

Concerning the consequences on population, European accidents seem to have less severe consequences on population when compared with studies of the total amount of accidents in ports worldwide. The number of accidents increased during the 20th century but it can be observed a clear reduction in the new century.

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1. Introduction

The shipping industry plays a vital role in the world economy and trade and allows the transport of a big quantity of goods, reducing costs and the emissions of CO_2 [1]. Within the shipping industry, ports are essential as they operate as contact points between sea/river and land to be able to unload and load the transported products. However, as in every mode of transport, the risk of accidents is always present. The transfer and storage of hazardous materials may contribute to these risks. Several authors have already studied the risk of accidents in ports in the past (Romer et al [2], Rigas and Sklavounos [3], Darbra and Casal [4]), demonstrating that accidents not only occur miles away of the coast. In fact, ports are very important industrial areas with a lot of activity. This involves that, in case of an accident, not only the environment can be damaged, but also the human lives can be in danger. Furthermore, in ports can also be found others facilities such as refineries or chemical plants, so the risk of an accident while manipulating or operating a chemical product is also present.

Throughout the 20th century and also in the 21st century there have been some accidents that have caused an important damage to the environment and have forced authorities to take measures to ensure safety in this sector. In Europe the disasters of *Mar Egeo* [5] and *Prestige* [6] in 2002, that affected mainly the coasts of Spain, became turning points. In the United States, the sinking of *Exxon Valdez* [7] in 1989 and *Deepwater Horizon* [8] in 2010 caused an important environmental damage and the responsible enterprises were compelled to pay very high economical compensations that unfortunately did not fix the natural disasters. In consequence, it should not omit the possibility of a severe accident in the transportation of hazardous materials.

In order to avoid these accidents, the European authorities have established a series of directives and laws, which aim is to ensure the safety and normal operation in European ports. Among this legislation, the Seveso directives and the Directive 2008/68 on inland transport of dangerous goods have played a vital role in the drop of accidents in ports areas since the beginning of 21st century. A brief description of these directives will be presented in Chapter 4 of this work.

In conclusion, the possibility of an accident in a port area is real. This project has compiled accidents from databases, reports and websites to establish trends and understand the causality and the origin of these accidents. What is the real situation concerning serious accidents in port facilities? Are there many of them? Are there few? Is their frequency stable or is it on the rise? What are their most common consequences? A historical analysis of the accidents that have occurred can answer these questions, providing very interesting information about the most frequent accidents in port facilities, their origins and causes, their consequences (number of people affected, effect on the environment, etc.). The results of this analysis should allow the identification of the main sources of risk and at the same time provide very useful information for laying down safer operating procedures and drawing up contingency plans.

2. Objectives and scope of the project

In this chapter, the main objectives and the scope of the project will be explained. In this way, the aim of this research and its purpose will be better understood.

2.1. Objectives

The main objective of this paper is to gather port accidents occurred in Europe from the beginning of 20th century until nowadays and analyse them. However, the objective of the study is not only to make a historical research of accidents in European ports from the beginning of 20th century on, but also to focus on the accidents occurred in the last decades to verify the safety measures taken in Europe and identify the most sensitive points of the maritime industry. For this reason, a comparison between the historical trends and the tendency in the last 27 years (since 1990) has been presented.

In order to meet the main objective of this study, the next sub-objectives have been identified:

- Research on the importance of the shipping industry and the port sector
- Bibliographic research of the accidents and legislation from databases, reports, websites and other sources
- Establishment of a methodology in order to ease the searching of the accidents according to the scope of the project
- Compilation of all the accidents occurred in Europe since the beginning of the 20th century in an Excel sheet
- Classification of the accidents (date, location, substance, type, origin, cause, population affected)
- Analysis of the classified accidents in order to establish trends and obtain reliable results

- Drawing conclusions and presentation of the main findings of the research according to the results obtained previously

In order to meet these objectives, the research has been organized as follows. Firstly, the shipping industry and the port sector in the world has been presented to give some context to the research. Then, in the following chapter, the most relevant European legislation related to port safety is presented. Afterwards, the most important characteristics of the methodology used to conduct this project are explained. In the following chapters, the results of the research are shown, followed by the demonstration of the sustainability and benefits of this project. Finally, the most important conclusions of this work are drawn and all the references used in this document are introduced.

2.2. Scope

Accidents occurred in European ports from 1919 until present have been analysed in detail to understand better their main characteristics and typology. Concerning the countries included in this research, documented accidents have been found in 21 EU countries (including all the EU members with coast except for Letonia). In addition, Switzerland has also documented inland port accidents that have also been taken into account. Finally, Norway, although it is not an EU member, has also registered some port accidents that have been included in this research.

It is important to explain what has been considered a “port accident”. It has been taken into account as a port accident any accident occurred within the limits of a port area or an accident of any mean of transport entering or leaving the port, which is not have to be always a ship. Consequently, any accident of a ship, train or truck beyond the boundaries of a port has not been considered, although they were carrying any kind of cargo to the port area. Moreover, despite the widespread view that a port must be in the coast, it can not be ignored that there are also inland ports, which have been also taken into account in this research. In fact, the inland navigation plays an important role in the European trade of goods thanks to the navigable rivers of Central Europe (e.g. Rhine river, Danube river or Seine river) [9].

It must be mentioned that MHIDAS [10], the most important database in the world concerning chemical accidents, stopped its activity in 2007. This supposed a notable loss of information concerning accidents in the world from 2007 on. For this reason and after researching in other databases, it was decided to include only European accidents to this study. The access to these accidents was ensured by the different EU databases that will be presented in this document. On the contrary, the information on accidents in the whole planet was not so trustable since there does not exist a global database of accidents involving chemical substances. Moreover, searching for accidents in a database can suppose a certain deviation in the results, as each database contains more detailed information about the country from where it is managed. As it will be seen in the results, a lot of accidents from France and UK have been collected because the databases from these countries are the most complete and reliable ones.

All the accidents compiled in the study involved chemical substances in order to point out the risks and consequences of transporting and manipulating this type of goods. This fact leaves out of the research any accident resulted with injured people or casualties without any relationship with chemical products (collapse of a building, ship impacts without any environmental damage, occupational accidents, etc.).

Finally, once all the accidents have been gathered, a specific research on the most recent accidents (from 1990 until nowadays) has also been conducted and both results have been compared with other previous works.

3. The importance of maritime industry and ports

In the following chapter, the impact of the maritime industry and, in consequence, the ports in the worldwide trade will be highlighted. Besides, it will be made a specific mention to the situation of European ports nowadays and their evolution.

3.1. Maritime transport and the shipping

Maritime transport is the transport of both people (passengers) and goods (cargo) by sea-going vessels [11]. Without shipping, the import and export of goods on the necessary scale for the modern world would not be possible. Shipping is the main mean of transport for international trade and it is estimated that 90% of world trade is transported by the shipping industry [12]. There are over 50,000 merchant ships trading internationally, transporting every kind of cargo, such as raw materials and commodities, finished goods, food or fuel. The world fleet is registered in over 150 nations, and manned by over a million seafarers [12]. Water transportation presents more advantages in transporting goods than road, rail and air transportation. The main strengths of maritime transport are: i) it is a more economic mode of transportation, consuming less energy per cargo moved, and therefore it is a more energy efficient transport, producing fewer exhaust emissions per tonne of cargo transported; and ii) it is a safer transportation method, having a lower frequency of accidents [13]. Below, these two advantages are explained in more detail.

In terms of energy efficiency, shipping is the clear leader compared to other transport modes. Since the costs of fuel currently account for up to 50% of operating costs [12], ship owners have a strong incentive to reduce their fuel consumption. The shipping industry has made efforts to increase fuel efficiency as a way of reducing shipping's environmental impact, for example conducting continual improvements in engines [14]. Figure 1 draws a comparison on the fuel efficiency by different transport modes. The graph shows that, by ship, one tonne of cargo travels 312 kilometres with one litre of fuel, being this one the most favourable options [1].

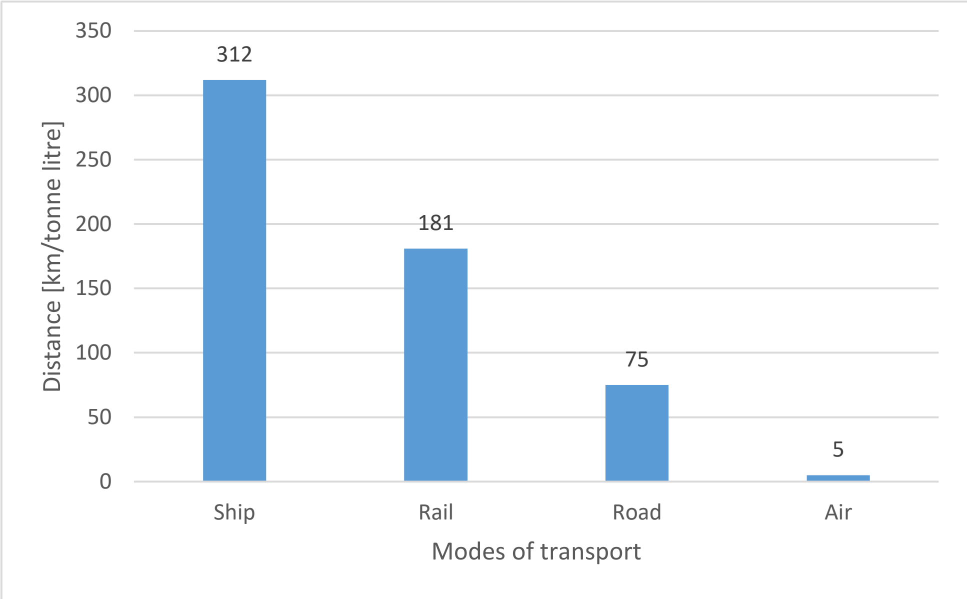


Figure 1. Comparison of the distance that one tonne travels with one litre of fuel [1].

In relation to this, shipping is also recognised as the most efficient form of commercial transport in terms of CO_2 emissions, compared to road vehicles and air transportation. As shown in Figure 2, shipping emits 10 grams of CO_2 per tonne of cargo transported for each kilometre. Nevertheless, it should be pointed out that the large scale of the shipping industry means that it is a significant contributor to the world's total greenhouse gas emissions, around 3% of total global CO_2 emissions [12].

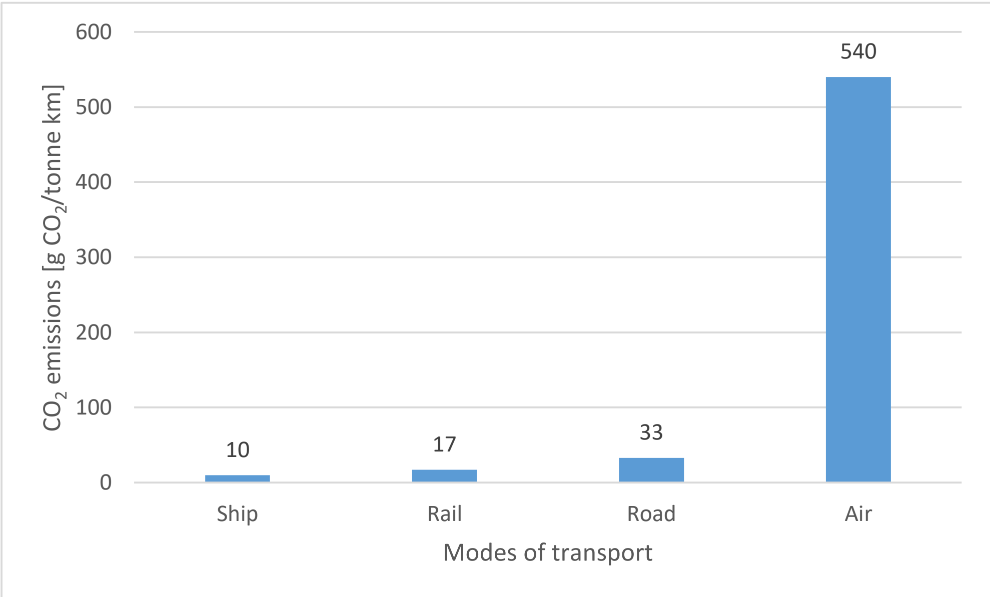


Figure 2. Comparison on the CO_2 emissions per tonne transported one kilometre [12] [1].

The maritime mode of transportation also compares very favourably when it comes to safety. As it is shown in Figure 3, ships have an average number of five accidents per billion tonne of cargo transported one kilometre, a number much lower compared to road transportation [15].

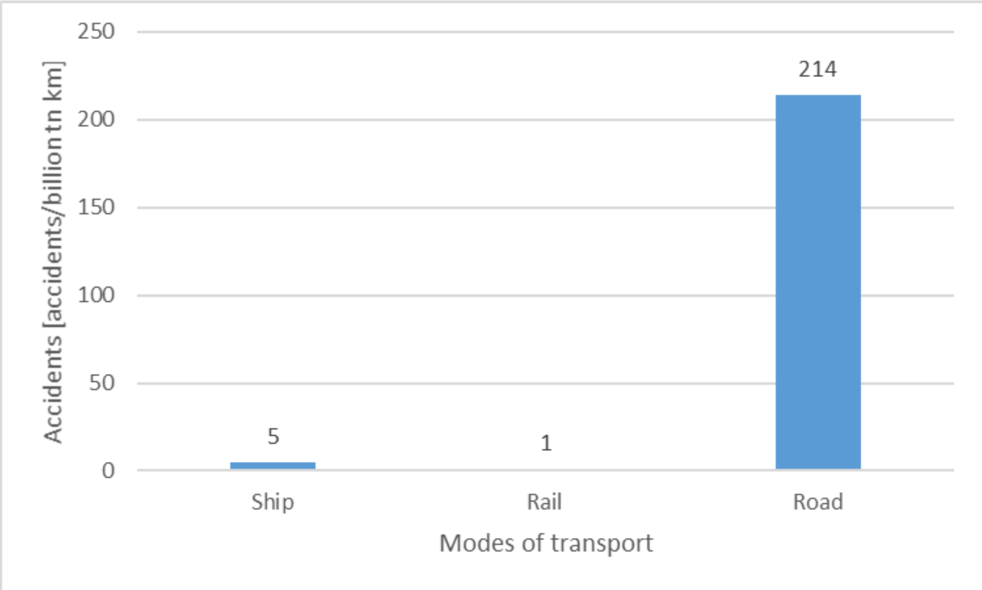
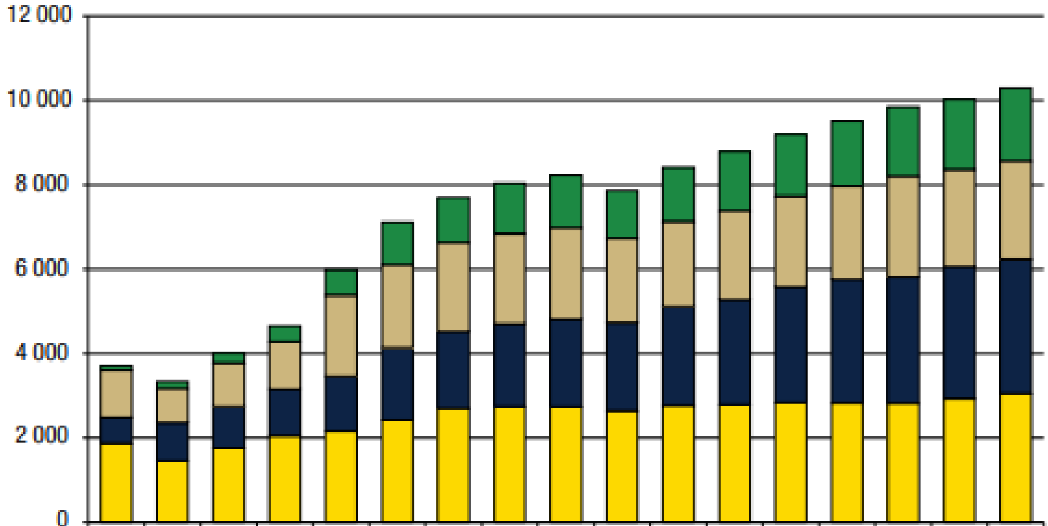


Figure 3. Comparison on the number of accidents per billion tonnes transported one kilometre [15].

The maritime transport, and more concretely ships, also pose other advantages compared to other means of transport. On one hand, there exist capacious vessels that can transport large amount of oil, containers or bulk cargo. This results on a higher efficiency in terms of human, economic and sustainable resources. On the other hand, there are ships suitable for all kind of cargo, such as LNG tankers, refrigerated cargo, bulk carriers, ro-ro, among others. This means that they are already prepared to carry any sort of commodity.

It is interesting to point out that shipping also contributes to reduce the road traffic congestion, since one marine ship is capable of carrying an average of 25,000 tons of cargo, equivalent to the capacity of 225 rail cars and 870 trucks [1] .This demonstrates that the use of water transportation is efficient to reduce traffic. This issue should be taken into account because it is strictly related to delays in transportation, increase of greenhouse gas emissions, and higher air contamination and noise.

Figure 4 below demonstrates that the world seaborne trade reached the total number of 10.29 billion tonnes in 2016, which is an increase of 2.6% compared to 2015 [16]. Globalisation and the rapid economic development in several parts of the world, such as China and India, are the major drivers of this shipping growth. Furthermore, the previsions indicate that this amount may double within the next 25 years [17] and may triple by 2060 [18].



	1980	1985	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Container	102	152	234	371	598	1 001	1 076	1 193	1 249	1 127	1 280	1 393	1 464	1 544	1 640	1 661	1 720
Other dry cargo	1 123	819	1 031	1 125	1 928	1 975	2 112	2 141	2 173	2 004	2 022	2 112	2 150	2 218	2 393	2 310	2 339
Five major bulks	608	900	988	1 105	1 295	1 711	1 814	1 953	2 065	2 085	2 335	2 486	2 742	2 923	2 985	3 121	3 172
Oil and gas	1 871	1 459	1 755	2 050	2 163	2 422	2 698	2 747	2 742	2 642	2 772	2 794	2 841	2 829	2 825	2 932	3 055

Figure 4. International seaborne trade (millions of tonnes) [16].

The figure demonstrates that the international seaborne trade has continued to raise in the recent years, although the existing global economic recession. The only year that it decreased during the last decade was in 2009, corresponding to the beginning of the economic downturn.

However, shipping requires some contact points between sea/river and land to be able to unload and load the transported products. These nodal points are ports, which play a crucial role in the logistic chain.

Besides, it is broadly acknowledged that over the last decades the international seaborne trade among EU member states and non-EU countries has increased massively, converting ports and harbours into important industrial centres.

3.2. The port sector

This section shows the evolution of the port industry over the recent years, initially from a global perspective and, secondly, from a European point of view. The information is mainly obtained from the United Nations Conference on Trade and Development [16] in the case of the global perspective, and from the Eurostat Statistics of the European Commission [19] in the European perspective.

As it has been shown before, shipping is recognised as the most efficient form of commercial transport in terms of CO_2 emissions, safety or energy efficiency, and ports play an essential role in the port sector. The traditional definition of a port is a shelter that allows the reception of ships. However, the concept of port has evolved rapidly in the recent decades. A detailed definition was proposed by European Commission [20] as "a port may be understood to be an area of land and water made up of such construction works and equipment as to permit, principally, the reception of ships, their loading and unloading, the storage of goods, the receipt and delivery of these goods to the hinterland, and the embarkation and disembarkation of passengers".

This definition is more comprehensive than the traditional one because it stresses that a port is not merely an organization that provides a single service, but instead many different activities are performed simultaneously within the "port area". In fact, a "port area" is characterized by a wide range of activities: whereas some of these activities are common to the majority of industrial areas (e.g. big oil terminals, presence of rail and road traffic, chemical and petrochemical plants, general manufacturing and industry), there are several activities that are to be encountered exclusively in a harbour setting. The latter involve all aspects of navigation and ships: loading and unloading of goods, oil jetties, shipyards, the presence of fishing fleets, marinas, dredging, the building of port infrastructures, etc. [21].

As a result, ports are complex organisations from all points of view: economically, socially, culturally, and administratively, because of the range of interests and responsibilities of the parties involved. Ports may differ very much in their size and the type of traffic. Some are highly specialised, serving only a specific industrial site, such as a refinery or a mine. However, most of them are open to calls by any kind of ships, regardless their ownership or origin [17]. These factors, in conjunction with the local geography and hydrography, imply that each port is unique [22].

There are more than 4,500 commercially active ports worldwide being the United States the country with the largest number of ports (552) [23]. According to the World Port Ranking 2016 [24], the top three world's busiest ports in terms of total cargo throughput are the Port of Shanghai (China), the Port of Singapore (Singapore) and the port of Guangzhou (China), as it can be seen in Table 1, which provides a top-20 ranking of the world's largest ports in terms of the total tonnage of their throughput. The first European port that appears on the ranking is the port of Rotterdam (The Netherlands) and it is located on the sixth position. The next EU port on the ranking is the port of Antwerp (Belgium), being located in the 17th position.

In Europe, there are more than 1,200 ports along the 100,000 kilometres of coastline, providing 1.5 million direct jobs, with the same amount employed indirectly [25]. Direct port employment is created through cargo handling services, ship operations and nautical services. Typical direct jobs include dock workers, ship agents, pilots, tug boat operators, freight forwarders, port authority employees, ship chandlers, warehouse operators, terminal operators and stevedores. Indirect jobs of ports' activities are, for example, jobs in local office supply firms, equipment suppliers, maintenance and repair, insurance companies, consulting and other business services.

Table 1.
World's largest ports in 2016 [24].

WORLD PORT RANKING				
TOTAL CARGO VOLUME				
TONS, 000s				
RANK	**PORT**	**COUNTRY**	**MEASURE**	**TONS**
1	Shanghai	China	Metric Tons	647.446
2	Singapore	Singapore	Freight Tons	593.297
3	Guangzhou	China	Metric Tons	544.374
4	Port Hedland	Australia	Metric Tons	484.510
5	Ningbo	China	Metric Tons	469.025
6	Rotterdam	Netherlands	Metric Tons	461.177
7	Qingdao	China	Metric Tons	443.978
8	Tianjin	China	Metric Tons	428.098
9	Busan	South Korea	Revenue Tons	349.708
10	Dalian	China	Metric Tons	318.413
11	Kwan yang	South Korea	Revenue Tons	283.106
12	Hong Kong	China	Metric Tons	256.730
13	South Louisiana	United States	Metric Tons	237.594
14	Port Kelang	Malaysia	Metric Tons	235.457
15	Xiamen	China	Metric Tons	234.197
16	Houston, TX	United States	Metric Tons	224.969
17	Antwerp	Belgium	Metric Tons	214.170
18	Nagoya	Japan	Freight Tons	193.257
19	Shenzhen	China	Metric Tons	189.509
20	Itaqui	Brazil	Metric Tons	179.914

In EU ports, the total gross weight of goods handled was estimated at close to 3.9 billion tonnes in 2016 [19], as demonstrated in Figure 5. In this case, the graph also shows a lightly increase (+0.5%) compared to 2015; however, the gross weight of goods handled in 2016 was still lower than the annual volumes handled before the economic downturn in 2009. The EU seaborne trade accounts for 38.6% of the total world seaborne trade. Figure 5 also shows the quarterly evolution for 2015 and 2016 for EU -28 main ports.

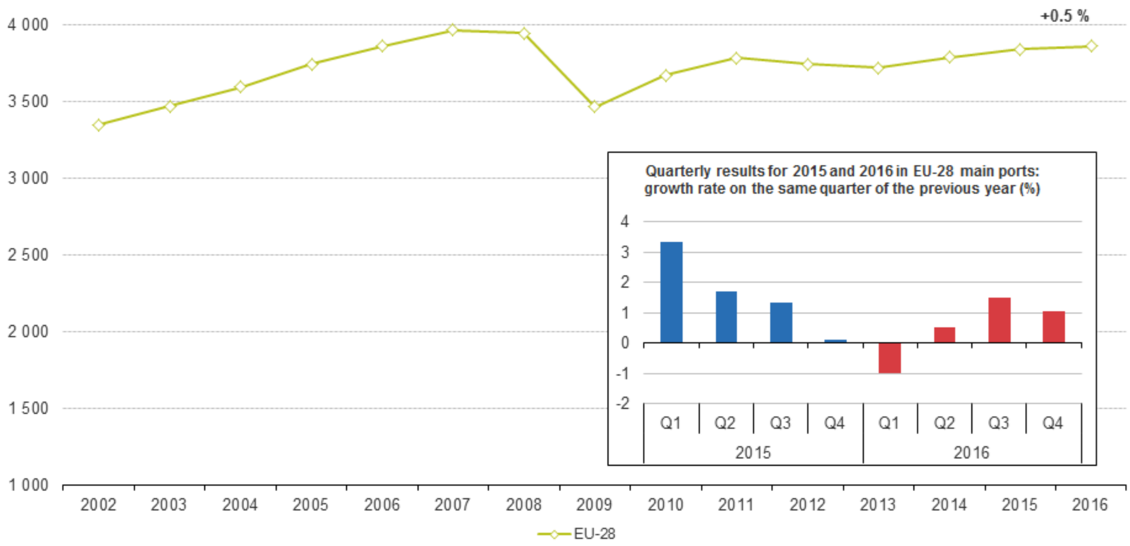


Figure 5. Gross weight of goods handled in EU ports [19].

The Eurostat Statistics [19] specifies that the ports of Rotterdam, Antwerp and Hamburg (all located on the North Sea coast) maintained their positions as the top three ports in Europe in 2016, in terms of both the gross weight of goods and the volume of containers handled. These three ports are clearly ahead the rest of European ports, as it can be seen in Figure 6, which shows the top 10 European ports on the basis of volume of containers handled in 2016. Rotterdam on its own accounted for close to 10% of the total tonnage of goods handled, Antwerp for more than the 4%, and Hamburg for almost the 3% [19]. With regards to containers, Rotterdam handled 11.7 million Twenty-foot Equivalent Units (TEUs) in 2016, which equals to 11% of the total EU containers handled. It was followed by Hamburg with 9.9 million TEUs (9.3%) and Antwerp with 8.9 million TEUs (8.4%) [19].

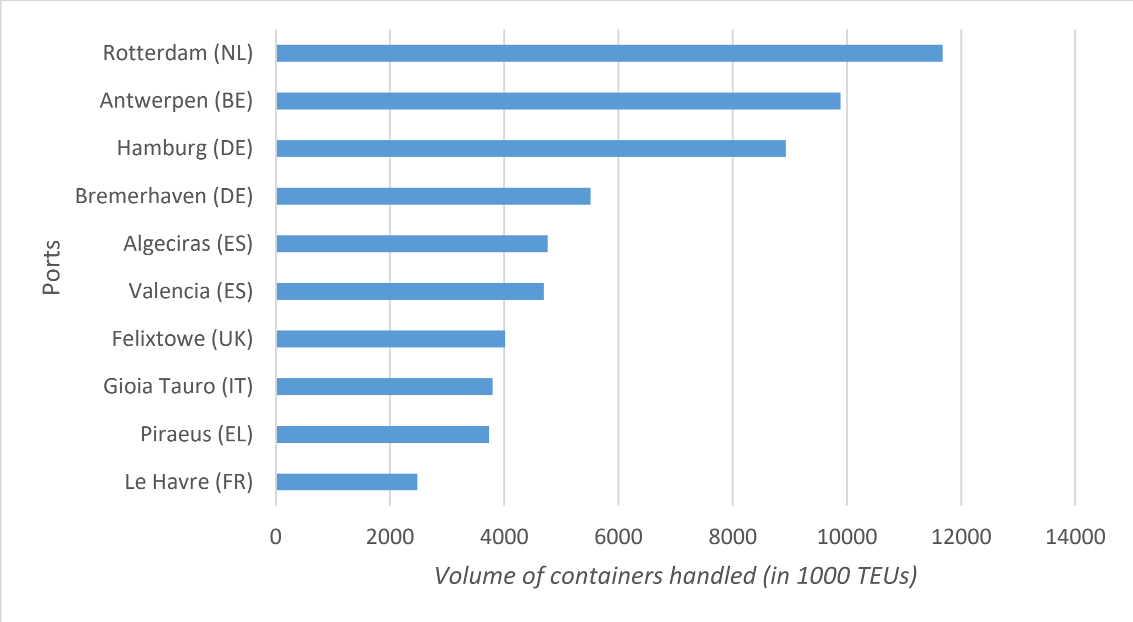


Figure 6. Top 10 European ports on the basis of volume of containers handled in 2016 [19].

All these top three cargo ports recorded increases in the tonnages handled in 2016 with respect the previous years. Whereas Rotterdam saw an increase of 0.8% in total tonnage from 2015, Antwerp and Hamburg recorded a growth of 5.6% and 0.9% respectively [19]. Most of the top 20 EU container ports reported an increase in the number of TEUs handled in 2016. The largest increases were recorded by the ports of Gdansk in Poland (+49.7%), London in United Kingdom (+26.0%) and Gioia Tauro in Italy (+25.3%). Only three of the top 20 ports reported handling a lower volume of TEUs in 2016 than in the previous year: Le Havre (-3.1%) and Marseille (-0.5%) in France and Felixstowe in United Kingdom (-0.7%). This information is included in Figure 7, where it can be seen the evolution of the top ten container ports on the basis of volume of containers handled. As it shows, the global economic recession of 2009 also affected the most important European ports but, since then, their tendency has continue growing and they have increased their volume of containers handled above pre-crisis numbers.

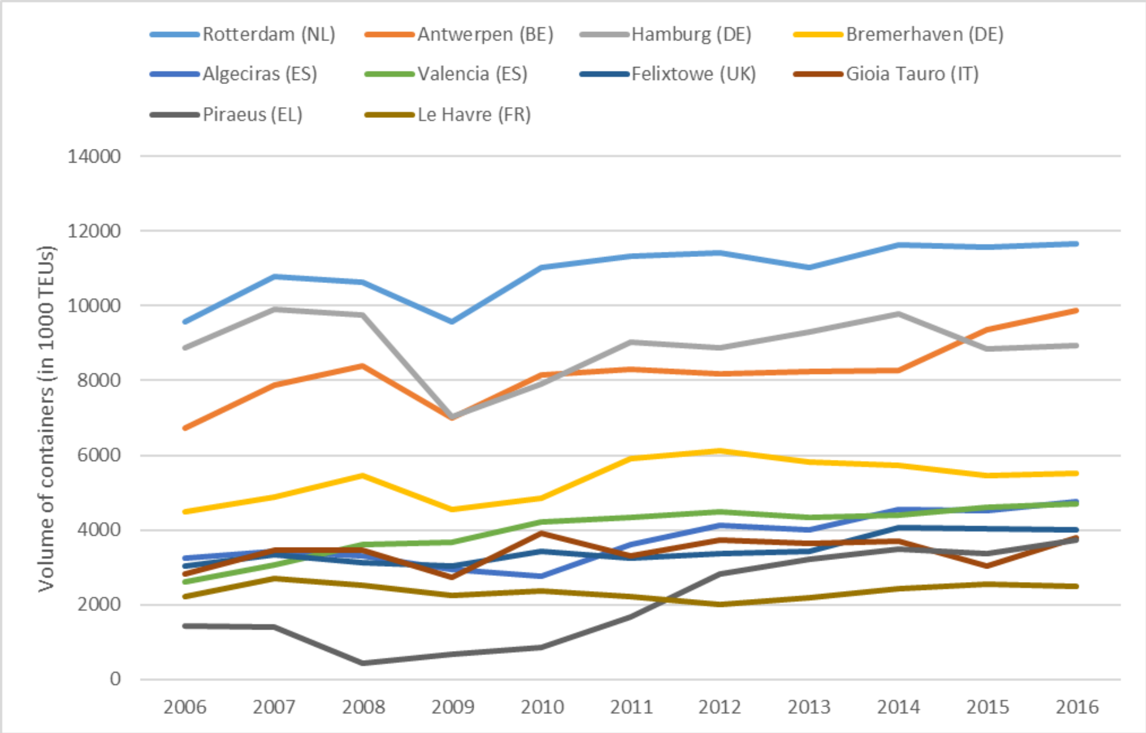


Figure 7. Evolution of top 10 container ports in Europe on the basis of volume of containers handled [19].

All this maritime traffic in European ports may generate accidents, as it has been mentioned before. The risk of an accident in any port that could damage the environment or affect human lives is always present. In order to avoid these situations, the European authorities have developed in the last decades specific legislation about port safety. In the next chapter, some of the most relevant directives and laws are presented.

4. Legislation

Throughout the last decades, different directives and regulations have been set by European and international institutions in order to ensure safety and the normal operation in port activities, as well as to avoid or minimize the probability of an accident. Among this legislation, the Seveso directives and other European Commission directives are the most relevant to the concerning issue of this study.

4.1.1. Seveso Directives

In Europe, the catastrophic accident in the Italian town of Seveso in 1976 prompted the adoption of legislation on the prevention and control of such accidents. On the afternoon of Saturday, July 10, 1976, a chemical plant was getting dangerously hot as cooling mechanisms were turned off. When the temperature inside one of the plant's tanks reached a critical level, a pressure release valve opened, and about six metric tons of toxic gas were emitted from the facility. The resulting gas cloud that drifted over the Seveso area contained an estimated one kilogram of TCDD, technically known as 2,3,7,8-tetrachlorodibenzodioxin. Within a few hours after the gas release, over 37,000 people throughout the Seveso area were exposed to unprecedented levels of dioxin, universally recognized as a carcinogen (a cancer-causing agent) [26]. As a consequence, a European directive called Seveso Directive was released in 1982 in order to regulate the safety measures that must be taken account in chemical plants that manipulate hazardous substances.

The so-called Seveso-Directive (Directive 82/501/EEC) was later amended in view of the lessons learned from later accidents such as Bhopal, Toulouse or Enschede resulting into Seveso-II (Directive 96/82/EC). In 2012, Seveso-III (Directive 2012/18/EU) was adopted taking into account, amongst others, the changes in the Union legislation on the classification of chemicals and increased rights for citizens to access information and justice. The Directive applies to more than 12.000 industrial establishments in the European Union where dangerous substances are used or stored in large quantities, mainly in the chemical and petrochemical industry, as well as in fuel wholesale and storage (incl. LPG and LNG) sectors.

Ports also include chemical storage areas, industries and other activities. Therefore, they are also affected by the Seveso directives. Considering the very high rate of industrialisation in the European Union the Seveso Directive has contributed to achieving a low frequency of major accidents. The Directive is widely considered as a benchmark for industrial accident policy and has been a role model for legislation in many countries world-wide [27].

4.1.2. Directive 2008/68/EC - inland transport of dangerous goods

This directive lays down common rules for the safe and secure transport of dangerous goods within and between EU countries by road, rail or inland waterway. It also covers aspects such as loading and unloading, the transfer to and from another mode of transport, as well as the stops in the course of the transport process. It extends the application of international rules to national transport of dangerous goods [28].

Transport of dangerous goods needs to be regulated in order to prevent, as far as possible, accidents to persons or property and damage to the environment, the means of transport employed or to other goods. However, with different regulations in every country and for different modes of transport, international trade in chemicals and dangerous products would be seriously impeded, if not made impossible and unsafe. Moreover, dangerous goods are also subject to other kinds of regulations, e.g. work safety regulations, consumer protection regulations, storage regulations, environment protection regulations [29]. According to this Directive, the majority of Member States are contracting parties to the European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR), subject to the Regulations concerning the International Carriage of Dangerous Goods by Rail (RID) and, in so far as is relevant, contracting parties to the European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways (ADN) [29]. Next, each one of these regulations is explained.

4.1.2.1. ADR

The European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR) was done at Geneva on 30 September 1957 under the auspices of the United

Nations Economic Commission for Europe, and it entered into force on 29 January 1968. A further revision applies from 1 January 2017 [30].

Under the European Communities (Carriage of Dangerous Goods by Road and Use of Transportable Pressure Equipment) Regulations 2011 to 2017 “the carriage of dangerous goods by road” is defined as any road transport operation performed by a vehicle wholly or partly on public roads, including the activity of loading and unloading, packing and filling, covered by the ADR.

The Regulations principally apply to the carriage of dangerous goods by road, in tanks, in bulk and in packages, in accordance with the provisions contained in the technical Annexes to the ‘European Agreement Concerning the International Carriage of Dangerous Goods by Road' (ADR) [30]. The substances legislated under the transport of hazardous materials regulations are classified in 9 categories depending on the hazard they represent, as it is shown in Figure 8 [31]. Besides the foresaid categories, the transport of hazardous materials considers 3 different types of packaging groups, which are differentiated according to the hazard of the product. The substances regulated by the transport of hazardous substances legislation have shipping names and UN numbers properly standardized [31].

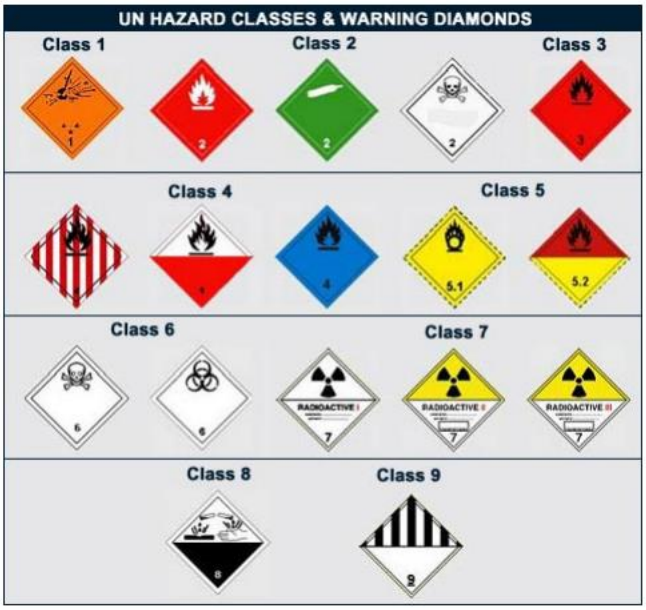


Figure 8. Symbols for warning of dangerous chemicals [32].

4.1.2.2. ADN

The European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways (ADN) was done at Geneva on 26 May 2000 on the occasion of a Diplomatic Conference held under the joint auspices of the United Nations Economic Commission for Europe (UNECE) and the Central Commission for the Navigation of the Rhine (CCNR). It entered into force on 29 February 2008.

The Regulations annexed to the ADN contain provisions concerning dangerous substances and articles, provisions concerning their carriage in packages and in bulk on board inland navigation vessels or tank vessels, as well as provisions concerning the construction and operation of such vessels. They also address requirements and procedures for inspections, the issue of certificates of approval, recognition of classification societies, monitoring, and training and examination of experts [33].

4.1.2.3. RID

RID (Regulation concerning the International Carriage of Dangerous Goods by Rail**)** was drawn up by the intergovernmental Organisation for International Carriage by Rail (OTIF), comprising 46 member countries and it is established on European territory through European directive 2008/68/EC. To ensure safety and protect the environment, RID sets out a list of dangerous goods which may, subject to a number of rules, be carried from loading to delivery site [34].

4.1.3. Other EU port directives and regulations

Along with the legislation mentioned before, the European Commission has determined a set of directives with the purpose of regulating and ensuring the safety and the normal operation of the port activities:

- Directive 2009/16/EC of the European Parliament and of the Council of 23 April 2009 on port State control (Recast) [35]

- Regulation (EC) No 1406/2002 establishing European Maritime Safety Agency [36]

- Directive 2009/45/EC on safety rules and standards for passenger ships [37]
- Regulation (EC) No 336/2006 on the implementation of the International Safety Management Code within the Community and repealing Council Regulation (EC) 3051/95 [38]
- Directive 2003/25/EC on specific stability requirements for ro-ro passenger ships [39]
- Directive 2001/96/EC establishing harmonised requirements and procedures for the safe loading and unloading of bulk carriers [40]
- Directive 1997/70/EC setting up a harmonised safety regime for fishing vessels of 24 metres in length and over [41]
- Regulation (EC) No 2099/2002 establishing a Committee on Safe Seas and the Prevention of Pollution from Ships (COSS) and amending the Regulations on maritime safety and the prevention of pollution from ships [42]

5. Methodology

In the following chapter, the methodology used to conduct this research is shown. This methodology can be divided in two parts: the bibliographic research and the classification of the accidents. This methodology is essential to be able to draw some results and conclusions in this project.

5.1. Bibliographic research

The survey has been performed by using both databases and other sources of information such as reports, websites or journals. Databases have been really useful tools to conduct this research, as their information is very reliable. The use of reports, websites or journal have completed the bibliographic research of this project, filling the gaps of information that databases could have.

5.1.1. Databases

The use of incident reporting databases is widespread in many domains such as industry, transportation, and health care since this tool is a very efficient way of compiling information. However, some databases are now publicly not available (MHIDAS [10] or FACTS [43]), which resulted in an important loss of information and an added difficulty to this project.

The operation of databases is very similar one to each other, but, at the same time, each one has its characteristics. In order to find the accidents a key word search has been conducted, using port related words such as: “port”, “harbour”, “transhipment”, “port terminal”, “dock”, “pier”, “yatch”, etc. In databases, accidents can also be found by year or country. Once the accidents have been gathered, each one has been analysed in detail to be sure that it was an accident occurring in a port and involving chemical substances.

Examples of databases that have been used are:

- **Analyse Recherche et Information sur les Accidents (ARIA)**

This is the main database from where the information about accidents has been gathered. It was created in 1992 by the French Ministry of Regional Planning and the Environment. ARIA has inventoried over 46,000 accidents and incidents occurring in France or abroad and around 1,200 new events are added to the database each year [44].

The ARIA (Analysis, Research and Information on Accidents) database (Figure 9) catalogues incidents or accidents that were, or could have been, deleterious to human health, public safety or the environment. These events stem from:

- Activities carried out at plants, workshops, warehouses, construction sites, quarries, breeding farms, etc. cited in legislation specific to Classified Facilities
- Transport of hazardous materials by rail, road, river/canal or sea
- Gas distribution and use
- Operations of pressurised equipment
- Mines and underground storage facilities
- Dykes and dams

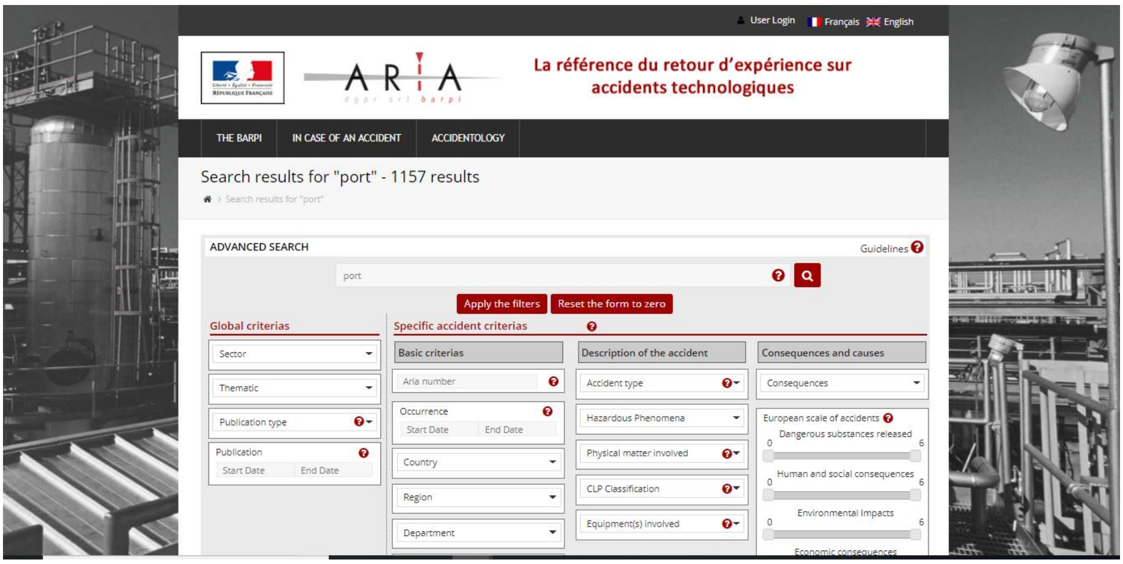


Figure 9. ARIA database [44].

As it can be seen, the ARIA database includes an important amount of information about accidents in many locations. However, according to the scope of the project, the search on the ARIA database has been limited only to ports and hazardous substances.

- **The Major Hazard Incident Data Service (MHIDAS)**

Along with the ARIA database, MHIDAS [10] is the source of most of the accidents that have been compiled in this work. Until it stopped its activity in 2007, MHIDAS used to be the most important database involving chemical substances. The MHIDAS database was developed and managed by the safety and reliability directorate (SRD) that belongs to the UK health and safety executive (HSE) and it included accidents that have occurred in 95 countries since the beginning of the 20th century [10]. The version used, in which there were 14,253 records of accidents, was last updated in November 2007.

In Figure 10 it can be seen an example of a search in this database. MHIDAS includes many categories in order to classify the accidents occurred since the beginning of 20th century by date, location, type, origin and many other categories. In this work, the way to find accidents occurred in European ports was introducing key words such as “port”, “harbour” or “dock”. If a specific search on the accidents occurred since 1990 on was required, it was possible to define this limitation. Once all the accidents were shown, it has been necessary to read the brief abstract of each accident in order to be sure that the accidents were in line with the scope of the project.

For many other studies (Darbra and Casal [4], Ronza et al. [21], Vílchez et al. [45]), MHIDAS has been the main database from where the information was compiled. As it has been mentioned before, MHIDAS is no longer available, and this fact has been determinant to take the decision of using other databases like ARIA.

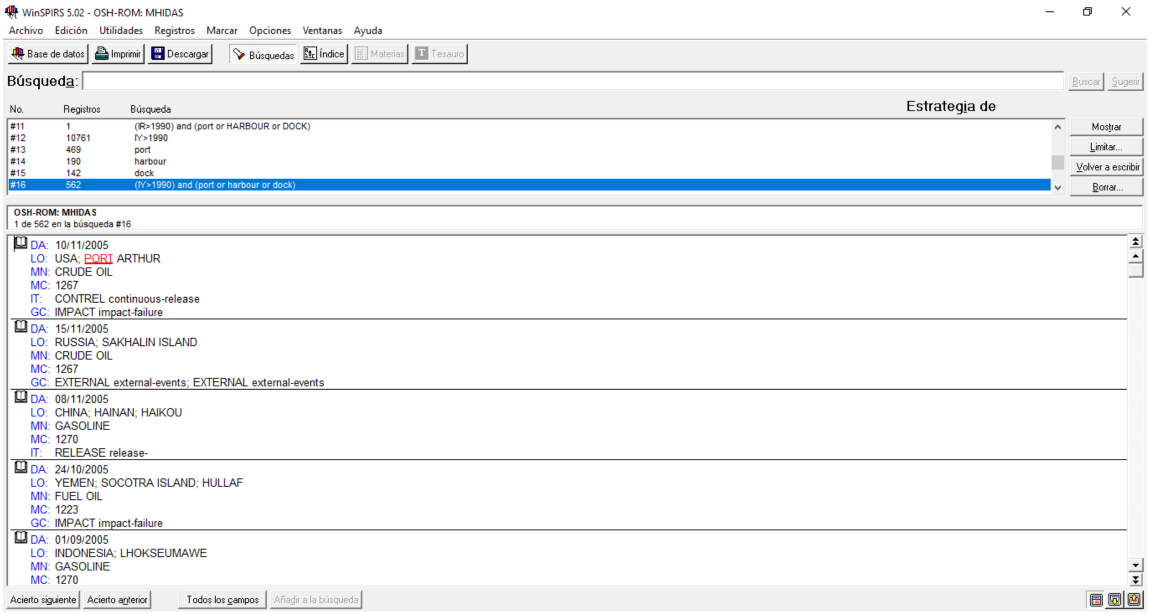


Figure 10. MHIDAS database [10].

- **The Failure and Accidents Technical Information System (FACTS)**

FACTS is the acronym for "Failure and Accidents Technical information System" [43]. FACTS is an accident database which contains information on more than 25,700 (industrial) accidents (incidents) involving hazardous materials or dangerous goods that have happened all over the world during the past 90 years. The accidents are coded in abstracts making the existing data suitable for risk analysis, risk management, damage prevention and statistics. The abstracts are very accessible, so that even the most complex accidents are easy to comprehend.

The FACTS chemical accident database was a product of TNO Industrial and External Safety, but the exploitation of the database is no longer done by TNO. The maintenance and exploitation of the database are continued by the Unified Industrial & Harbour Fire Department in Rotterdam-Rozenburg [43].

- **The Major Accident Reporting System (eMars)**

The Major Accident Reporting System (MARS and later renamed eMARS after going online) was first established by the EU's Seveso Directive 82/501/EEC in 1982 and has remained in place with subsequent revision to the Seveso Directive in effect today [46]. The purpose of the eMARS is to facilitate exchange of lessons learned from accidents and near misses involving dangerous substances in order to improve chemical accident prevention and mitigation of potential consequences. For non-EU OECD and UNECE countries, reporting accidents to the eMARS database is voluntary. The information of the reported event is entered into eMARS directly by the official reporting authority of the country in which the event occurred. This database includes accidents concerning hazardous materials in Europe from the beginning of the 20th century and its operation is very similar to MHIDAS or ARIA.

- **The Global Integrated Shipping Information System (GISIS)**

The Global Integrated Shipping Information System is managed by the International Maritime Organization (IMO). This is the United Nations specialized agency with responsibility for the safety and security of shipping and the prevention of marine pollution by ships. IMO is the global standard-setting authority for the safety, security and environmental performance of international shipping. Its main role is to create a regulatory framework for the shipping industry that is fair and effective, universally adopted and universally implemented. In other words, its role is to create a level playing-field so that ship operators cannot address their financial issues by simply cutting corners and compromising on safety, security and environmental performance [47].

In this database, accidents from all over the world since 1900 concerning shipping activities are described. These data can be selected in terms of incident date, flag of the ship or the country where the accident occurred. It must be taken into account that shipping accidents do not always involve port accidents as an accident can occur miles away the coast, so, in order to select the accurate information for this project, the description of the accidents must had been carefully read to ensure that an accident could be included in the study.

5.1.2. Other sources

Although the aforementioned databases provide a lot of information, they also have some limitations. When analysing a specific accident in these databases the information is often incomplete, the description is rather short and details on the accident sequence are lacking. In other cases, there are certain accidents that are not available in the databases and due to the stoppage of their activity, the latest accidents must be consulted in other sources. For example, MHIDAS can be accessed only after paying a substantial fee. Moreover, it is not infallible and has some inaccuracies. This requires a detailed search for specific information on most accidents, which can be performed by consulting accident reports from different sources, such as the following ones:

- **European Maritime Safety Agency**

The European Maritime Safety Agency is one of the EU's decentralised agencies. Based in Lisbon, the Agency provides technical assistance and support to the European Commission and Member States in the development and implementation of EU legislation on maritime safety, pollution by ships and maritime security. It has also been given operational tasks in the field of oil pollution response, vessel monitoring and in long range identification and tracking of vessels. Its aim is to ensure a high, uniform and effective level of maritime safety, maritime security, prevention of, and response to, pollution caused by ships as well as response to marine pollution caused by oil and gas installations. A major political impetus to the setting up of EMSA in 2002 was the fallout from the *Erika* (1999) and the *Prestige* (2002) accidents and their resulting oil spills. [48].

This agency provides a set of annual reports and documents in its website concerning incidents in European coasts that have been very useful to complete the research with some accidents that did not appear in the previously mentioned databases.

- **Maritime Herald**

Maritime Herald is leading news journal about shipping, maritime transport and offshore business. The website is world leader in maritime news, providing the latest information about world shipping and includes reports on different topics such as seaport accidents, environmental issues or piracy [49]. In this website, the accidents are classified chronologically and there is no possibility of using key words to improve the search.

- **Centre of Documentation, Research and Experimentation on Accidental Water Pollution (Cedre)**

Cedre is a French public service association. It was created on 25 January 1979 as part of the measures taken following the sinking of the oil tanker *Amoco Cadiz* to improve the preparation for the fight against accidental water pollution and strengthen the French intervention system. It is responsible at the national level for the documentation, research and experiments concerning pollutants, their effects, and the specialized methods and means used to combat them. Its mission of advice and expertise encompasses both marine and inland waters and the head office is located in Brest's port and industrial zone [50].

Almost 40% of Cedre's funding is provided by a State subsidy managed by the French Ministry of Ecology. This grant is earmarked to cover our activities within the scope of our public service mission. The remaining 60% comes from agreements and contracts with:

- French public organisations: State, administrations, local authorities, public establishments,
- the European Union,
- French and foreign private businesses: industrial companies and professional bodies

This webpage includes accidents of the shipping industry from all over the world and they are ordered alphabetically, chronologically and by the spill area. Within this last category, accidents are gathered in five subcategories: offshore, inshore, on land, inland waters and port/harbour.

5.2. Classification of the accidents

Once all the accidents have been collected, they have been gathered in an Excel sheet in order to ease their classification and manipulation. The classification of the 654 accidents is based on the fields used by the MHIDAS database. However, it has been impossible to fill all the fields as in most cases the information from databases is incomplete. In Table 2, a description of the fields used in this work is shown.

Table 2.
Descriptions of the fields used to classify the accidents.

CLASSIFICATION OF THE ACCIDENTS		
Abbreviation	**Definition**	**Description**
AN	Accident number	Every database assigns each accident with a code. Each code includes a letter to identify those accidents from other sources (e.g. A1234 for ARIA and 1234 for MHIDAS)
DA	Date	Date of the accident
YEAR	Year	Year of the accident
ID LO	Location	Location where the accident happened (city and country)
COUNTRY	Country	Country where the accident happened
ID PD	Population density	Population density of the area affected. It is divided in three categories: Urban, Village and Rural. Not very common
MN	Material name	Name of the substance(s) involved in the accident
IT	Incident type	Type of the accident
OG	Origin	Origin of the accident
GC	General cause	General cause of the accident
SC	Specific cause	Specific cause of the accident
KR	Killed	Number of deaths in the accident
IR	Injured	Number of injured in the accident
ER	Evacuated	Number of people injured in the accident
NP	People affected	The sum of the people killed, injured and evacuated
DG	Damage	Estimation (in millions of dollars) of the damage caused by the accident. Not very common
IG	Ignition time	Time (in seconds) between the start of the leakage and the start of the ignition. Not very common
AB	Abstract	It includes a brief description of the accident

The use of an Excel sheet has allowed to make a better classification of all the accidents as it can be seen in Figure 11.

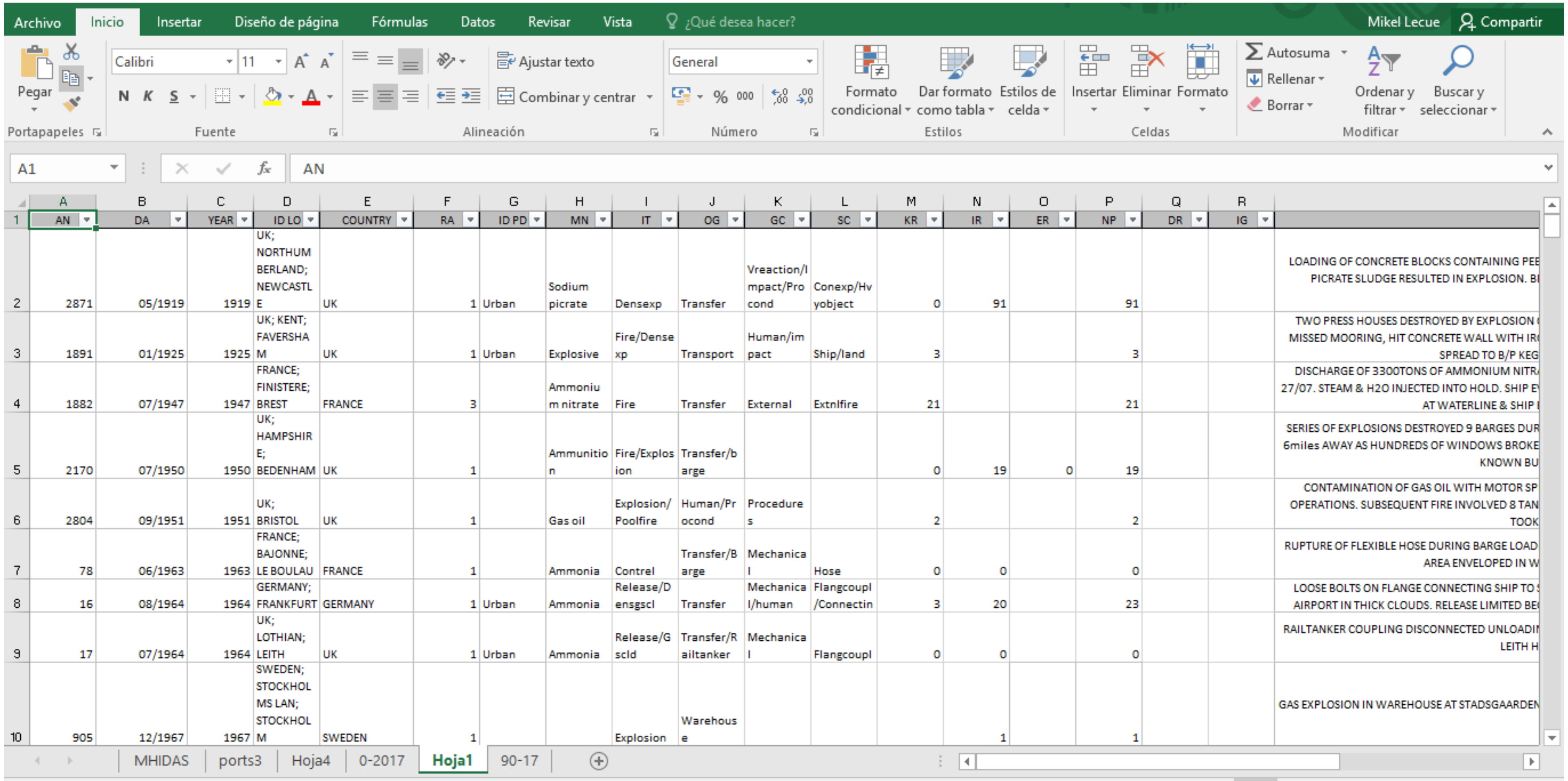


Figure 11. Excel sheet used to classify the accidents.

The number of accidents gathered is very high (654) and each accident can have 18 fields as it is shown in Table 2. In total, 11,772 possible Excel cells. Therefore, this is huge quantity of information that must be well organized. Another possibility could have been the use of an Access sheet to classify and store all this information, but it was decided not to use it because of the simplicity of an Excel and its easiness in terms of handling of information.

As it can be seen in Figure 12, one of the advantages of gathering the information in an Excel sheet is the possibility of filtering data. This tool has been very useful to identify the accidents from 1990 on or analyse the type, causes or origin of them.

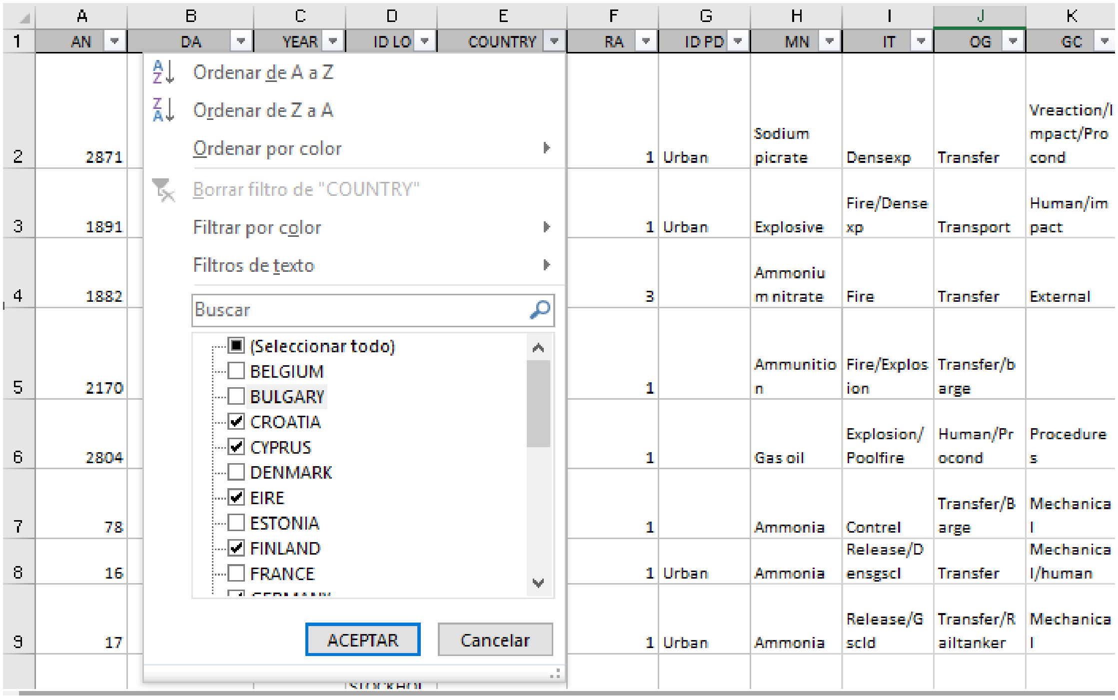


Figure 12. Example of filtering of information

Once all these accidents have been classified and completed with the available information, it has been possible to start with the analysis of the results, which are presented in the next chapter.

6. Results

The aim of the study is not only to make a historical research of accidents in European ports from the beginning of 20th century on, but also to focus on the accidents occurred in the last decades to verify the impact of the safety measures taken in Europe and identify the most sensitive points of the maritime industry. For this reason, a comparison between the historical trends and the tendency in the last 27 years (since 1990) has been presented in the following results.

6.1. Distribution of accidents over the time

As it can be seen in Figure 13, around 80% of the documented accidents occurred in Europe in port areas have happened after 1990. This can be explained by two reasons: the increase of traffic in the recent years [16], but on the other hand, a better access to this type of information in the last decades.

It is also interesting to notice the decrease of accidents in the new century. Until the 1990s the number of documented accidents increased exponentially, but since the beginning of 21st century the number of accidents decreased. As it is shown in Figure 13, in the 1990s there were documented 268 accidents, in the 2000s 168 accidents and in the current decade the trend is to register less than 100 accidents in the European ports. The decreasing accident rate since 2000 could be explained by general improvements in the safety culture of the chemical industry brought about by strict new regulations (e.g. EU directives) and more effective operator training; for example, prompt action in the event of an accident could prevent propagation and the development of a domino effect. The increasing automation of industrial facilities may also have helped to reduce the number of accidents.

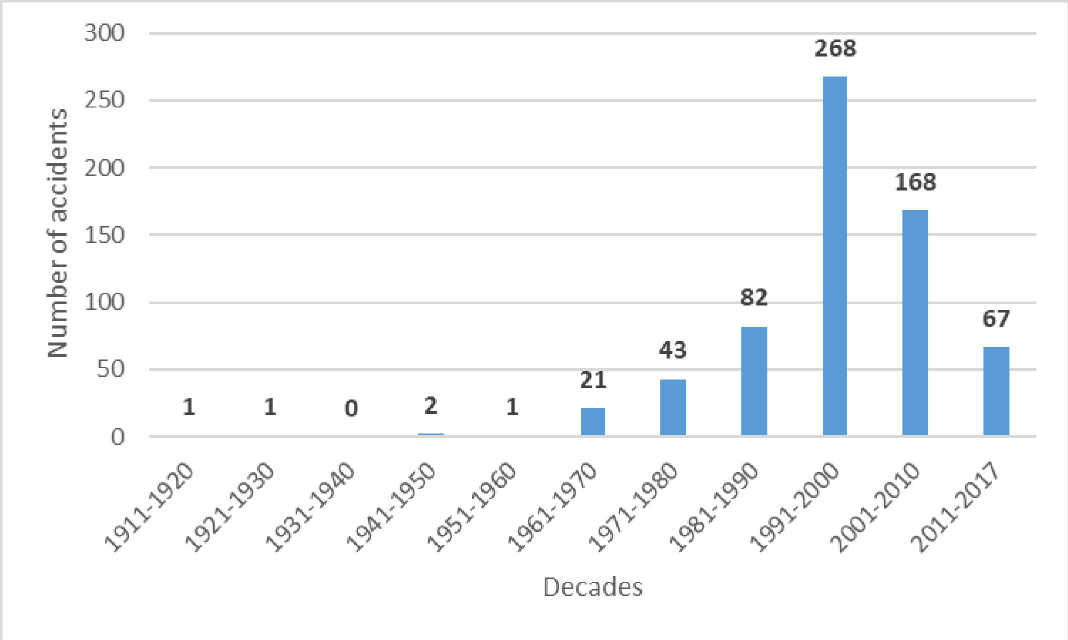


Figure 13. Distribution of accidents by decades

6.2. Location of the accidents

As it has been mentioned in Chapter 2.2., documented accidents have been found in 21 EU countries (including all the EU members with coast except for Letonia). In addition, Switzerland has also documented inland port accidents that have also been taken into account. Finally, Norway, although it is not an EU member, has also registered some port accidents that have been included in this research due to its undeniable economic ties with some European countries.

Concerning the location of the accidents and according to Figure 14, France is the country with the highest percentage of accidents (29.9%), followed by United Kingdom (25.8%). This seems logical as these countries afford a high percentage of all the maritime activity in Europe [19], but it should not be ignored the resulting deviation of using databases from these two countries as it has been mentioned before. Other countries where several accidents have occurred are Germany (6.3%), Netherlands (5.9%) and Spain (4.9%), which also hold some of the most important ports in Europe.

As it can be seen in Figure 14, UK used to be the European country with the higher accident rate in seaports until 1990, whereas France is the country with the greatest number of accidents if the study is extended until now. However, this information can be affected by the fact that MHIDAS (managed by UK) stopped its activity some years ago whereas ARIA (managed by France) is still available.

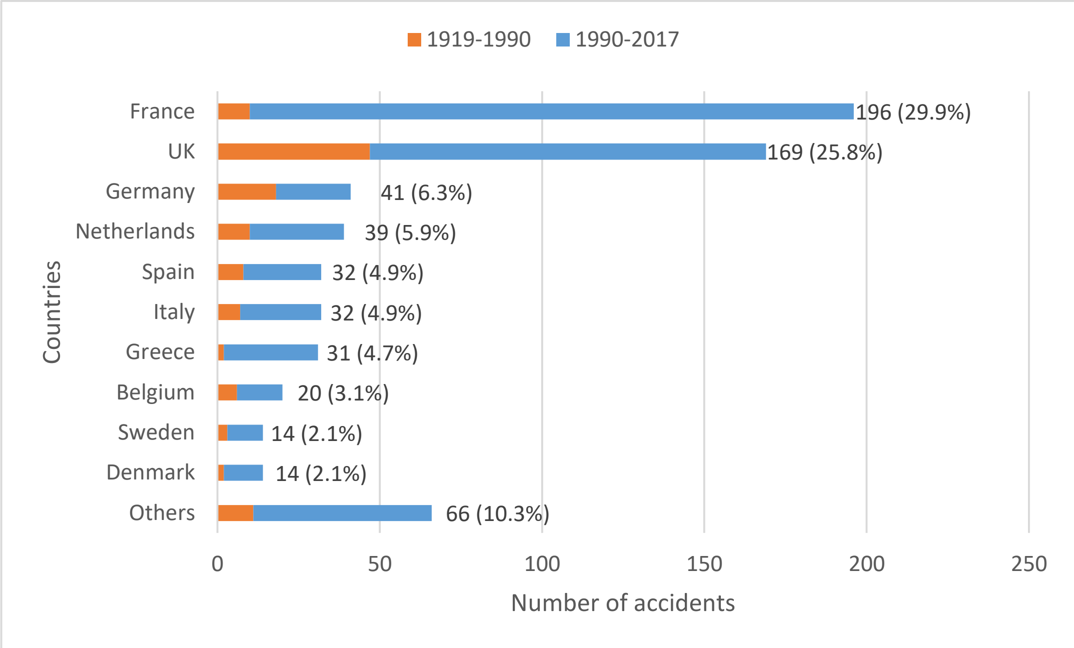


Figure 14. Location of the accidents.

6.3. Substances involved

Regarding the substances involved in the accidents, they are, in more than half of the cases (56.8%), oil or derivates, such as fuel oil, crude oil and other hydrocarbons as it can be seen in Table 3. These results are similar to those obtained by Ronza et al [21], where 59% of the worldwide accidents involved oils or hydrocarbons. This could be explained because in a port many times oil products are manipulated, for example, when bunkering a ship, when loading or unloading hydrocarbons or in a petrochemical company located in the port.

Other products usually involved in the accidents are mainly chemicals (24%). Among these chemical the most frequent substances are chlorine, ammonia and methanol, typical substances of the chemical industry, which uses ships or trains to transport its products. In third place appear acids (3.2%) and then natural gas (2.6%).

Table 3.
Substances involved.

Substance	Number of accidents	(%)
Oil or derivates	**370**	**56.8**
Fuel oil/Gasoline	119	32.2
Crude oil/Petrol	93	25.1
Lubricants	32	8.7
Diesel	26	7.0
Chemicals	**159**	**24.0**
Chlorine	18	11.3
Ammonia	14	8.8
Methanol	13	7.8
Nitrogen	12	7.6
Sodium	8	5.0
Acids	**21**	**3.2**
Natural gas	**17**	**2.6**
Others	**87**	**13.3**

6.4. Origin of the accidents

As it can be seen in Figure 15, above 40% of the accidents occurred during transport operations. It should be noted that the ‘‘transport’’ category includes all accidents that occurred in moving ships (entering or leaving the port), in the manoeuvring and approaching of ships within the port boundaries, and in lorries or trains entering or leaving port facilities. Taking into account that one of the basic functions of ports is precisely the movement of goods, it is no surprise to find out this percentage. In addition, and for the same reason, it is also logical that 31,5% of accidents have occurred during transfer operations (loading and unloading cargo), a typical activity in a port. These operations must be considered highly dangerous, not only because of the large amounts of hazardous substances that are manipulated, but also because of the decisive influence of the human factor during these operations. In total, it can be stated that more than 70% of the accidents occur in typical port activities. Other origins are storage areas and process plants, being around 20% of the total of the port accidents. These results are in line with the study of Ronza et al. [21].

Transfer used to be more important in the past than transport, as it can be seen in Figure 15. This trend has slightly changed in the last decades due to the fact that new safety measures have been taken to ensure safety loading and unloading. Among these measures, automation of operations plays a big role. However, accidents during transport have grown spectacularly during the last years and this point should be taken into account by port authorities.

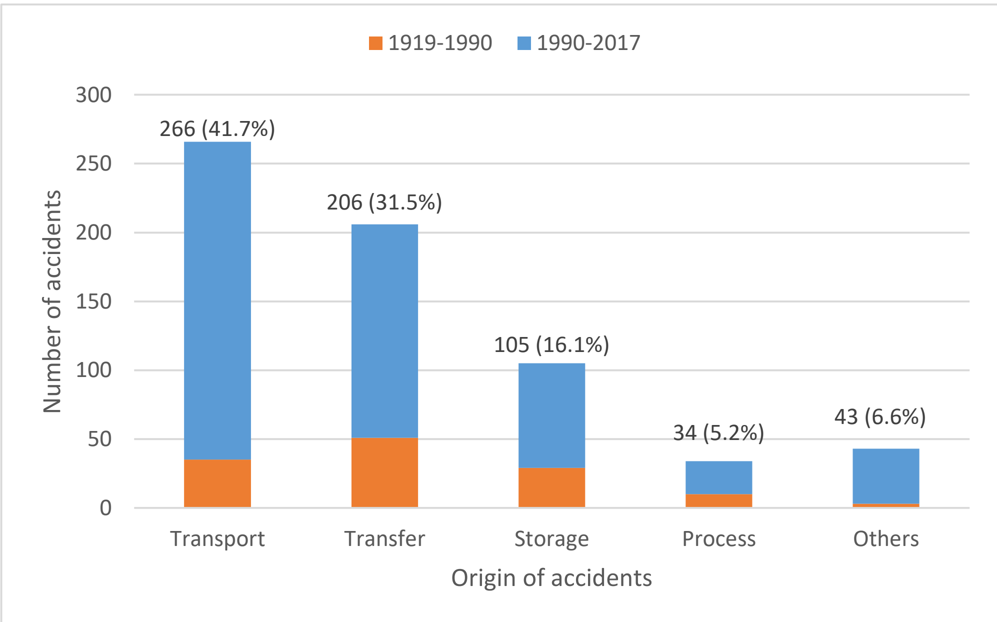


Figure 15. Origin of the accidents

6.5. Type of accidents

Concerning the type of the accident, the release or spillage of a chemical substance is the most common one, present in more than half of the accidents (as it can be seen in Figure 16). It is important to notice that a particular accident may, strictly speaking, be classified into more than one category. Thus, for example, an accident might consist of a release that then causes an explosion, or a release might give rise to an explosion followed by a fire. This introduces an inevitable degree of uncertainty into the statistical treatment of the data, being able that all the accident categories add more than 100%. In addition, release is the type of accident that has increased the most in the recent decades, therefore action is required since it is the starting point of other types of accidents as commented.

As it can be seen in Figure 16, until 1990 there was no difference in the frequency of occurrence between the three main types of accidents (release, fire and explosion), but in the last 27 years it can be seen how the number of accidents concerning the spillage of a chemical substance has grown spectacularly and more than the others, being clearly the main type of accident in European seaports. In second place appear fires, with a rate of 23.2% and then explosions with 16.4%. In last place, with a very low percentage compared with the other types, come gas clouds (3.4%). These percentages are similar to the results obtained by Darbra and Casal [4].

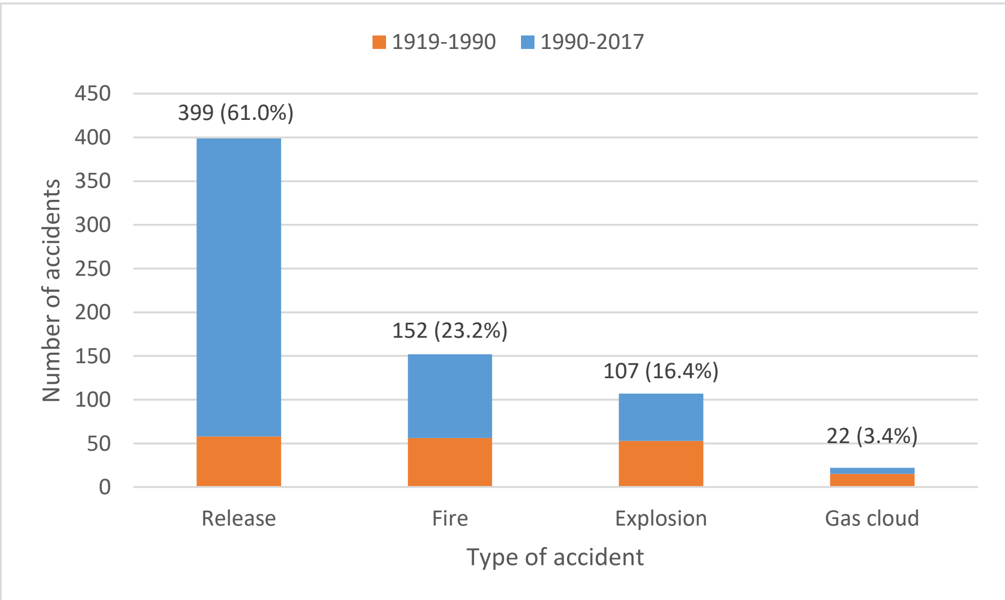


Figure 16. Type of the accidents in seaports.

6.6. General causes of the accidents

All the accidents that appear in this research have been classified in eight types of possible general causes: mechanical failure, impact failure, human factor, instrumental failure, services failure, violent reaction, external events and upset process conditions. It should be mentioned that only 37.6% of the accidents had information about this category; then, the rest have not been included in this analysis.

As Table 4 shows, 45.1% of accidents in ports are caused by an impact or collisions, for example between ships or between a ship and dry land. This percentage is in line with the results of Darbra and Casal [4], who in their study of the whole world found that 43.6% of the accidents in ports were caused by the same reason. Impact is followed by human factors (27%), mechanical failures (19.5%) and external events (17.5%), that, together with impact, make up more than 100%, as an accident may be caused by two or more causes at the same time. It is important to highlight the high rate of accidents caused by human factors. These results are in line with the ones obtained by Vílchez et al. [45] in 1994 (25%), but the rate is higher if they are compared with the results of Darbra and Casal (15,9%) [4]. This fact can mean that, despite the improvements in safety, the accidents caused by human factors are still a challenge to face. The rest of the causes (violent reaction, instrumental failure, services failure and upset process conditions) show percentages that make them hardly relevant.

For the majority of general causes, one or several specific causes can be defined. Table 4 summarises the specific causes corresponding to the main general causes: impact, human factor, mechanical failure and external events. It can be seen that within the impact category, 86.5% (52.3% + 34.2%) of accidents have as their specific cause a ship/land or ship/ship collision. Considering the human factors, the most important ones are general operations, with 29.9%, and overfilling, with 16.4%. Regarding mechanical failures, the main cause are hoses (18.8%), flange coupling failures (16.7%) and valves (14.6%). Finally, the most common external events are fire (39.5%), high winds (34.9%) and lightnings (11.6%).

Table 4.
General and specific causes of accidents in seaports.

Cause	Number of accidents	(%)
Impact	**111**	**45.1%**
Ship/land	58	52.3
Ship/ship	38	34.2
Heavy object	4	3.6
General operation	4	3.6
Human	**67**	**27.3%**
General operation	20	29.9
Overfill	11	16.4
Procedures	8	11.9
Ship/land	5	7.5
Mechanical	**48**	**19.5%**
Hose	9	18.8
Flange coupling failure	8	16.7
Valve	7	14.6
Metallurgic	2	4.2
External	**43**	**17.5%**
External fire	17	39.5
Highwinds	15	34.9
Lightning	5	11.6
Others	**12**	**4.9%**

6.7. Population affected

Concerning the population affected by accidents, this can be classified in two variables according to the scale of the consequences: number of deaths and number of people injured.

6.7.1. Number of deaths

In relation to the number of deaths, a series of categories have been established to categorise them: 0, 1–10, 11–100, etc. (Figure 17). Unfortunately, for 45.6% of the accidents analysed, there is no information available as to whether or not there were fatalities. Given the importance of this statistic, it can be assumed—although there are no guarantees that this was really the case—that these were probably accidents in which there were no deaths. As for the 54.4% of those for which this information is available, only 20% cause deaths. This percentage is much lower compared with other studies of ports in which all the accidents of the world were included, such as the one of Darbra and Casal [4], in which 46% of the accidents with information recorded fatalities. This can be related to the strict safety measure taken in Europe compared to other countries, as mentioned before. Of those that did cause fatalities (the total number of fatalities recorded in the database stands at 308), a small percentage (18.8%) had between 1 and 10 deaths; 1.1% caused between 11 and 100 deaths and there has not been any accident in a European port with more than 100 deaths, as it is shown in Figure 17.

The deadliest port accident in European history occurred in Whiddy Island, in Ireland. The Whiddy Island disaster, also known as the Betelgeuse incident, occurred on 8 January 1979, around 1:00 am, when the oil tanker Betelgeuse exploded in Bantry Bay, at the offshore jetty for the oil terminal at Whiddy Island. The explosion was attributed to the failure of the ship's structure during an operation to discharge its cargo of oil. The explosion and resulting fire claimed the lives of 50 people (42 French nationals, 7 Irish nationals, and 1 British national).

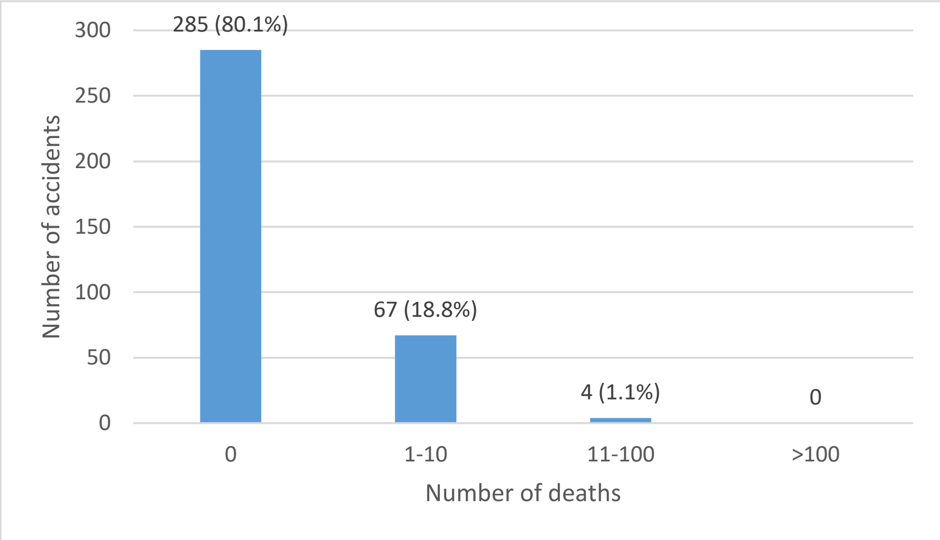


Figure 17. Classification of accidents according to the number of deaths in which information is available.

6.7.2. Number of people injured

In this case, 59.2% of the 654 accidents analysed have information on the number of injured people. Among these accidents, 29.5% of them presented this consequence on population. This is in line with the results obtained by Darbra and Casal [4]. As it is represented in Figure 18, 70.5% of the accidents for which information is available did not involve injuries, and of the rest, 22.2% had between 1 and 10 people injured and 6.2% between 11 and 100 injured. Only four caused more than 100 injuries, all of them before 1990.

Among these four accidents, the most severe one in terms of injured people occurred in Utrecht, Netherlands, in 1967. A dump ship was being loaded with obsolete pyrotechnic ammunition when one of the items activated. The resulting fire initiated a detonation of high explosives and substantial damage to the surrounding industrial area. As a consequence, 200 people were injured and 2 people killed. This accident probably would have not occurred these days due to the stricter measures in terms of safety and the developing of technology to ensure the safe transfer of dangerous good.

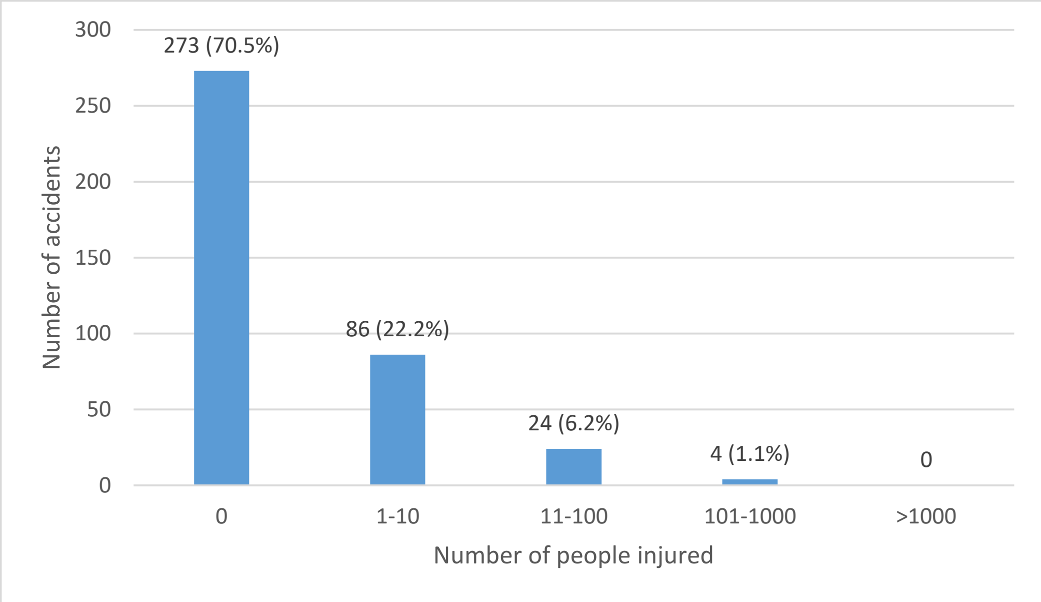


Figure 18. Distribution of accidents according to the number of people injured.

As it can be seen in Figure 19, if only accidents occurred in the last 27 years are taken into account, just 10.7% of the accidents presented casualties and 20.1% of the accidents involved injuries, which shows once again the reduction achieved due to the latest improvements in safety measures.

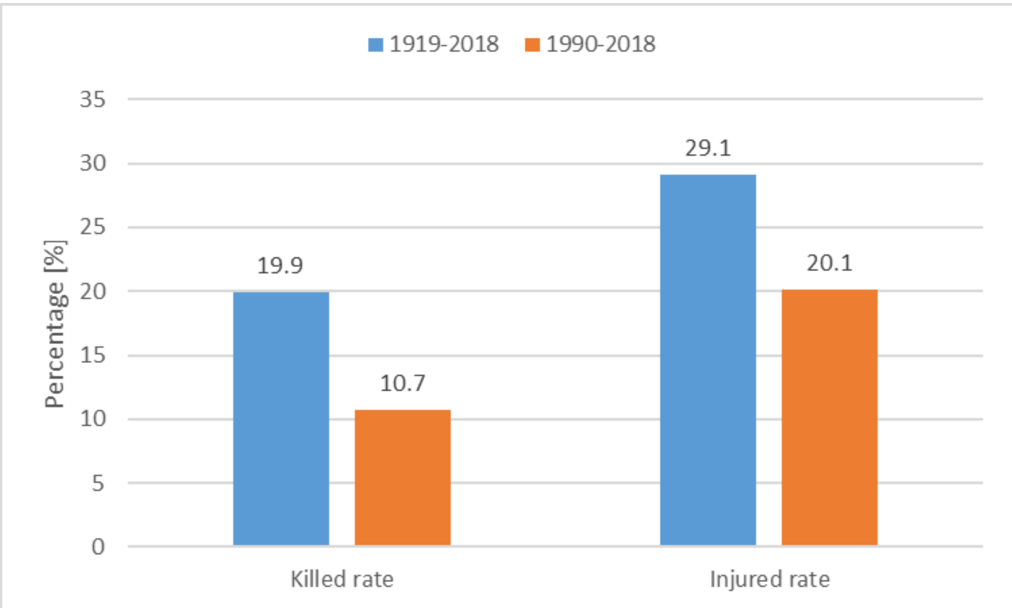


Figure 19. Comparison between the killed and the injured rate since 1919 and in the last 27 years.

7. Sustainability study

As it has been demonstrated along this document, the probability of an accident within the limits of a port should not be ignored. The aim of this chapter is to show the impacts and benefits that this project can have in the environment, society and economy, so countermeasures can be taken to avoid or minimize the accidents.

7.1. Environmental benefits

As it has been defined previously, all the accidents taken into account in this project involve chemical substances. These substances may have certain impact in the environment when an accident occurs, especially in the sea and rivers, where ports are located.

Through 20th century and the beginning of 21st century there have been some accidents in European seawaters that have had a very important impact in the environment. Among these accidents, the disasters of *Mar Egeo* [5] in 1992 or *Prestige* [6] in 2002 that affected the coasts of Spain, Portugal and France, and *Erika* [51] in 1999 that affected the French coasts, with 77.000 tonnes and 35.000 tonnes of heavy fuel oil spilled respectively, caused severe damages in the European shores and forced the European authorities to take action on this matter.

According to the results shown in this research, the most common type of chemical accident in seaports has been the release of a product, the majority of accidents occurred during transport and the most usual substance involved in the accidents has been oil or a derivate product. In consequence, it can be assumed that the most common accident in seaports through history has been the release of oil. Knowing this fact can be very important to avoid these accidents in the future that can pollute the environment by taking relevant measures. Moreover, all large ships still use fossil fuels, which is one of the main substances released in ports. If the shipping industry could be capable of developing a renewable energy based fuel (as the car industry is doing), then potential accidents involving the transfer of fuel would decrease, along with the CO_2 emissions.

7.2. Social benefits

The social benefits of this project can be summarized in the fact that if the most dangerous and sensitive activities in ports are identified, then the probability of a mortal accident in a port area will decrease.

As it has been demonstrated in the research, Europe has a lower rate of dangerous accidents in port areas compared to the rest of the world, and even lower since the beginning of 21st century. This point has been achieved through the improvement of safety measures in the relevant port activities. These safety measures are related, on the one hand, with a stricter legislation and the commitment of the European Commission and its members (Seveso directives and other directives that have been mentioned in Chapter 4) and, on the other hand, the improvement of technology (e.g. automation in transfer activities).

In addition, the identification of the main causes and types of accidents in ports has demonstrated that the training of workers and operators should be a vital fact when handling with hazardous materials. Port operators should emphasize in this point when hiring new employees and it would be advisable to encourage their workforce in continuous learning. An example of the importance of training in these situations is that qualified and trained workers, along with new technologies, can avoid accidents caused by human factors, which, as it has been shown in this research, still are one of the most important causes of accidents in ports.

7.3. Economic benefits

When an accident occurs, the most evident consequences are the environmental damages and, in the worst cases, the casualties. But another aspect that must be taken into account are the economic losses. In fact, as it has been mentioned previously, ports are industrial areas with an important economic activity, so the business aspects also play a role when studying the consequences of a port accident.

It is not always easy to measure the economic losses after an accident, as the fines to the companies are imposed years after the date of the accident, so databases and reports are not capable of updating this information. Besides, in case of casualties or injured, it is very difficult to value the prize of a human life (compensations). In any case, when it has been imposed an economic value to an accident, the amount of money has been very important. For example, one of the most serious accidents that have occurred in Europe took place in Naples, Italy, in 1985. In this accident, the fire and explosion during the transfer or petrol from ship to storage tanks caused 4 killed and 170 injured. The economic damages raised to $20 M due to the severe damages in the port of Naples that this accident caused. In the last years, another example of an accident that caused an important economic damage was the spill of oil of a bunker ship while transfering it to a refinery in Donges, France, in 2008. The spillage caused an important environmental damage along the French coast and the operator bore the cost of 50 M euros to cover for the damage incurred, clean up and compensate effected businesses. Another example of the important economic consequences of these accidents is the release and explosion of LPG in the refinery facilities in the port of Priolo in Italy, in 1985. In this case, the total economic cost of this accident was estimated in $60 M.

As it can be seen, the economic losses should not be ignored. The amount of money at stake is very important and all the parties that have business interests in port areas have to be able to identify the most sensible aspects of their activities as it has been done in this project in order to prevent unexpected expenses in their annual accounts.

8. Conclusions

Ports are complex systems that involve a certain risk of accidents. Despite all the benefits that shipping industry means in terms of energy efficiency, CO_2 emissions or safety compared with other means of transport and the legislation which aims to ensure safety in port areas, several authors in the last years have demonstrated that the possibility of an accident in a port area can suppose a real threat. Besides, the transport and manipulation of hazardous material adds more risks to this activity. Therefore, it is very important to analyse the occurred events in order to prevent future disasters. This project has reviewed the accidents occurred in European ports in order to evaluate them and extract some conclusions to improve safety in these areas.

Firstly, 654 accidents concerning chemical substances in European ports since the beginning of 20^{th} century have been gathered. These accidents have been found in both databases (e.g. MHIDAS, ARIA, eMARS) and other sources, such as websites or reports (e.g. European Maritime Safety Agency, Cedre). The use of different databases and sources has allowed to fill the gaps of information that the outdated databases could have, ensuring the reliability of this research and being a reflection of the reality. All of these accidents have been collected and classified in an Excel sheet to ease their handling. Once all the accidents have been compiled, some results and conclusions have been drawn.

The main characteristic of all these accidents is that they involve chemical substances with their consequent risk for society and environment. Accidents occurred in European ports from 1919 until present have been analyzed in detail to understand better their main characteristics and typology. As a consequence, the main origin of the accidents has been identified as well as the most common type of accidents. Other aspects that have been studied are the number of people dead or injured. The type of substances involved in the accidents and their cause has also been researched, together with frequency and location of the accidents. All these results have been compared with previous studies on port accidents and with a specific research also conducted in this paper for recent accidents (from 1990 until now). This has allowed to find differences and similitudes, and to establish trends.

As it has been concluded in the research, the number of accidents increased during the 20th century, partly due to the increase of traffic in the recent years and a better access to this type of information in the last decades, however, it can be observed a clear reduction in the new century. According to the location of the accidents, France has been the country with the higher percentage of accidents, probably due to the fact the accidents in this country have been very well documented through ARIA database. The same happens with UK, the second country with the greatest number of accidents recorded, which also accounts with MHIDAS that provides detailed information on accidents. Other countries where several accidents have occurred are Germany, Netherlands and Spain, which also hold some of the most important ports in Europe.

The most common type of substance involved in the accidents is oil or related products and most of the accidents involved a release, being the type of accident that has increased the most in the last years, followed by fires and explosions. In consequence it can be assumed that the most usual accidents in European ports concerning hazardous materials since the beginning of the 20th century has been the spillage of oil. This kind of accidents have not a direct impact on human's health, but their impact on the environment can be very important if the accurate measures are not taken.

The origin is mainly transport and transfer, typical port operations. It must be highlighted that the number of accidents involving the transfer of a product in ports has decreased in the last decades in comparison to transport accidents, showing the benefits that the developing of technology, such as the automation of some procedures, has brought to the shipping industry.

The most common cause of accidents in ports in the last century has been the collision between a ship and a dry land and between ships, followed by the accidents caused by human factors. This point shows the insufficient training in this area. Therefore, it must be pointed out the importance of the training of workers and operators in the port activities, being a key factor to reduce the frequency and the severity of port accidents caused by the human factor.

Concerning the consequences on population, European accidents seem to have less severe consequences on population when compared with studies of the total amount of accidents in ports worldwide. Both the percentage of injured people and the killed rate are lower than the rest of the world and this fact can be explained by two factors: the development of technology, that has reduced the risk of a lethal accident in typical port activities such as transfer operations, and, on the other hand, the stricter European directives and laws in terms of safety, which have turned out to be successful in their aim of ensuring the safety in port activities. If only accidents occurred from 1990 on are taken into account, the percentages of injured people and killed is even lower, which confirms the statement that technology and the European directives have been a key factor to reduce the mortality in port activities.

Regarding the sustainability, this project involves some benefits in terms of environment, society and economy. Transporting or manipulating hazardous materials can suppose a certain risk to the environment. However, knowing which have been the most common type of accidents in ports in the past can help to avoid their repetition in the future and the pollution of the natural environment. The same occurs in the social field. If the most sensible activities in the port sector are identified, then the probability of occurrence of a mortal accident drops considerably. Concerning the economic consequences of an accident in a port area, it has been demonstrated that these accidents can suppose important losses to the companies that are operating in the port, as well as several compensations in case of injured people or killed. Consequently, port corporations should be aware of the most common type of accidents in their environment and their origin (which has been done in this research) in order to avoid the economic losses that an accident can suppose.

In conclusion, European countries are in the right path to reduce the hazard of the accidents that can occur in their ports. In any case, Europe should not slow down in its efforts to improve and implement new safety measures and continue with this trend. Knowing the past is a way to improve the future. Avoiding past mistakes and looking for new opportunities is a way to reduce risks in ports.

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