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A survey of accidents occurring during the transport of hazardous substances by road and rail

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Abstract

A study of 1932 accidents that occurred during the transport of hazardous substances by road and rail from the beginning of the 20th century to July 2004 was carried out. The results obtained show an increase in the frequency of accidents over time. More than half of the accidents happened on roads (63%). The most frequent accidents were releases (78%), followed by fires (28%), explosions (14%) and gas clouds (6%). The various causes of the accidents, the type of substance involved and the consequences for the population (number of people killed, injured or evacuated) were also analysed. Among the diverse measures taken to improve this situation, the training of professional people involved in transportation seems to be of major importance.

Keywords: Historical analysis; Major accidents; Land transportation; Rail transportation; Road transportation; Hazardous substances

1. Introduction

Land transport is very important for a country's economy because it is used for the mobility of both goods and persons. Every day a great number of lorries and trains transport a large volume of products, including chemical substances. Accidents may represent a serious risk for the population and they often cause water, air and soil to become polluted. Due to the properties of some substances transported by road (such as chemical products, hydrocarbons and fertilisers), the high volume of road traffic and the high density of population, the possibility of an accident occurring and having severe consequences should not be neglected. In fact, several surveys have indicated an increasing trend in the frequency of accidents in the transportation of hazardous materials.

This paper aims to provide an updated survey on the situation in this field, by analysing the accidents that occur during the transport of dangerous goods by road and rail: their causes, consequences, materials involved, severity and frequency, and drawing some conclusions on the measures to be taken in order to reduce this frequency.

2. Accident selection method

The Major Hazard Incidents Data Service (MHIDAS), which was used to carry out the present study, is managed by the SRD, which belongs to the UK Health and Safety Executive. It stores details of over 9000 incidents that have occurred during the transport, processing or storage of hazardous materials, which resulted in or had the potential to cause an off-site impact. Certain types of incidents (such as those involving radioactive materials, for example) are specifically excluded from the database.

The database contains incidents from over 95 countries and all the information in it is taken from public-domain information sources. The database, which is continuously being updated, was started in the early 1980s, although it contains references to incidents that took place in the early years of the 20th century. The July 2004 Version [1], in which there are 12,369 records of accidents, was used for this study.

One of the limitations of this database is the fact that one accident may have more than one record (e.g. 1055A, 1055B and 1055C) if there is more than one cause, more than one incident

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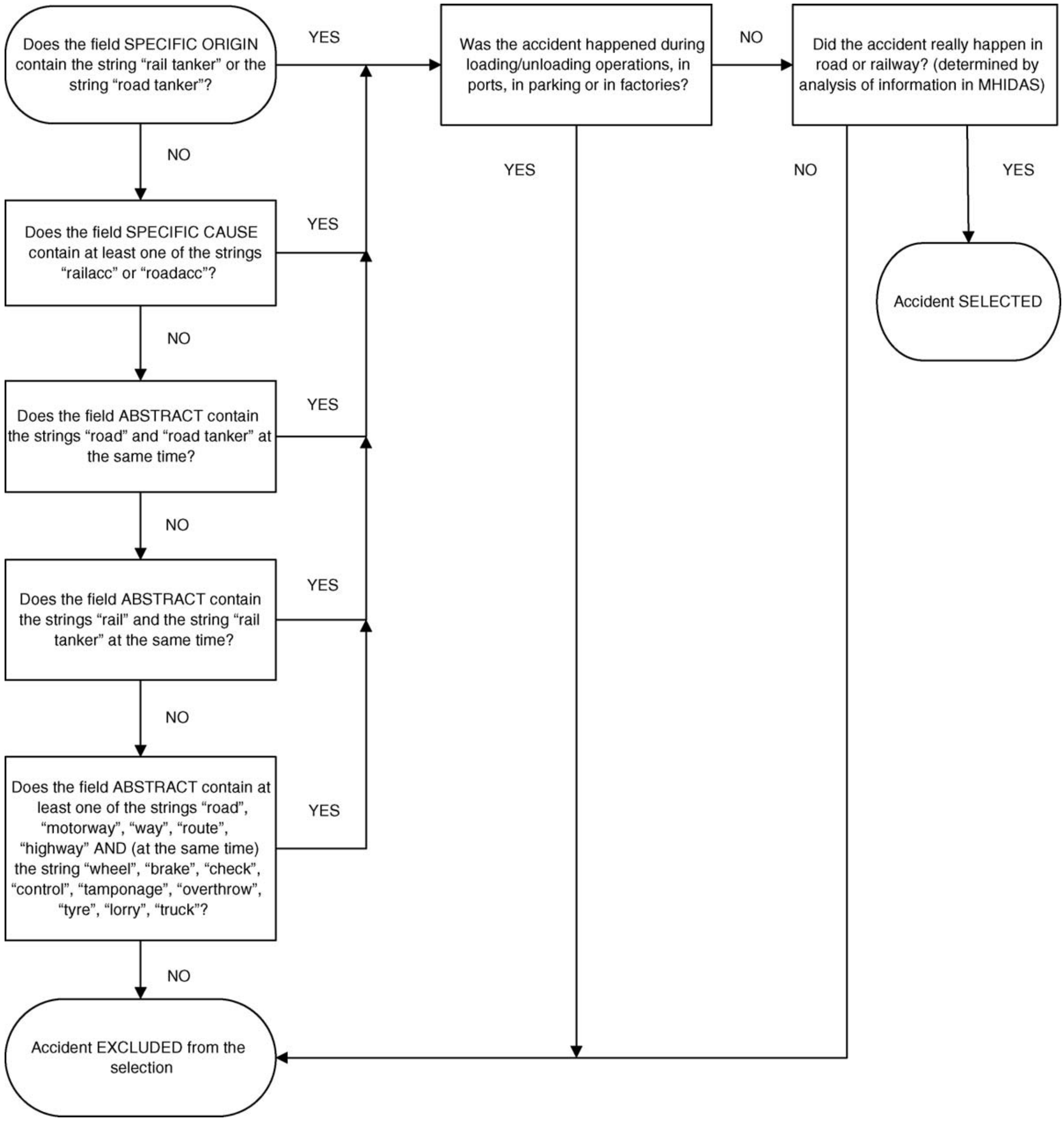

Fig. 1. Search criteria applied in order to extract land transport accidents from MHIDAS.

type or various substances were involved. This problem was solved by creating a new database (based on Microsoft Access). Thus, the same accident can only be selected once and various searches can be made quickly and without repetitions. A group of only new incidents (coming from different sources) can be obtained. In order to identify the records that are specifically related to road and railway accidents, the search criteria shown in Fig. 1 were used and implemented in a computer code (from MHIDAS to the Access database). This is the same procedure as that used by Ronza et al. [2].

Several incidents that did not occur on roads or railways were automatically included in the selection and it was therefore necessary to check each record to eliminate errors (see Fig. 1). Accidents occurring during loading/unloading operations (which are relatively frequent) and in parking lots, ports, factories and depots were not considered.

The fields used in this study are the same as those of MHIDAS. Moreover, for each accident more information was drawn up and placed in new additional fields: Source (name of the database or other sources used), Road/Rail, Country, Type of road, Initial event (sequence of events that led to the accident), Class (explosive, toxic, flammable, etc., in accordance with the European classification system), Vehicle type, Phenomena (time sequence of phenomena after the accident) and Pollution (type of pollution eventually caused).

3. Accident classification criteria

During this analysis the following agreements and hypotheses were adopted:

1. The incident type (IT) field classifies each accident under four basic categories: fire, release, explosion and gas cloud. Each accident may belong to one or more of these types. Each basic IT may include more detailed information (whether the accident involved a fire, whether it was a pool fire, a jet fire, etc.). However, such additional information, which is often incomplete or even lacking, is irrelevant to the present study. It was therefore ignored, and only the four basic types were applied to the Phenomena field.

   Bearing in mind that MHIDAS normally reports accidents according to their actual evolution; an evident shift or change in the sequence of events was corrected when detected. For example, an accident involving a "release" followed by (or including) a "pool" release is classed in the "release" category, according to the present criteria. Likewise, an event described as an "unconfined explosion" is simply classed as an "explosion".

   The database does not always report releases causing gas clouds, though it is evident that gas clouds are a direct consequence of an unwanted gas emission; therefore, all gas clouds were considered to be preceded by a release.
2. MHIDAS does not contain a field that explains which initial event causes the incident. The *general cause* (GC) and *specific cause* (SC) fields do not include a time sequence of events, so a new field, *Initial event*, was added, replacing the previous two.

   The main problem is often one of establishing the correct succession of events: for example, the abstract of the famous accident in Mississauga in Canada reports *Series of explosions/BLEVEs followed derailment of LPG tankcars. Missiles thrown 667 m. Fire threatened derailed chlorine tanker which leaked for 51 h while fire burned + further 48 h until hole plugged. Mass evacuation of area organised.* The GC field in the database states External–Impact–Mechanical, while the SC field states Extnlfire–Overheat–Railacc, so it is possible to establish some sort of sequence (such as Impact, Railacc, External, Extnlfire, Mechanical and Overheat) although one cannot be 100% sure. For this reason, an Internet search for further information was sometimes required.
3. The database often proves to be quite vague when it splits up the different substances. Generic categories like "oil" or "chemicals" often appear in the Material name field. For this reason, the substances were grouped according to their names as reported by MHIDAS (e.g. the category "petrol" includes "petroleum products", "petroleum naphta", etc.).

4. Results

4.1. Distribution of the accidents over time

The various authors who have analysed variations in the frequency of accidents as a function of time for chemical plants, transportation of hazardous materials or maritime transportation have found a significant increase in the number of accidents in recent years. For the large number of accidents processed in the present analysis, this trend is again found.

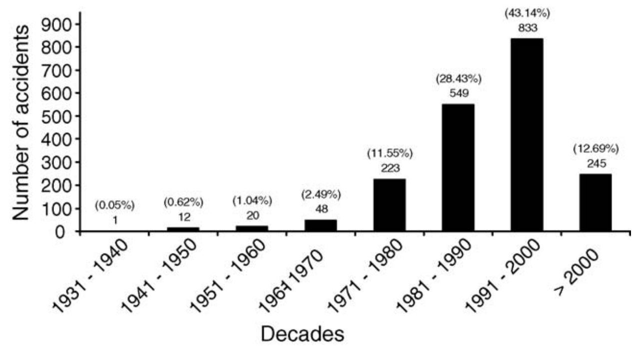

Fig. 2. Distribution of accidents as a function of time.

The distribution of the accidents as a function of time is plotted in Fig. 2 (one accident was removed because the date was unknown). It can be observed that there is a gradual increase with a significant rise in the period 1981–2000.

This behaviour must be essentially attributed to the influence of two factors: the increase in land transport (road and rail) and better access to information on accidents. It is likely that this second factor partly masks the general trend seen in Fig. 2.

4.2. Accident location

The location of the accidents was studied from three points of view: the country in which the accident happened, the kind of land traffic (rail or road) and the type of thoroughfare.

The accidents were divided into three categories according to the place where they occurred: (1) United States, Canada, Australia, Japan, New Zealand and Norway, (2) the European Union and (3) the rest of the world.

More than half of the registered accidents occurred in the first category, 35% in the second and only 9% in the third. Although obviously the greatest volume of land traffic of hazardous substances in more industrialised countries explains these results, there is probably a certain bypass in the data, as, due to the origin of the data base, a more intensive and complete search of accidents occurring in the UK and the USA was possible. Thus, the USA (47%) and the UK (30%) are the countries with the highest percentage of accidents during the transport of hazardous materials by rail or road, while Germany and France, whose chemical industries are similar in size to that of the UK, show much lower values.

As for the kind of land traffic, of the total number of accidents found (1932), 37% occurred on railways and 63% on roads. In the survey performed by Haastrup and Brockhoff [3] on 691 accidents (including maritime and pipe-line transport), 207 (30%) occurred on road and 256 (37%) on rail; if only road and rail accidents are considered, these percentages become 45% (road) and 55% (rail), somewhat different from the values obtained here.

Of the accidents occurring on roads for which the type of road is known, the most frequent category is highways (81.4%), followed by level crossings and minor roads (both with 7.6%), and finally tunnels (3.3%). The database contains 13 accidents, which occurred inside tunnels. If the one that occurred in 1949 is not considered, then seven occurred in rail transport and five in road transport.

The accidents that occurred in railway tunnels were mostly caused by derailment (six cases). In two of these incidents there were no further consequences; in the other five, derailment was followed by fire. There were fatalities in two of them. The accidents that occurred in road tunnels were mostly caused by road accidents (four cases); in three of them there were fatalities. In all of the tunnel accidents involving a fire, extinguishing the fire was quite difficult because of the smoke, and in some cases the fire burnt for several days.

4.3. Phenomena

The accidents are classified into four different types: release, explosion, fire and gas cloud. However, 18% of the accidents were not classified into any of these four types.

From the ones whose type was known, the analysis shows that releases are the most common type of accident, appearing in 78% of cases, followed by fires in 28%, explosions in 14%, and finally gas clouds in only 6%.

The total percentages add up to more than 100% because a particular accident may, strictly speaking, be placed in more than one of these categories. 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; most accidents do in fact start with a release.

Taking into account the hypotheses and criteria presented in Section 3, the general event tree shown in Fig. 3 was obtained. This tree was drawn up thanks to the availability of data for 1573 accidents, whilst for the rest the incident sequence was not specified.

The figures in square brackets represent the probability of occurrence in comparison with the level immediately above that (i.e. obtained from the ratio of the number of accidents to the number of accidents at the higher level). The figures at the end of each branch show the overall probability of occurrence of each specific accident sequence in comparison to the whole set of events.

The following observations can be made with reference to the results:

- The percentage of release cases without further events (fire, explosion and gas cloud) is highest at 62%.
- In general, release–fire sequences account for 9.5% of cases, while release–fire–explosion sequences account for 0.6%. Therefore, 1 out of every 8 releases gives rise to a fire and 1 out of every 16 release–fire events causes an explosion.

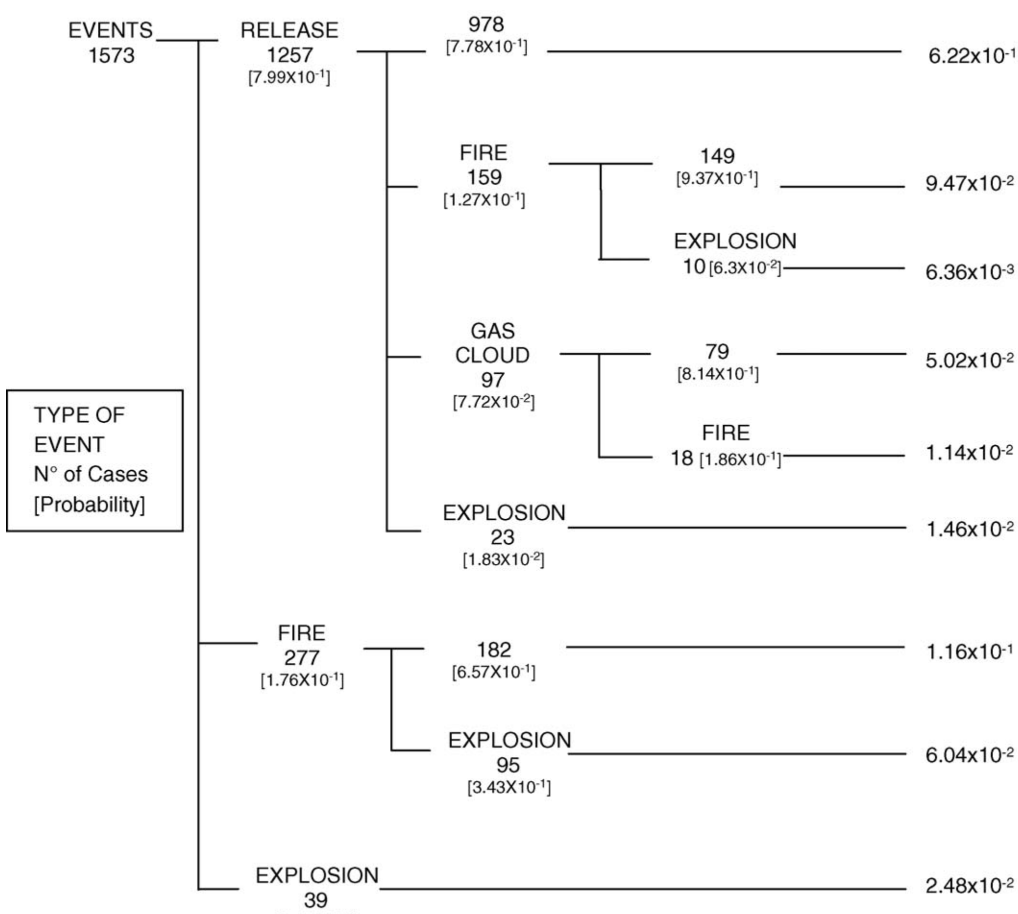

Fig. 3. General event tree and relative probabilities of occurrence.

- The release–gas cloud–fire sequence occurs once for every 5.4 times a release–gas cloud sequence occurs.
- Immediate explosions after a release occur in 1.5% of cases.
- Fires (all types and sequences) are present in 29% of cases.
- In the general set of accidents, only 1 out of every 4.3 fires leads to an explosion.
- Considering all the events in Fig. 3, 1 out of every 9.4 accidents leads to an explosion, 1 out of every 3.6 accidents leads to a fire and, more specifically, 1 out of every 15 accidents leads to fire–explosion.

Comparing these results with the ones obtained by Ronza et al. [2] in a previous study of accidents occurring in ports, a similar trend concerning releases and fires can be observed. However, the number of accidents leading to an explosion is far greater in ports than in land traffic.

4.4. Initial event

Eight types of possible causes were taken into consideration: mechanical failure, impact failure, the human factor, instrumental failure, services failure, violent reaction, external events and upset process conditions. It should be mentioned that 9% of the accidents were not classified into any of these general causes and were therefore not included in this analysis.

According to the analysis, 73.5% of accidents in road and rail transport were caused by an impact or collision between vehicles, derailment of trains or lorries crashing, etc. (an origin which often implies human error). They were followed by types of mechanical failure, external events and human factors, which together add up to more than 18%. The percentages for the remaining causes show that the latter are quite relevant (8%), so the general category of “Others” was created.

For the majority of general causes, one or several specific causes can be defined. As can be seen in Table 1, within the impact category a road collision was the specific cause of 44% of the accidents, while the cause of 37% of the accidents was a rail crash. These data agree with the information published by Tiemessen et al. [4], who found that overturning of a road tanker followed by a release was the most significant transport accident type in The Netherlands. The main cause of mechanical failure was valves at 29%. In this category, there were a great variety of causes, which is why the “Others” section has such a high percentage (42%). The most common external events were external fires (44%), sabotage (9%) and explosions (8%). Finally, in considering human factors, the most significant ones were general operations at 35%, and procedures at 11%. In this case the “Others” percentage is also quite high because there are a great variety of specific causes.

Of the total of 1932 accidents the most frequent initial event (general cause + specific cause) is Impact–Roadacc at 30%, followed by Impact–Railacc at 25% and Impact–Vehicle at 13%.

4.5. Population affected by the accidents

The population affected by the accidents can be divided into three variables according to the scale of the consequences: number of deaths, number of people injured and number of people evacuated.

Table 1
Specific causes of accidents

General cause	Specific cause	Number of accidents	Percentage of category
External	External fire	58	44
	Other causes	25	19
	Sabotage	12	9
	External explosion	10	8
	Floods	9	7
	Temperature	8	6
	High winds	7	5
	Ground	4	3
Human	Other causes	65	47
	General operations	48	35
	Procedures	10	7
	Maintenance	7	5
	Design	4	3
	Communication	3	2
Impact	Road accident	727	44
	Rail accident	603	37
	Vehicle	278	17
	Heavy object	19	1
	Other causes	11	1
Mechanical	Other causes	59	42
	Valve	40	29
	Metallurgical	12	9
	Overheating	7	5
	Corrosion	5	4
	Brittle	5	4
	Hose	5	4
	Fatigue	4	3
	Overpressure	3	2

4.5.1. Number of deaths

In 67% of the accidents analysed there is no information available as to whether or not there were fatalities. In the 33% for which this information is available, the majority of accidents (more than 61%) did not cause deaths.

Of those that did cause fatalities, a very high percentage (almost 32%) involved 1–10 deaths; 5% involved 11–50 deaths and only 9 involved more than 50 deaths (of which only 5 involved more than 100 deaths). The accident that caused most deaths (581) was a railway derailment in Dronka, Egypt, in November 1994.

As to the deaths per decade, it was noted that there has been a clear increase in the last decade. This could be directly related to the fact that the number of accidents has also increased in the recent years due to the increase in land traffic. Moreover, recent improvements in access to information on accidents also means that there are more specific figures on the number of deaths.

Accident mortality statistics can be used to obtain social risk curves using accumulated frequency/number of deaths graphs, usually called *f–N* [3], which relate the number of deaths in a particular accident to the relative probability of there being that number of deaths.

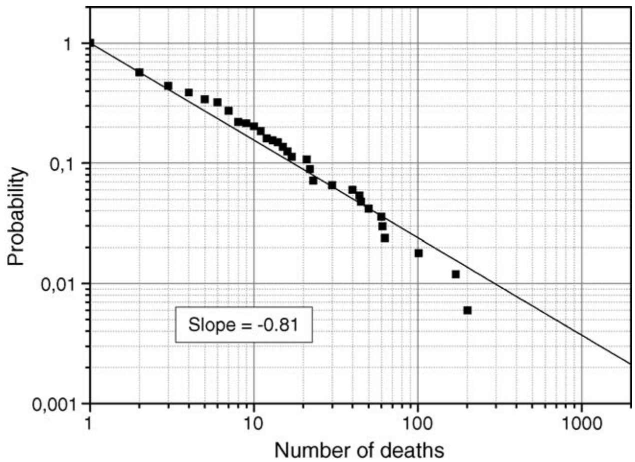

Fig. 4. Accumulated probability of a road accident with N deaths.

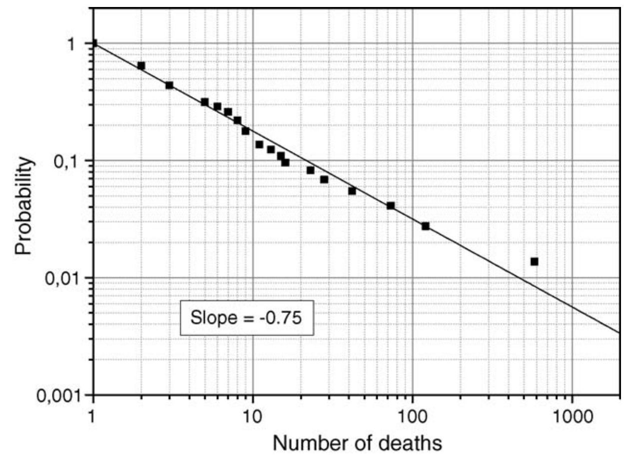

Fig. 5. Accumulated probability of a rail accident with N deaths.

Although it is not possible to calculate the frequency (deaths/year) because information is not available on all the accidents that occurred, it must be assumed that the sample used is representative; this therefore allows a "relative frequency" to be estimated for accidents in which there are 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 in establishing 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 degree of severity will occur.

For this analysis, we used accidents in which there was at least one fatality, grouped them according to the number of fatalities and calculated the cumulative probability or frequency, using the following expression:

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

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

The values obtained for the accidents selected can be seen in Figs. 4 and 5. For $1 < N < 1000$, the best fit (minimum square method) for a curve of type $P = N^b$ gives $b = -0.81$ for road accidents. A straight line with a slope of -0.81 is obtained by plotting the data on a log–log axis system. This indicates that the probability of an accident involving 10 or more deaths is 6.5 ($P = 10^{-b}$) times greater than that of an accident involving 100 or more deaths.

In the case of rail accidents (Fig. 5), the slope is slightly different, $b = -0.75$, i.e. the probability of an accident involving 10 or more deaths is 5.6 times greater than that of an accident involving 100 or more deaths.

According to these data, the consequences of an accident are likely to be slightly more severe if the accident occurs on a railway rather than on a road.

The same plot for accidents in process plants and in the transport of hazardous substances [5] gave a value of -0.84, for accidents occurring in port areas the gradient was -0.68 [6] and for natural disasters (earthquakes, floods, etc.) Fryer and Griffiths [7] obtained gradient values of between -0.4 and -0.7.

The severity of accidents was also analysed as a function of the level of development of the countries in which the accidents took place. Fig. 6 shows the influence of the level of development, comparing incidents occurring in (1) United States, Canada, Australia, Japan, New Zealand and Norway, (2) the European Union and (3) the rest of the world.

Although the class "rest of the world" is the one with the lowest percentage of accidents (as stated above), the severity is clearly higher than in the first two (see Fig. 6). This group includes most developing countries, where the quality of the roads and vehicles and the safety measures during the transportation of hazardous goods may not be as effective as in the other two groups. The difference between the behaviour of the graphs for groups (1) and (2) is practically nil. This is in good agreement with the data published by Carol et al. [8] on accidents in industrial facilities.

4.5.2. *Number of people injured*

As in the previous section, the number of people injured was grouped into categories (1–10, 11–100, etc.). In this case,

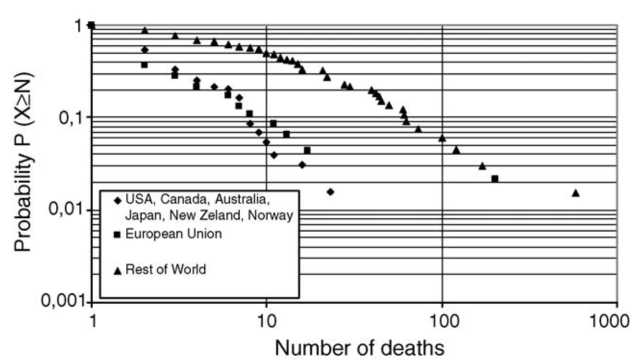

Fig. 6. Severity of the accidents as a function of the state of development of the country.

information on the number of people injured is only available for 41% of the 1932 accidents analysed. The total number of people injured was 11,282. Half of the accidents for which information is available did not involve injuries, and in 32% of the remaining cases, between 1 and 10 people were injured. Only four accidents caused more than 500 injuries. The accident with the highest number of injuries (1000 people) was the one that occurred in Mexico in 1981, when a train derailed near a train station.

4.5.3. Number of people evacuated

It was only possible to obtain evacuation data for 29% of the accidents, which involved the evacuation of a total of 763,097 people. Of the 561 accidents, 97 involved no evacuations, 133 involved the evacuation of between 1 and 10 people, 90 accidents between 11 and 100 people, 162 accidents between 101 and 1000 people, 69 accidents between 1001 and 10,000 people, 4 accidents between 10,001 and 20,000 people and 6 accidents more than 20,000 people. The incident in which the greatest number of people was evacuated is the famous train derailment in Mississauga, Canada, in 1979.

5. Conclusions

The historical analysis carried out on a sample of 1932 accidents shows an upward trend in terms of frequency. In fact, it is well known that the land transport of hazardous materials has increased significantly in the last decades, due to the annual increase in the number of tonnes km/year, and this is certainly one of the reasons for this situation. Furthermore, it should also be taken into account that better and broader accident reporting practices currently exist, which probably partly masks the aforementioned trend. However, the information gathered seems to indicate that if safety measures are not improved there will be a growing number of accidents in the next few years.

Of the total number of accidents found, 37% occurred on railways and 63% on roads. These data are different from the sparse data found in literature: in another survey [3] on 463 accidents, 45% of accidents occurred in road transport and 55% in rail transport.

According to the event tree, the most frequent phenomenon without further consequences is release, which occurred in 62% of cases, followed by fire, which occurred in almost 12% of cases. However, as one phenomenon was often followed by another, the following information is probably more significant: the most frequent sequence is a release followed by a fire (12.7%), a gas cloud (7.7%) and an explosion (1.8%). Approximately 1 out of every 9.5 accidents leads to an explosion, 1 out of every 3.5 accidents leads to a fire and 1 out of every 15 accidents leads to a fire and an explosion.

The most frequent initiating event of accidents is impact, with 73.5% of the accidents being due to collisions. More than half of the accidents did not cause any fatalities. Of those accidents in which there were deaths, in the majority of them the number of deaths was between 1 and 10. The probability/frequency curve has a gradient of -0.81 for road accidents and -0.75 for rail accidents. According to these data, it seems that once an accident happens the consequences will probably be slightly more severe if it occurs on a railway rather than on a road.

The severity of accidents that occur in developing countries is significantly greater than that of accidents that occur in the developed world. This substantiates the risk planning policies in place in developed countries.

In half of the accidents there were no injuries; most of the remaining accidents involved 1–10 or 11–50 injuries. Finally, the scarcity of data available on the number of people evacuated indicates that if there is an evacuation (which is rather unusual) the number of people involved is usually between 101 and 1000 (29%), followed by the class of between 1 and 10 (24%). Only in six cases were there more than 20,000 evacuees.

Overall, the study presented here reveals a worrying trend in the frequency of accidents.

There is clearly a need to improve safety measures in the various aspects of land transport to tackle the growing frequency detected in the occurrence of accidents. It should be emphasised again that 73.5 % of accidents were initiated by collisions (i.e. traffic accidents) and that most accidents in tunnels were caused by derailment (rail) and by road accidents. Therefore, besides general aspects, such as maintenance of trains and lorries, better road conditions, etc., training of professional people involved in this transportation seems to be of major importance.

Acknowledgements

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References

[1] MHIDAS, Major Hazard Incident Data Service, OHS_ROM, Reference Manual, July 2004.
[2] A. Ronza, S. Félez, R.M. Darbra, S. Carol, J.A. Vílchez, J. Casal, Predicting the frequency of accidents in port areas by developing event trees from historical analysis, J. Loss Prev. Process Ind. 16 (2003) 551–560.
[3] P. Haastrup, L. Brockhoff, Severity of accidents with hazardous materials: a comparison between transportation and fixed installations, J. Loss Prev. Process Ind. 3 (1990) 395–405.
[4] G. Tiemessen, J.P. van Zweeden, Risk assessment of the transport of hazardous materials, in: Loss Prevention and Safety Promotion in the Process Industries, vol. 1, AEIC, Barcelona, 1998, pp. 299–307.
[5] J.A. Vilchez, S. Sevilla, H. Montiel, J. Casal, Historical analysis of accidents in chemical plants and in the transportation of hazardous materials, J. Loss Prev. Process Ind. 8 (1995) 87–89.
[6] R.M. Darbra, A. Ronza, S. Carol, J.A. Vílchez, J. Casal, A survey of accidents occurred in ports, in: 11th International Symposium Loss Prevention and Safety Promotion in the Process Industries. Loss Prevention, vol. D, CSCHI, Praha, 2004, pp. 4305–4311.
[7] L.S. Fryer, R.F. Griffiths, Worldwide data on the incidence of multiple-fatalities accidents, Saf. Reliability Directorate 149 (1979) (SRD R).
[8] S. Carol, J.A. Vílchez, J. Casal, Study of the severity of industrial accidents with hazardous substances by historical analysis, J. Loss Prev. Process Ind. 15 (2002) 517–524.