# ANNEX I. ANÀLISI HISTÒRICA D'ACCIDENTS EN PORTS DE MAR

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**Summary**

A total of 1,033 accidents occurred in ports from the beginning of the 20th Century up to October 2003 have been analyzed and statistically treated to study the following aspects: frequency as a function of time, type and causes of accidents, consequences on people (number of deaths, injured people and evacuated people), etc. The relative importance of the diverse types of accidents has also been studied, as well as the variation of the severity of accidents as a function of the state of development of the countries.

**Introduction**

The importance of ports as a potential source of accidents of diverse types (spills, explosions, fires, toxic clouds) is closely linked to the function of the port itself and to the installations and activities associated to it, which feature transfer from water to land (and vice versa) of large amounts of waterborne cargo with a wide diversity of materials: oils, coal, soya, chemicals, cars, etc. A significant amount of this cargo consists of hazardous materials, so in many ports it is common to find risks associated to the process industry. But, moreover, the particular nature of a harbour implies the existence of a set of activities which involve added hazards: loading/unloading of materials to/from ships, oil and chemical tankers navigating and manoeuvring in a restricted area, oil jetties, etc.

As a result of this situation, accidents occur in ports with a certain frequency, some of them with light consequences and some with an important impact. An effort to determine the exact situation of harbour related hazards seems therefore to be very interesting: is the frequency of accidents in ports increasing? Are these accidents usually important or, on the contrary, most of them are negligible? What are the most common causes or origins of the accidents? Are the accidents more frequent in certain countries?

Although several authors have analyzed the risks of marine transport (Rømer, Haastrup and Styhr Petersen, 1995) through historical analysis, only a few of them have studied the specific case of ports. Recently, two communications have been published trying to give an answer to the aforementioned questions (Ronza *et al.*, 2003; Darbra and Casal, 2004). The paper by Darbra and Casal is a historical analysis based on a survey of 471 accidents occurred between the beginning of the 20$^{th}$ Century and October 2002. Ronza *et al.* used a survey of 828 accidents to identify the sequences of the accidents and, by using the corresponding event trees, to predict the probability of the diverse accidents.

The present paper is the result of an exhaustive analysis of accidents occurred in ports, both sea ports and inland harbours: 1,033 accidents have been studied to establish with a certain reliability -on a statistical basis- their main common features.

**Accident selection methodology**

The surveyed accidents have been extracted from MHIDAS (MHIDAS, 2003), a database developed and managed by the Safety and Reliability Directorate (SRD) of the UK Health and Safety Executive (HSE); it includes accidents occurred in 95 countries since the beginning of the 20$^{th}$ Century. The present study refers to the October 2003 version, which contains 13,250 records on 11,784 accidents.

In order to identify the accidents occurred in ports, a search criteria has been devised and implemented in a computer code. This is based on a previous method (Ronza *et al.*, 2003), searching several port related keywords in some fields of MHIDAS. The previous set of keywords (harbour, port, dock, pier, jetty, quay; ship related words together with loading/unloading key terms) has been expanded; among the new keywords are “bunkering”, “charge” and “transfer” (referred to ships), etc. Accidents caused by sabotages have been removed. The automatic search criteria proved to include several accidents which did not actually happen in port areas: these have also been removed by checking all the records one by one. Eventually a few records, not reported by MHIDAS, have been added to the set; these are mostly related to accidents happened in the Port of Barcelona.

Subsequently, the data have been treated to gather them in categories as a function of various accident features. Several characteristics come directly from MHIDAS (incident type, general cause, involved substance, casualties and affected population, etc.) but others have been specifically defined by reading through all the record data set (e.g. type of operation carried out during the accident).

**Distribution of the accidents over time**

The diverse authors who have analyzed the variation of the frequency of accidents as a function of time, for the chemical plants, the transportation of hazardous materials or the maritime transportation, have found a significant increase in the number of accidents in recent years (Rømer *et al.*, 1993; Vílchez *et al.*, 1995; Darbra and Casal, 2004). For the large number of accidents treated in the present analysis, this trend is again found. The distribution of the accidents as a function of time is plotted in Fig. 1. It can be observed that there is a gradual increase, with a significant rise in the period 1991-2000.

This behaviour must be attributed essentially to the influence of two factors: on one hand, the expansion of port trade and maritime transport, and, on the other hand, a better access to information about accidents that have occurred recently. This second factor masks probably the general trend seen in Fig. 1.

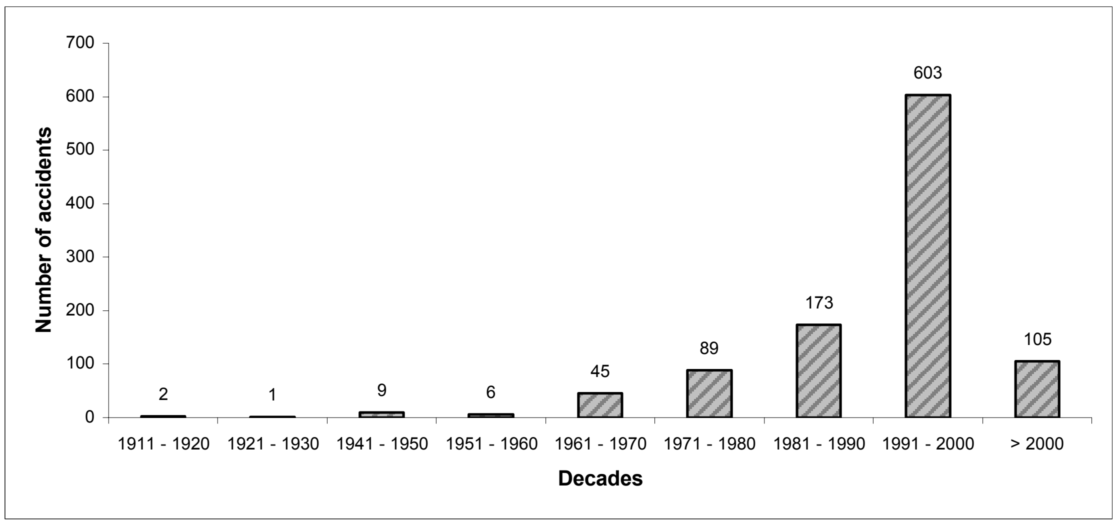


**Figure 1.** Distribution of accidents *vs* time.

**Characterization of the accident**

Concerning the accident type, MHIDAS classifies the accidents in four different categories: loss of containment, explosion, fire and gas cloud. Nevertheless, 182 accidents (18 % of the whole set) are not assigned any incident type; these are mainly near misses like ship-ship and ship-land collisions without direct involvement of hazardous substances in a loss of containment, fire, etc. On the other hand, a particular accident may, strictly speaking, be classified into more than one of these categories. Thus, for example, an accident can imply simultaneously "loss of containment" and "fire", or even "loss of containment", "explosion" and "fire", etc. For this reason, the following figures, deduced from the set of accidents of assigned type, sum more than 100 %:

- 70 % of the accidents (595 cases) involved a loss of containment;
- 30 % (255 cases) involved fire;
- 24 % (201 cases) involved explosion;
- 5 % (43 cases) involved gas clouds.

These data show clearly that, among the consequences that can cause harm to people, fire is the most common accident, followed by explosion and, with lower frequency, gas cloud. By comparing these data to those published by Vílchez *et al.* (1995), who analyzed all MHIDAS accidents (regardless of their setting), some differences can be noticed: port areas are comparatively characterized by less fires, explosions and gas clouds (particularly the latter).

Concerning the operation performed when the accident occurred, an analysis has been carried out by checking the accidents one by one and linking them to one out of seven categories previously established: 1) approach (a ship approaching or leaving the port); 2) manoeuvre (ships moving in port waters or mooring); 3) loading/unloading (of ships); 4) maintenance (of ships at docks); 5) storage (of goods in land terminals and warehouses); 6) process (in industrial plants located in the port area); and 7) transport (of goods by train, lorry or pipeline through the port area). The corresponding distribution can be seen in Fig. 2. The most important contribution is by far loading/unloading of goods, followed by manoeuvre and approach. It is interesting to highlight that these three activities plus ship maintenance, peculiar to port areas and operations, sum up 82 % of the total of accidents. Storage, land transport and process, which in principle are linkable to any industrial plant, have only a relative importance.

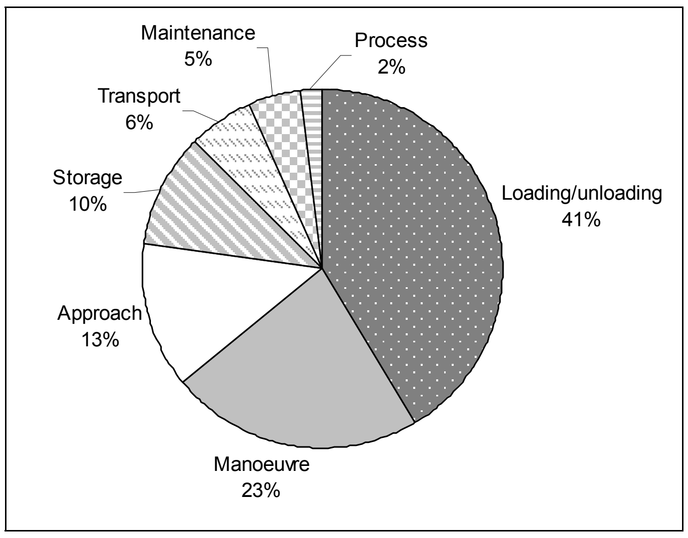


**Figure 2.** Operation carried out during the accident.

When the accidents are classified as a function of their causes, the distribution of Fig. 3 is obtained. As previously mentioned for the incident type, one accident may have no specified cause or, sometimes, more than one. Amongst the accidents in which the cause was known, impact was the most common one (48.5 %), followed by human error (22.2 %), mechanical (21.5 %) and external causes (19.1 %).

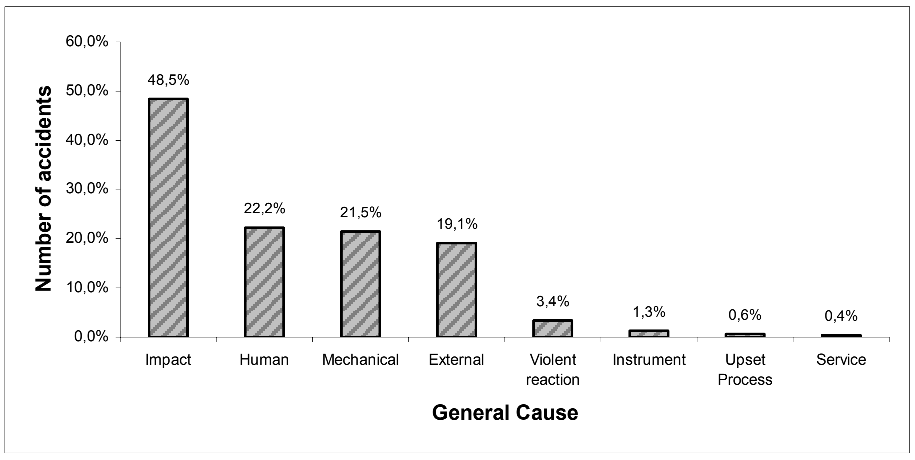


**Figure 3.** General causes of the accidents.

As to the substances, more than one half of the accidents (62 %) involve oils. As it can be seen in the "top 10" of Table 1, the most common substance is crude oil (present in 20 % of the accidents) followed by fuel oil and gasoline. It is noticeable that 8 out of these 10 substances are hydrocarbons, mainly energetic oils. LPG is present in 4 % of the cases (while LNG only in 1 %). Table 1 has been designed grouping among each other the substances according to their names as reported by MHIDAS (e.g. "petrol" has been considered the same as "gasoline"); nevertheless, sometimes the database proves to be quite vague (see categories "oil" and "chemicals" in Table 1).

**Table 1.** Substances involved in the accidents

| Substance | % accidents |
|---|---|
| Crude oil | 20 % |
| Fuel oil | 11 % |
| Gasoline | 9 % |
| Diesel fuel | 8 % |
| Oil | 5 % |
| LPG | 4 % |
| Kerosene | 3 % |
| Chemicals | 3 % |
| Ammonia | 3 % |
| Naphtha | 2 % |

**Consequences on population**

Concerning the population affected by accidents, MHIDAS reports information on three variables according to the scale of the consequences: number of deaths, number of people injured and number of people evacuated. However, the database does not provide such data in an important number of accidents. Therefore, in most of these cases, it could be assumed that the number of people affected is nil. In spite of this reasonable assumption, there is a more important remark to bear in mind: even the most complete accident database would not gather all the accidents, especially overlooking those without or with light consequences on population. So, this analysis is restricted to the accidents in which the number of deaths, injured or evacuated people is at least one since, this information is certainly true.

Concerning the number of casualties, the MHIDAS reports 144 accidents with one or more deaths. Of these, 85 % range between 1 and 10 and 13 % between 11 and 100. Accidents with a number of deaths between 101 and 1000 (1) or higher than 1000 (2) must be considered completely atypical from the statistical treatment of data. These are the famous accidents of Halifax (1917, 2,000 casualties), Bombay (1944, 1,377 victims) and Port Chicago (1944, 321 deaths).

For a better analysis of the lethality of the accidents, the *p*-*N* curve (see Haastrup and Brockhoff, 1990) has been plotted in Fig. 4. In this figure, the abscissae represent the severity of the accident, expressed as the number of fatalities; the values of the ordinate axis are the probability that an accident with casualties originates a number of fatalities equal or higher than $N$ (for $N = 1$, $p = 1$). As it can be seen, the three aforementioned accidents (with $N > 100$) show a completely different behaviour comparing to the rest, due to the involvement of huge amounts of conventional explosives. For $1 < N < 100$, the best fit (minimum square method) for a curve $p = N^b$ gives $b = -0.68$; plotting the fit in a log-log axis graph, a straight line is obtained with a slope of -0,68. This means that the probability of an accident with 10 or more deaths is 4.8 ($= 10^{-b}$) times greater than that for an accident with 100 or more deaths. In the same figure, the accidents occurred after 1974 have also been plotted; as this curve clearly shows, when not considering those accidents which happened long ago and in a different technological environment, where safety measures and risk planning were not comparable with the ones existing nowadays, accidental consequences prove to be less severe ($b = -0.82$). This can be attributed to both improved safety conditions and to MHIDAS' tendency to gather preferentially catastrophic accidents for the first half of the 20th Century.

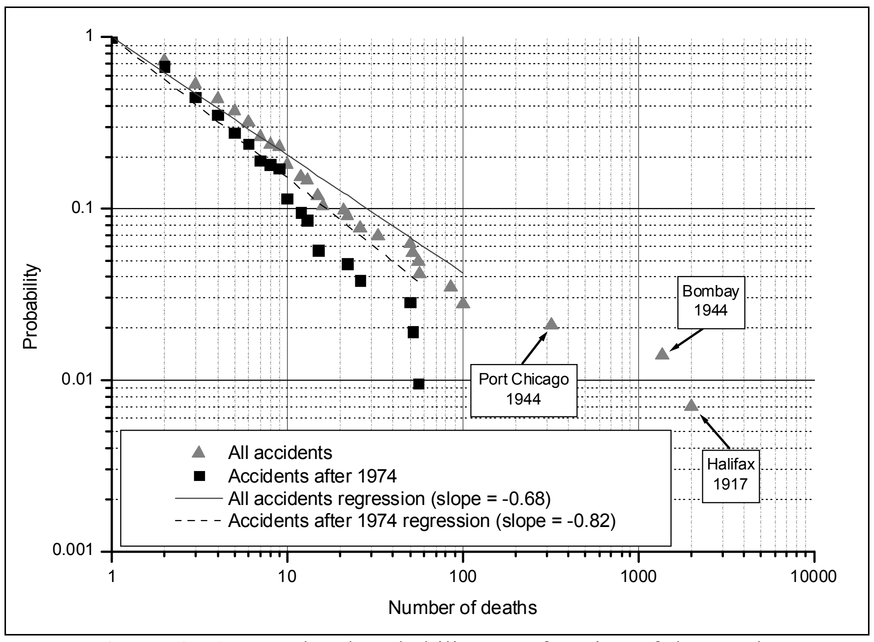


**Figure 4.** Accumulated probability as a function of the number of deaths (the apparent deviation in the fit is due to the fact that the equation of the straight line was obtained from the original $p= N^t$ fi ).

As for the number of people injured in the accidents, MHIDAS provides information on 174 accidents with at least one injured. Amongst these, in 125 (72 %) the number of injured people ranged between 1 and 10, and in 41 (24 %) ranged between 11 and 100. Concerning the people who had to be evacuated, the database gives detail of 54 accidents with 1 or more evacuees. The distribution has been plotted in Fig. 5. It can be observed that the distribution is comparatively smooth, i.e., accidents having a negative influence on very large amounts of population in terms of evacuated people cannot be considered atypical.

The number of fatalities has also been used to compare the existing situation in different countries. In Fig. 6 the countries have been grouped according to different geographical and economical criteria. Again, only accidents occurred after 1974 have been considered. Different trends can be observed. Thus, the data show that the accidents occurred in less developed countries would have worse consequences (more people are killed) than those occurred, for example, in USA, Canada, Australia and Japan or in European Union countries. These results (which may again be altered by MHIDAS' selective access to information, e.g. recording preferentially major accidents for underdeveloped countries) are in good agreement with those obtained previously by Carol *et al.* (2002) for industrial accidents.

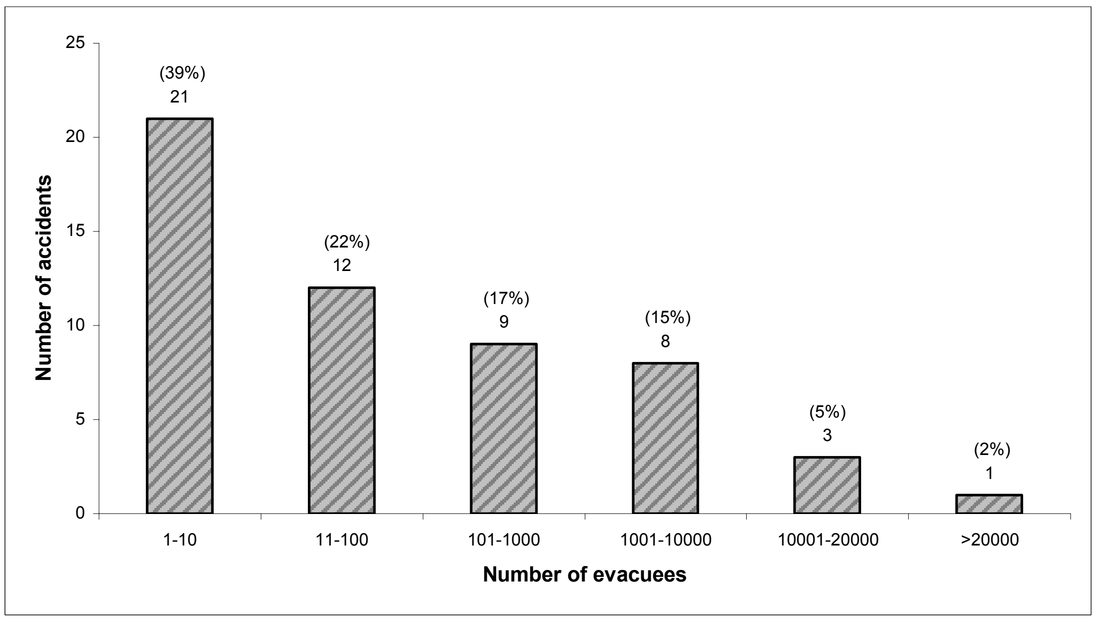


**Figure 5.** Number of people evacuated.

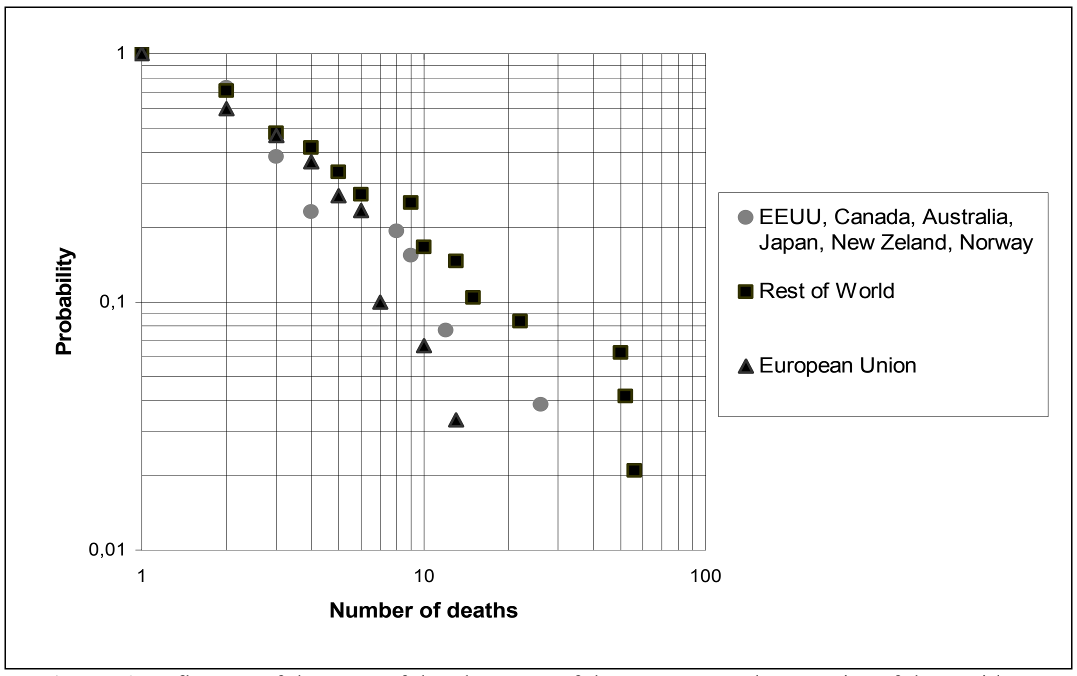


**Figure 6.** Influence of the state of development of the country on the severity of the accident.

**Conclusions**

The historical analysis has shown that the frequency of accidents which occur in ports is continuously increasing. This fact should be a warning for both the administration and the port authorities: unless new safety measures and methodologies are applied, the number of accidents will increase in the next years. This is specially worrying when one considers the fact that many ports are located very close to highly populated urban areas.

Most of the accidents (82 %) occur during typical port operations, i.e. loading/unloading of cargo, ships manoeuvre or approach and vessels maintenance. On the other hand, other activities also carried out in a port such as storage, land transport or process appear to be less relevant.

The most frequent accident affecting population is fire (30 % of cases), followed by explosion (24 %) and, with much less incidence, by gas cloud (5 %). This follows the same order as in the process industry but the percentages are quite different: whereas releases are relatively more frequent in port areas, gas clouds are less important.

Concerning the consequences on people, many accidents in the database do not include any reference to them; it must be supposed that when this happens it is because there were no significant consequences. In those accidents in which there are deaths, the most frequent ones are those with a number of killed people ranging between 1 and 10. Very few accidents have more than 100 casualties. The data obtained show that the probability of an accident with 10 or more deaths is 4.8 times greater than that for an accident with 100 or more deaths; nevertheless, the severity is lower when only recent accidents are considered.

Finally, the *p*-*N* curves indicate that accidents in underdeveloped or developing countries are more severe than those that occur in technologically more advanced countries. This substantiates the risk planning policies in place in developed countries.

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