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Historical analysis of accidents in seaports

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Abstract

A study has been carried out of accidents occurring in seaports. A total of 471 accidents occurring between the beginning of the twentieth century and October 2002 have been analysed. The results obtained show a significant increase in the frequency of accidents over time: 83% of the accidents occurred in the last 20 years and 59% in the past decade. The most frequent accidents were releases (51%), followed by fires (29%), explosions (17%) and gas clouds (3%). More than half the accidents occurred during transport: loading/unloading operations, storage and process plants also make a large contribution to the total. The various causes of the accidents have also been analysed, as have the type of substance involved and the consequences for the population (number of people killed, injured and evacuated). Finally, some conclusions are drawn concerning the need to improve certain safety measures in ports.

Keywords: Risk analysis; Historical analysis; Major accidents; Seaports

1. Introduction

Seaports are very important facilities for a country's economy because goods—in what can amount to very large quantities—and people come and go through them. Given their position in coastal areas and the great variety of substances handled there, ports (especially those of a certain size) are now considerably complex systems from an environmental point of view. They tend to be associated with water and air pollution and soil contamination, problems related to dust and noise, the generation of waste, dredging operations, movements of ships, lorries and trains, warehouse storage of hazardous substances, etc.

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In addition, ports are usually close to urban centres. In fact, for historical and practical reasons, many ports are closely linked, physically and socially, to a city, and their physical proximity to it can be very great.

These circumstances mean that the impact on the environment—including people—of certain accidents can be very serious. Given the properties of some substances that pass through ports (chemical products, hydrocarbons, fertilisers, etc. (Planas-Cuchi, 1997) and the operations that are carried out on them (loading and unloading, storage, transport) the possibilities of there being an accident are hardly negligible. In fact, there are periodic fires, explosions and toxic releases, with possible consequences of an impact on the environment, alarm among the population, financial losses, etc. In addition to these direct consequences, another quite important aspect of these situations is the negative image they give to the port, with the possible creation of a feeling of rejection among the population (Planas-Cuchi, 1998). On the other hand, it must be taken into account that, in the latter circumstances, the possibility of moving the port facilities further away from the population is, in the majority of cases, practically impossible. Furthermore, the shipping of materials over the years is lightly but continuously increasing; thus, from 1996 to 2001 the total throughput in the 14 main EU ports has increased from 950×10^6 to 1100×10^6 t.

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.

To carry out this historical analysis, we have used information contained in the Major Hazard Incident Data Service (MHIDAS) (MHIDAS, 2002), developed and managed by the Safety and Reliability Directorate (SRD) as a representative of the Major Hazard Assessment Unit of the UK Health and Safety Executive. MHIDAS includes accidents occurring in 95 countries. This database was created in 1980, but it includes accidents that have occurred since the beginning of the twentieth century and is periodically updated. The version used, in which there were 12,844 records of accidents, was last updated in October 2002.

A restricted search in MHIDAS, for example, for "accidents in ports" gives the result as a number of records, not as a number of accidents. Thus, one accident can be in several records, which means that when it comes to carrying out statistical processes, the values obtained can show a considerable error. To correct this effect, a new database has been created in which all repetitions have been omitted. In this way, 471 accidents in seaports have been identified from the beginning of the twentieth century to the present day. It is this sample which has been used for this study. Unfortunately, information on financial losses is not available for any of these accidents, so this aspect could not be studied.

2. Distribution of the accidents over time

The variation over time of the annual number of accidents reported in MHIDAS database is represented in Fig. 1. As can be seen, the number of accidents has increased spectacularly in recent decades; 83% of the accidents have taken place in the last 20 years and 59% in the past decade. It is interesting to observe that this trend is similar to that obtained by exhaustive analysis of all accidents occurring in the chemical industry and in the transport of hazardous goods (data from Vílchez et al., 1995, on a sample of 5325 accidents from MHIDAS database).

This progressive increase over time in the frequency of recorded accidents must be attributed to two factors. The first is better access to information about accidents that have occurred recently (it must be taken into account that the databases on accidents are a relatively recent creation: MHIDAS database was created in 1980). This alters the statistical significance of the sample used. If more information were available about all the accidents that have occurred, the increase over time would probably not be so great. The second factor is the notable growth in industrial activity in many countries, with the consequent increase in the transport of hazardous products, directly related to the increase in port activity. Overall, although the trend shown in Fig. 1 may be slightly exaggerated, it must be accepted that the frequency of accidents in ports is increasing and that in the next few years it will increase considerably.

3. Types of accidents

The database used classifies the accidents into four different types: release, explosion, fire and gas cloud; Nevertheless, 21% of the accidents have not been classified into anyone of these four types.

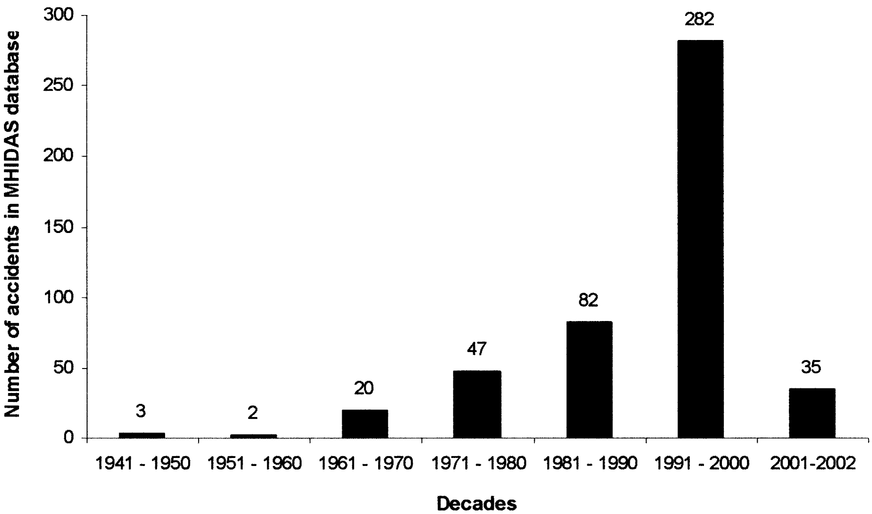

Fig. 1. Distribution of accidents (MHIDAS database) as a function of time.

On the other hand, a particularly accident may, strictly speaking, be classified into more than one of these categories. 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; in fact, many accidents begin with a release. This introduces an inevitable degree of uncertainty into the statistical treatment of the data.

As can be seen in Fig. 2, releases are the most common type of accident, appearing in 51% of cases. In second place appear fires, with a rate of 29%, then explosions with 17%. In last place, with a very low percentage compared with the other types, come gas clouds (3%).

It has not been possible to analyse the typology of accidents in more detail within these categories (e.g. types of fire: pool-fire, flash-fire, jet-fire, fireball, etc.) due to the lack of information in the majority of records in the database used.

4. Origin of the accidents

The database considers seven different categories to designate the place or activity in which the accident occurred: process plant, storage, transport, load/unload, waste, domestic/commercial and warehouse.

Of the 471 accidents in ports, only 1.1% are of unknown origin. For the rest, the distribution according to origin is represented in Fig. 3. Here it can be seen that the principal origin of accidents in ports is transport, with 56.5% of cases. Then, with lower but very similar percentages (around 13%) come accidents in loading/unloading operations, in storage facilities and in process plants. If the accidents classified as being of warehouse origin are added to those that occurred in storage, that gives 15.5% for this origin, moving it up into second place.

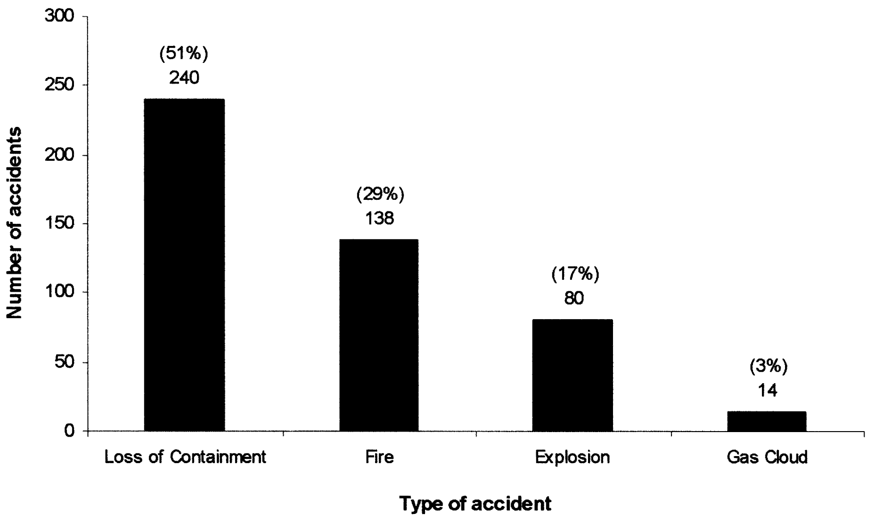

Fig. 2. Types of accidents in seaports.

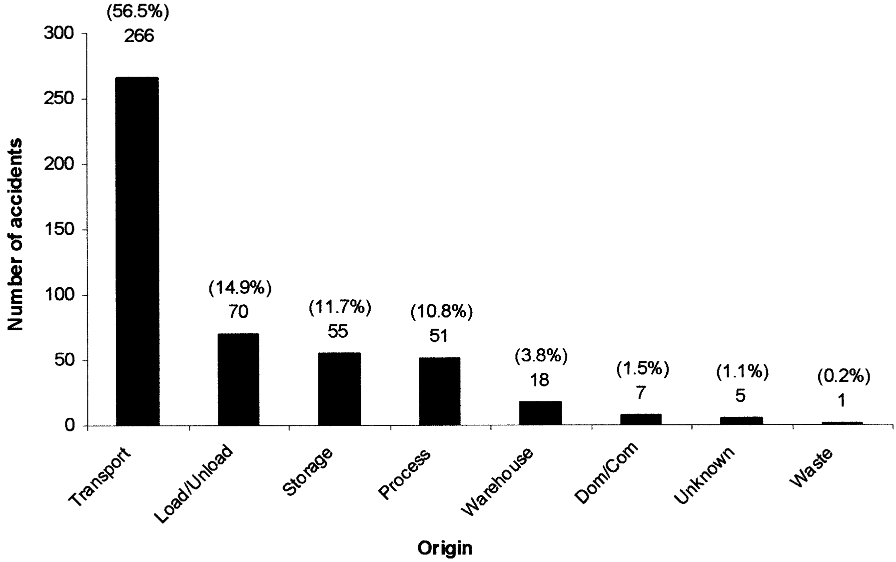

Fig. 3. Origin of the accidents in seaports.

It should be noted that the "transport" category includes, in principle, all accidents that occurred in moving ships (entering or leaving the port), 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 that 56.5% of accidents occurred during this activity. In addition, and for the same reason, it is also logical that 14.9% of accidents should have occurred during loading/unloading operations. It should be noted that this percentage is similar—although higher, for the reasons mentioned—to that found for the same operations in the analysis of all accidents (Vílchez et al., 1995) (8%).

The specific origin of the accidents has been analysed for the four most important general origins: transport, load/unload, storage and process plant. The percentages for each specific origin can be seen in Table 1.

Regarding accidents that occurred during transport, the majority (65%) took place in ocean-going vessels (quite logically, given the intense movements in and out of a port and ship manoeuvring within it), followed by accidents in pipelines; the database considers flow through a pipeline to be "transport"; given the characteristics of port facilities this definition is acceptable, although in other activities—for example the chemical industry—this category would probably be considered "process" or "storage". In the "load/unload" category, it is significant that 14% of accidents occurred in hoses (very practical equipment, but highly prone to breakage). Finally, in storage, the largest number of accidents occurred in atmospheric pressure storage vessels, which are the most common type in port facilities.

The classification of accidents in relation to the substances involved is difficult because of the lack of information in some of the records. In addition, in some accidents more than one substance was involved (this is the reason why, again, the

Table 1
Specific origin of the accidents in seaports

Specific origin	No. of accidents	% Of category
Transport		
Ocean going vessel	173	65
Pipeline	31	12
Portable transport containers	26	10
Barge	14	6
Road tanker	12	4
Rail tanker	7	3
Tank container	3	1
Loading/unloading		
Ocean going vessel	24	34
Pipework	10	14
Hose	10	14
Not defined	6	8
Barge	5	7
Portable transport containers	4	6
Road tanker	4	6
Solid conveyance	2	3
Pipeline	2	3
Tank container	2	3
Pumps/compressors	1	1
Rail tanker	1	1
Storage		
Atmospheric pressure storage vessels	31	56
Portable containers	9	16
Solid storage	5	9
Not defined	5	9
Small commercial tank	1	2
Pipework	1	2
Pressurised storage vessels	1	2
Solid conveyance	1	2
Barge	1	2
Process		
Not defined	19	37
Pipework	7	13
Process vessels	6	12
Reactor	5	10
Pumps/compressors	6	12
Fired process equipment	4	8
Heat exchangers	3	6
Process machinery drives	1	2

sum of the percentages in the data given later is greater than 100). With the available information, the accidents have been divided into the following categories: oils, chemicals, Acids, Natural Gas and "others". The greatest proportion of accidents (59%) occurred with oils, followed by chemicals (4%), acids (3%) and natural gas (3%); 40% of the accidents involved other substances.

5. General causes of the accidents

The database takes into consideration eight types of possible causes: mechanical failure, impact failure, human factor, instrumental failure, services failure, violent reaction, external events and upset process conditions. It should be mentioned that 36% of the accidents have not been classified in any of these general cause; then, these have not been included in this analysis.

As Fig. 4 shows, 43.6% of accidents in ports are caused by an impact or collision between ships or between a ship and dry land, vehicle collisions, etc. Then come mechanical failures, external events and human factors, together making up more than 50%. Accidents caused by human factors make a significant contribution (15.9%). The rest of the causes show percentages that make them hardly relevant.

For the majority of general causes, one or several specific causes can be defined. Table 2 summarises the specific causes corresponding to the main general causes: impact, mechanical failure, external events and human factor; given that the number of accidents in each category diminishes as the degree of specificity increases, the statistical significance also diminishes in a similar way.

It can be seen that within the impact category, 71% (45% + 26%) of accidents have as their specific cause a ship/land or ship/ship collision. Regarding mechanical failures, the main cause is valves, with 14%. In this division there is a great variety of causes, which is why the others section has such a large percentage (50%). The most common external events are highwinds (25%), sabotage (14%) and fire (13%). Finally, considering the human factors, the most important ones are general operations, with 23%, and overfilling, with 11%. In this case the others percentage is also quite high because there is a great variety of specific causes.

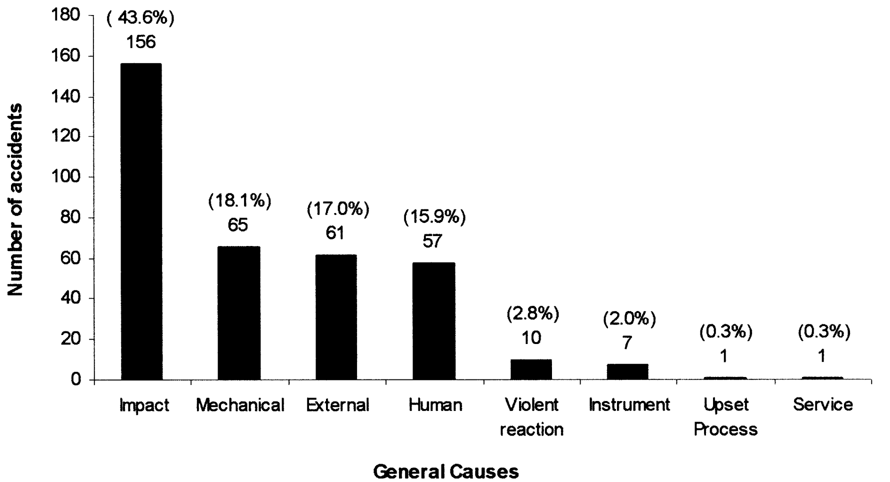

Fig. 4. General causes of accidents.

Table 2
Specific causes of accidents in seaports

Specific cause	No. of accidents	% Of category
Impact		
Ship/land impact	79	45
Ship/ship impact	45	26
General operation	8	5
Heavy object	8	5
Rail accident	7	4
High winds	7	4
Other causes	20	11
Mechanical		
Valve	13	14
Flange coupling failure	8	9
Metallurgy failure	7	8
Hose	6	7
Highwinds	6	7
Over pressure	5	5
Other causes	45	50
External		
High winds	21	25
Sabotage	12	14
External fire	11	13
Ship/land impact	6	7
Ship/ship impact	5	6
Other causes	30	35
Human		
General operation	21	23
Overfilling	10	11
Maintenance	9	10
Procedures	7	8
Ship/land impact	6	6
Other causes	39	42

6. Population affected by the accidents

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

6.1. 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. (Fig. 5). Unfortunately, for 77% 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

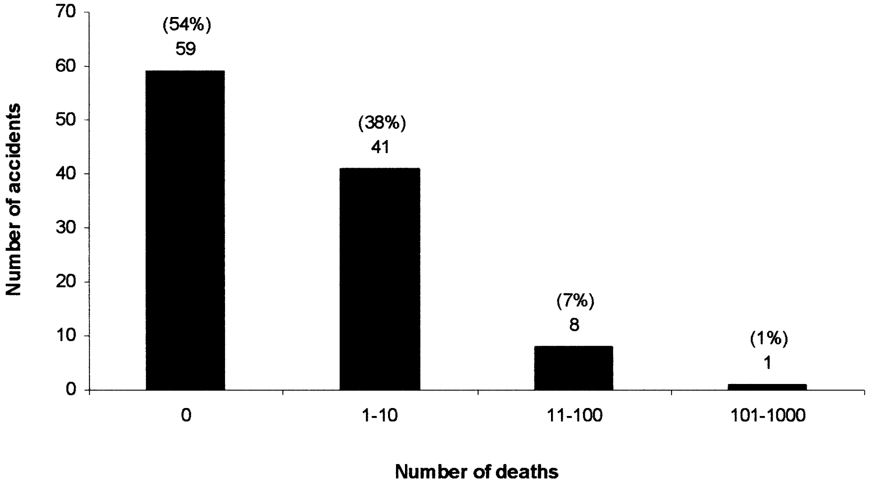

Fig. 5. Classification of accidents according to the number of deaths.

were no deaths. As for the 23% of those for which this information is available, the majority of accidents (54%) did not cause deaths. Of those that did cause fatalities (the total number of fatalities recorded in the database stands at 656), a very large percentage (38%, that is, 82% of the accidents with fatalities) had between 1 and 10 deaths; 7% caused between 11 and 100 deaths and only 1 caused more than 100 deaths (this was an accident that happened in Port Chicago, California, on 17 July 1944).

The accident mortality statistics can be used to obtain social risk curves using accumulated frequency–number of deaths graphs, usually called f–N (Haastrup & Brockhoff, 1990), which relate the number of deaths in a particular accident to the relative probability that there should be this number of deaths. Although it is not possible to calculate the frequency (deaths/year) because information is not available on all the accidents that occurred, it can be accepted that the sample used is representative; this therefore allows a “relative frequency” to be estimated for accidents with a number of deaths above a certain value, expressed in terms of relative probability.

For these, the value of 1 on the y-axis is the value arbitrarily assigned to all the accidents that involve at least one death. Both axes are logarithmic. This type of graph is useful to establish whether the probability that a type of accident with a given severity will occur is proportional to the probability that another accident with a different severity will happen.

For this analysis, we used accidents with at least one fatality, grouping them into categories and calculating the cumulative probability or frequency using the following expression:

$$P_{(x \geqslant N)} = F_j = \frac{\sum_{i=j}^{n} N_i}{\sum_{i=1}^{n} N_i}$$

where N is the number of deaths (x-axis), $P(x \geqslant N) = F_j$ is the probability that in an accident the number of deaths will be $\geqslant N$ (y-axis), n is the total number of categories or rankings and N_i is the number of accidents in a given category i.

The values obtained with the chosen accidents can be seen in Fig. 6. The graph approximately follows a straight line with a gradient of −0.7; this indicates that the probability of an accident with 10 or more deaths is seven times greater than that for an accident with 100 or more deaths. The same representation for accidents in process plants and in the transport of hazardous substances (Vílchez et al., 1995) gives −0.84, while for natural accidents (earthquakes, floods, etc.) Fryer and Griffiths (1979) obtained gradient values of between −0.4 and −0.7.

To compare these statistics with those corresponding to the sea transport of hazardous goods, it is interesting to mention the data of Rømer et al. (1993) who used DAMA database: of 151 accidents, 52 involved deaths, of which 20 happened in ports.

The severity of accidents has also been analysed as a function of the type of accident (explosion, fire, release) and of the state of development of the countries in which accidents took place.

Fig. 7 shows the f–N curves corresponding to the accident types "explosion", "fire" and "release". The severity for explosion and fire is essentially the same, while it is lightly lower for release. The influence of the state of development can be seen in Fig. 8, which compares incidents in (1) the European Union, (2) North America, Japan and Australia and (3) "Other countries". It can be seen that the severity is higher in (3), decreases for (2) and shows the lowest values for (1).

6.2. Number of people injured

As in the previous section, the number of people affected has been grouped into categories (1–10, 11–100, etc.). Fig. 9 shows the number of accidents in each category.

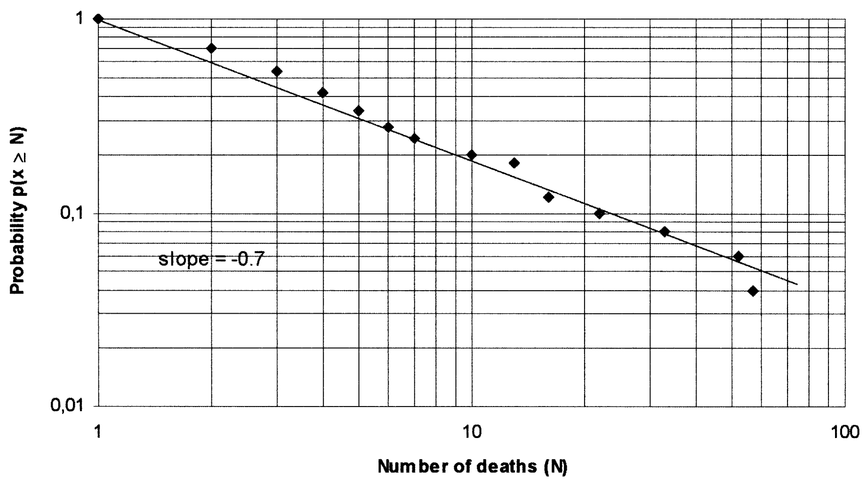

Fig. 6. Accumulated probability of an accident with N deaths.

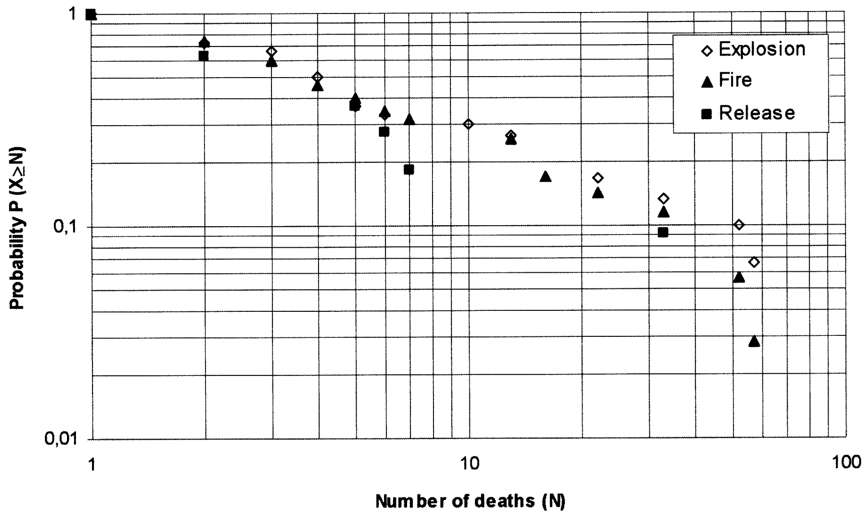

Fig. 7. Severity of the accidents as a function of the type of accident.

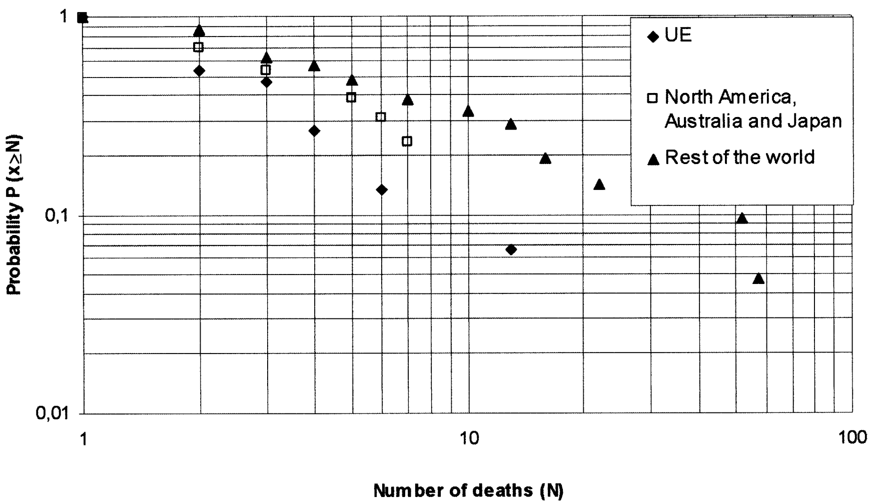

Fig. 8. Severity of the accidents as a function of the state of development of the countries.

In this case, only 31% of the 471 accidents analysed have information on the number of injured people. The total number of people injured was 799. As can be seen in the graph, half the accidents for which information is available did not involve injuries, and of the rest, 30% had between 1 and 10 people injured. Only one caused more than 100 injuries. It is interesting to observe that the number of injuries shows a clear downward tendency in the last 30 years: 359 in 1971–1980, 188 in 1981–1990, 147 in 1991–2000 and 1 in 2001–2002; this trend can be partly attributed to the increasing use of remote movement of containers (e.g. in the port of Barcelona the

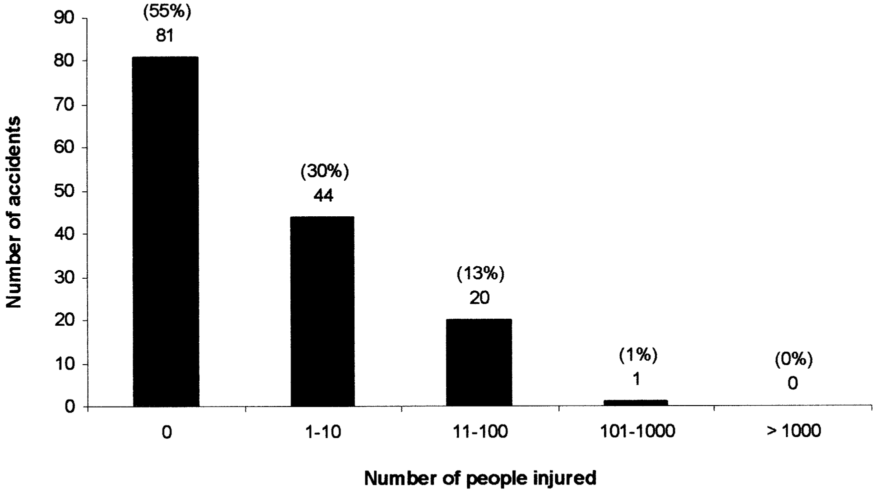

Fig. 9. Distribution of accidents according to the number of people injured.

transportation of materials by containers has raised forty times in the last 30 years). In contrast, no definite tendency can be observed in the number of deaths.

6.3. *Number of people evacuated*

It has only been possible to obtain evacuation data for 11% of the accidents, which involved a total of 35,445 people evacuated; thus, this part of the study is rather limited. Of these 53 accidents, in 19 no-one was evacuated, in sixteen between 1 and 10 people were evacuated, in six between 11 and 100, in seven between 101 and 1,000, and in four between 1000 and 10,000. In only one accident were more than 10,000 people evacuated. This was an accident at Industria ICAM in Priolo (Italy) in 1985 (this accident properly did not take place in the port, but in an industry of the harbour zones). This data was closely related to the population density in the areas where the accidents took place. Of the 111 accidents for which information on this aspect is available, 85 took place in areas of high density (urban areas) and 26 in areas of low density (rural areas).

7. Conclusions

The historical analysis carried out on a sample of 471 accidents has shown a clear upward trend regarding the frequency of occurrence. It should be taken into account the limitations of the MHIDAS database for this type of analysis: this trend is probably increased by the characteristics of the information stored (greater inclusion of accidents that have occurred recently versus loss of information about accidents that happened some time ago). However, these figures—attributable in part to the increase in port activity and the growth in sea transport of hazardous substances—should serve as a warning. This trend allows us to predict that if safety measures are not improved there will be a growing number of accidents in the next few years.

As regards the types of accidents, in accordance with the classification made by the database used, the most frequent was release (there was a release in 51% of cases). However, as a release was often followed by another phenomenon the following information is probably more significant: the most frequent of these phenomena was fires (29%), followed by explosions (17%) and gas clouds (3%). A very large proportion (56.5%) of these accidents had their origin in transport, that is to say, in the movement of ships, primarily, but also of lorries and trains; and an important share of the responsibility must also be attached to loading and unloading operations, with 14.9%. Although it is well known that these operations are dangerous, this statistic indicates that more emphasis must be placed on the safety measures applied to them. Concerning the original causes of accidents, the most frequent is impact; practically half the accidents (43.6%) were due to collisions between ships or between ships and dry land, or to road or train accidents in port areas. The human factor was the cause of 15.9% of accidents.

More than half the accidents did not cause fatalities. Of those accidents in which there were deaths, in the majority the number of deaths was between 1 and 10. The probability–frequency curve has a gradient of -0.7; that is to say, the probability that an accident with 10 or more deaths will occur is seven times greater than that for an accident with 100 or more deaths. The severity of explosions and fires is generally higher than that corresponding to releases. Furthermore, the severity of accidents occurred in the European Union is lower than that of accidents occurred in other countries. As for the number of people injured, in half the accidents there were no injuries; in the rest, the majority caused 1–10 or 10–100 injuries. Finally, the little data available on the number of people evacuated indicates that if there is evacuation (it seems that this is unusual) the number of people involved is usually between 1 and 10. Only in one case were there more than 10,000 evacuees.

Overall, the study presented here reveals a worrying trend in the frequency of accidents. There is a clear need to improve safety measures in the various aspects of port operation (manoeuvre of ships, lorries etc., loading/unloading operations, storage of products) to tackle the growing frequency detected in the occurrence of accidents.

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