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Status and functioning of the European Commission's major accident reporting system

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Abstract

This paper describes the background, functioning and status of the European Commission's Major Accident Reporting System (MARS), dedicated to collect, in a consistent way, data on major industrial accidents involving dangerous substances from the Member States of the European Union, to analyse and statistically process them, and to create subsets of all non-confidential accidents data and analysis results for export to all Member States. This modern information exchange and analysis tool is made up of two connected parts: one for each local unit (i.e., for the Competent Authority of each EU Member State), and one central part for the European Commission. The local, as well as the central parts of this information network, can serve both as data logging systems and, on different levels of complexity, as data analysis tools. The central database allows complex cluster and pattern analysis, identifying and analysing the succession of the disruptive factors leading to an accident. On this basis, 'lessons learned' can be formulated for the industry for the purposes of further accident prevention. Further, results from analysing data of major industrial accidents reported to MARS are presented. It can be shown that some of the main assumptions in the new 'Seveso II Directive' can directly be validated from MARS data. © 1999 Elsevier Science B.V. All rights reserved.

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1. MARS: A brief recap

The background and functioning of the Major Accident Reporting System (MARS), operated and further developed by the Major Accident Hazards Bureau (MAHB) of the

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European Commission's Joint Research Centre (JRC) in Ispra, Italy, has been described in detail elsewhere, [Refs. [1–4]; as well as on MAHB's www homepage under http://mtrls1.jrc.it/mahb/MARS.html], and can briefly be summarised, as follows.

1.1. MARS

It is the mandatory major industrial accidents database and reporting scheme within the European Union, based on the legal requirements of the 'Seveso Directive' [5].

It includes 'major accidents' of certain types and 'unusual' characteristics (which, in a way, is also a definition of a 'major accident' itself, see, e.g. the quite fuzzy definition in previous legislation [6]). In this context, an 'unusual' (major) accident shall be understood as an event which is characterised by its 'unwontedness' in terms of associated large consequences and/or somehow unusual or unexpected nature [7]. The possible yield of valuable information from such events for the purposes of generating 'lessons learned' from accidents for industry and regulatory bodies is considered to be high.

Major Accident Reporting System has the following purposes.

(1) The rapid dissemination of the information supplied by Member States pursuant to Article 15 (1) of the 'Seveso Directive' among all Competent Authorities (CAs) of the EU Member States.

(2) Distribution to CAs of an analysis of the causes of major accidents and the lessons learned from them.

(3) Supply of information to CAs on preventive measures.

(4) Provision of information on organisations able to provide advice or relevant information on the occurrence, prevention and mitigation of major accidents [5].

Thus, apart from information distribution (which is described in detail elsewhere, see Refs. [1,2]), the main purpose of MARS is to analyse the data reported by the Member States to the Commission with regard to *generation of lessons learned from accidents*.

This shall be done within the overall objectives of the Directive, i.e.

- prevention of major accidents involving dangerous substances;
- limitation of their consequences on man and the environment.

The practical functioning of the MARS information exchange network as well as aspects of its possible future development are discussed in the concluding Section 6 of this paper.

2. Objectives of analysis

The ultimate aim of a query on any industrial accidents database is the generation of 'lessons learned'.

Since technicians, engineers and managerial people both from industry and regulatory bodies often use this term (consciously or unconsciously) in an extremely vague manner, expecting 'something of practical value' from a scientific database without often being able to express what they are actually interested in, we shall start this section by giving a clear definition of lessons learned:

> A ‘good work practice’ or innovative approach that is captured and shared to promote repeat applications or an adverse work practice or experience that is captured and shared to avoid a recurrence (U.S. Department of Energy, Society for Effective Lessons Learned Sharing, 1997).

‘Lessons learned’ from major industrial accidents should help to identify significant areas of concern—both hardware- (equipment) and software- (management, regulation) related—and to set priorities for possible further improvements. Points where more research and/or regulation for industry might be necessary can be identified as well as input to (qualitative) risk analysis be given by identifying relevant top events, initiating events, intermediate events and accident progression scenarios.

3. Evaluation of the status of MARS

3.1. The method of analysis

In the first instance, the contents of MARS are reviewed for completeness and homogeneity and the accidents are categorised according to certain event descriptors of interest, defined by the structure of the reporting format which constitutes the architecture of the database (see detailed description in Ref. [2]). This qualitative evaluation results in numbers (percentages) indicating the relative contribution of a particular (qualitative) realisation of a certain accident event descriptor with regard to the entire event sample. [1]

Such types of ‘analysis’ are—mainly due to easy access to modern spreadsheet software—most popular among ‘analysts’, allowing speedy production of colourful histogram plots and pie-charts, which usually satisfy managers in industry and regulatory bodies, but are unfortunately unable to generate anything related to lessons learned from accidents.

However, although this has nothing to do with data *analysis* (it is just a regrouping of data, while ‘analysis’ focuses on replacing the apparent structure of data by their underlying—usually causal—structure), the results of such exercises can be useful to give coarse indications on which type of information is included in the database. Thus, in our opinion, the only meaningful use of such ‘analyses’ is to produce summary information, which can be helpful for a potential user to assess whether or not he or she is interested in principle in the type of information included in a particular database and thus in making further queries on it.

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[1] A descriptor of an accident could be its ‘type of occurrence’ or ‘type of adverse effect on human beings’; the respective realizations can either be qualitative (e.g. ‘release’ as a qualitative realization of ‘accident type’) or quantitative (e.g. ‘20 fatalities’ as the quantitative realization of the ‘number of fatalities’ of descriptor ‘type of adverse effects on human beings’).

3.2. How 'likely' are MARS-type of accidents?

Accidental events which are notifiable to MARS are events which occur in 'Seveso establishments', as defined by the Directive.

Similar to its predecessor, the scope of the 'Seveso II Directive' follows a so-called two-tier approach which means that for each named substance and for each generic category of substances and preparations, two different qualifying quantities (threshold levels) are mentioned in the Directive, a lower and an upper value (e.g. for chlorine: 20 and 100 t). It is assumed that the risk of a major-accident hazard, arising from an establishment in which dangerous substances are present, increases with the quantities of substances present at the establishment. Consequently, the Directive imposes more obligations on upper-tier than on lower-tier establishments (see Directive [5] or discussion paper on the legal background of the new Directive in Ref. [8]).

The number of such sites in the Member States of the European Union is not yet available, but it seems likely that—although the number of upper-tier establishments will definitely increase as a consequence of the stricter requirements of the new Directive—the total number will not become much more than a few thousands, say 3–5000.

Currently, there have been about 300 + major accident events notified to the MARS database [2], accidents which have been reported by the Member States according to 'Seveso I' requirements and definitions [3]. Since, so far, in (almost) no 'Seveso establishment,' more than one major accident occurred, it can be concluded that the ∼ 300 accidents in MARS occurred in ∼ 300 'Seveso establishments.' We will *not* estimate a 'major accident frequency': $\lambda = \sum_{i=1}^{N}(x_i/NT_i)$ (with x_i being the number of major accidents in establishment i, T_i the operating experience of establishment i in years and N the total number of the establishments), since this would only make sense if all establishments were comparable, i.e. 'similar' with regard to all of their characteristics (type of industry, substances handled, etc.).

The main result here is that—although the ∼ 300 accidents in MARS are a quite small and—for probabilistic purposes—extremely inhomogeneous sample (see discus-

[2] The number of events reported so far is—fortunately—not very large, but what makes MARS unusual among industrial accident databases (such as TNO's FACTS, AEA's MHIDAS containing several thousand events, or national databases such as ARIA in France or ZEMA in Germany) is the level of detail, which is usually sufficient to establish the detailed causes of the accident, both the intermediate causes and the underlying ones. Each event in MARS is structured in the form of ∼ 200 data variables of which ∼ 30 are free text fields (describing causes, evolution, consequences of major industrial accidents that occurred since 1984 in the EU). Thus, ∼ 51 000 individual categorical (selection lists, click boxes) and numerical data values define together with ∼ 9000 free text fields the total amount of information included in the database. Concerning common trends in the data collected by these different databases, what can be said is that—at least for comparably well-defined events such as 'major accidents'—especially the distribution of causal factors, it shows clear similarities. Typically, the importance of underlying management and organizational weaknesses as well as of maintenance-related human failures in contrast to operator errors is identified. For further details, reference shall be given to a cross-comparison of the 'major accidents' data collected in various EU and OECD countries included in Ref. [17].

[3] 'Seveso II' has to be implemented in national legislation before February 1999.

sion in Section 3.5.1)—the sheer fact that in the past, in ∼10% of the major-hazardous industries in the European Union (i.e. in 'Seveso establishments') an accident worth to be notified to the Commission actually occurred, highlights the importance of the information included in MARS for the purposes of further accident prevention and mitigation of their consequences.

3.3. How 'complete' is the coverage of major accidents in MARS?

For any accidents database, whether it is nuclear, chemical process/storage or transport-related, depending on the 'severity' of an accident, a certain discrepancy between the number of accidents that actually occur and those that are recorded in a database can be observed (Fig. 1) [9].

In other words, since 'major accidents' usually cause severe damage or danger, these relatively rare events have a high probability of being publicised and thus recorded in a database. Thus, it can be assumed that this basic completeness is given for 'major accidents' in MARS.

The main result here is that MARS seems to cover, to a high degree of completeness, accidents that occurred within the European Union and had an associated large 'seriousness' ('major accidents').

3.4. How 'unusual' are MARS-type of accidents?

To describe the 'unwontedness' of accidents in quantitative terms, a proposal for an industrial accidents gravity scale has been prepared by the European Commission [10]. This scale was adopted by the CAs of the Member States in 1993 as an analysis tool on a trial basis, producing a single-valued 'Gravity Level G' from $G=1$ to $G=6$ (from 'worthy of note', $G=1$, to 'catastrophic' type of accidents, $G=6$). $G=0$ would stand for negligible consequences. The detailed definitions of the 18 accident descriptors used in this scale (including descriptors related to the quantities of substances involved, to the

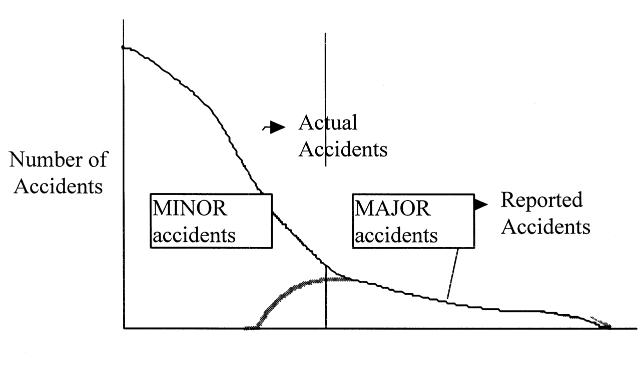

Fig. 1. Discrepancy between actual and reported accidents.

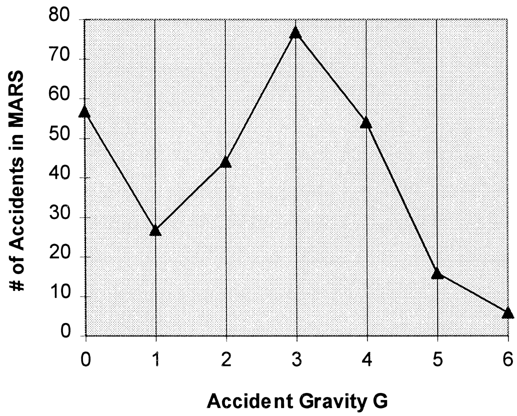

Fig. 2. Distribution of accidents in MARS as a function of gravity (status June 1997).

consequences to man and the environment and to response measures), their quantitative measures and respective scaling are given in [7]. [4] In summary, (1) this '*G*-Scale' is attractive and worth using because of its large number of accident descriptors related to consequences (many of them describing environmental impact), to emergency and restoration measures, and to the 'nature' of the event itself (e.g. quantity of substances released). (2) Further, since the results can be summarised in an easily understandable single index—ranging from $G=1$ to $G=6$—the scale permits, in principle, rapid and simple communication with all parties involved.

As described above, the 'major accidents' in MARS based on 'Seveso I' (currently all events in the database) have as a common underlying 'definition' the assumption that all these events are 'unusual' in the sense that the circumstances of their occurrence and/or their consequences caused significant attention from the public, authorities and/or industry. Before starting any 'analysis' of the accidents in MARS, we have to be sure that this basic homogeneity in the type of accidents is given by determining the gravity values and plotting their distribution.

As can be seen from Fig. 2, the accidents reported to MARS cluster around gravity values $G=3$–4 ($\sim$ 50% of the events), which means that—considering the fact that the notification criteria of the new 'Seveso II Directive' will result in the obligation of reporting accidents with gravity lying between $G=2$ and $G=3$ and above [11]—the majority of events in MARS are really 'major accidents' in the sense of the (new) Directive ($G \geq 2$ corresponds to $\sim$ 70% of the events in MARS). $\sim$ 20% of the events are beyond scale, i.e. have negligible consequences. This shows that also the second important purpose of MARS (besides generating lessons learned from major accidents) is fulfilled to a large extent: collecting, analysing and distributing information on

[4] The definition of the $G=1,2,\ldots,6$ gravity categories is based on quantitative 'widths' which are essentially determined by logarithmic scaling. The way of combining the resulting scores of each of the descriptors is determined by taking the maximum *G*-value.

accidents/incidents or 'near misses' which Member States regard as being of particular technical interest for preventing major accidents and limiting their consequences and which do not meet the (quantitative) criteria in the (new) Directive.

The plot of the moving average trendline in the gravity of accidents in Fig. 3 shows that the average 'seriousness' of accident occurrences has been relatively stable over the last decade (oscillating between $G = 2$ and $G = 3$).

There seems, however, to be some interesting variations in this behaviour: while in the first half of the reporting period, the average gravity of accidents slightly decreased (not necessarily due to a decrease in the actual occurrence frequency of major accidents, but most probably due to an increased reporting of 'other' events of potential interest in the above sense), this trend seems to have somehow reversed in later years. If this is indeed due to changes in reporting and not due to changes in actual accident occurrences, then it could be argued that the reason can be found in the fact that from ∼1993 when concrete discussions began and early 1994 when the Commission published its original proposal for a new 'Seveso Directive' [12], the CAs preferred to wait about which changes are coming and to send only accidents which are 'clearly' major accidents instead of providing other information of potential interest as well.

3.5. Some examples on MARS data evaluation

3.5.1. Trend in major accident occurrences

Fig. 4 shows the growth of the MARS database in the form of a trend of the occurrence dates of the events notified to MARS (status June 1997).

As can be seen from this figure, major accident occurrences within the European Union seem to occur at a relatively constant rate in time. Although such a statement

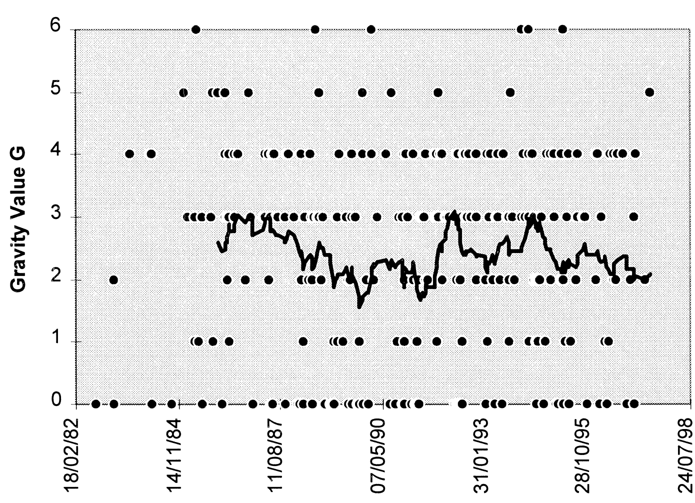

Fig. 3. Trend of gravity of accidents notified (status June 1997).

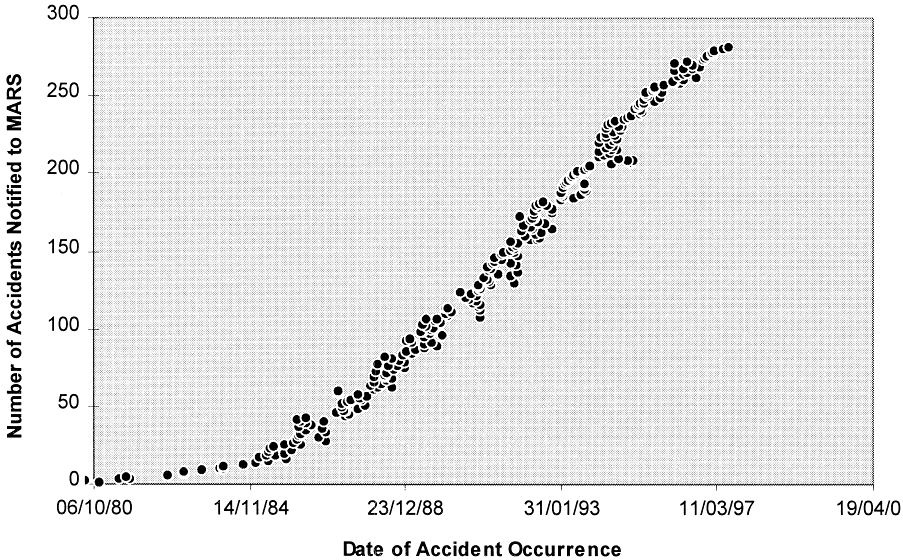

Fig. 4. Number of accidents notified to MARS as a function of their occurrence date (status June 1997).

should only be given with great care (as explained in detail elsewhere [13], the generation of event frequencies can usually not be accomplished by any industrial accidents database due to missing information on the underlying plant/system/component population) *under the two assumptions*.

(1) That a 'major accident' is—independent of its specific characteristics, such as type of accident, consequences, substances involved, industrial establishment in which the accident occurred, etc.—a concept homogenous enough to be of relevance for further consideration.

(2) That the basic completeness of notification of such 'major accidents' to MARS is given (which seems quite likely to be true, see above).

The constant growth curve in Fig. 4 would clearly contradict arguments put forward in recent conferences on industrial safety that focus should move more and more away from analysing major accidents, as there is a feeling that in many industry sectors, they are largely controlled by now, to analysing the many minor accidents that occur in industry (which are often precursors to major accidents).

Although research on such 'near-misses' is of great importance, especially for the purposes of quantitative risk assessment (as has been shown both for the nuclear [14], and for the chemical process industries [13]), the ~ constant major accident growth rate in Fig. 4 would be an argument for continuation of major accidents research and the classical statement of the UK's 'safety guru', T. Kletz would still be valid:

> It might seem to an outsider that industrial accidents occur because we do not know how to prevent them. In fact they occur because we do not use the knowledge that is available [15].

The main result here is that, from the above data plotting, of course nothing can (or rather should) be said on the numerical value of the occurrence rate λ of a 'Seveso-type of accident,' but we are quite confident that the important result of a $\sim$ constant rate, $\lambda(t) \approx \lambda$, holds true.

3.5.2. Trend in major accident notifications

Fig. 5 shows the time difference between dates of the occurrence of major accidents and dates of their notification to MARS. As can be seen from this figure, the vast majority of events is notified to the Commission (i.e. to MARS) in a complete 'Full Report' version (i.e. by submitting a full accident analysis report, see Refs. [1,2] for notification procedure) after $\sim$ 15 months following accident occurrence.

The moving average trendline in these data points shows a *shortening of the time delay* between accident occurrence and notification to MARS down to averaged values of a few weeks or months *with one significant exception*: from $\sim$ event 210, the trend significantly turns and the averaged delay times increase again to values of $\sim$ 15 months. It is not by chance that this period corresponds to the time when the Commission published its original proposal for a new 'Seveso Directive' in early 1994 [12]. Possible changes in the legal framework tend to cause confusion among administrators and their usual reaction is to wait and see how things come.

3.5.3. Industrial activities

Fig. 6 shows the distribution of the number of accidents notified vs. an important descriptor—the type of industrial activity of the establishment in which the major accident occurred. As can be seen from this graph, MARS accidents originate to more than 80% from a relatively small set of industries: mainly petrochemical (20%),

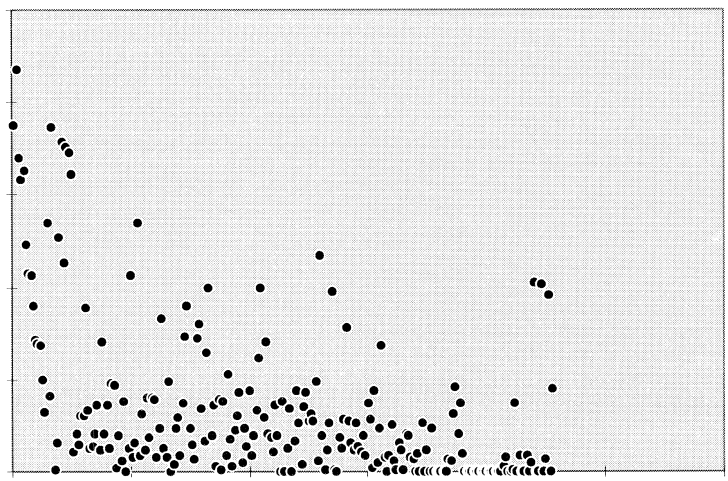

Fig. 5. Delay in notifying accidents to MARS (status June 1997).

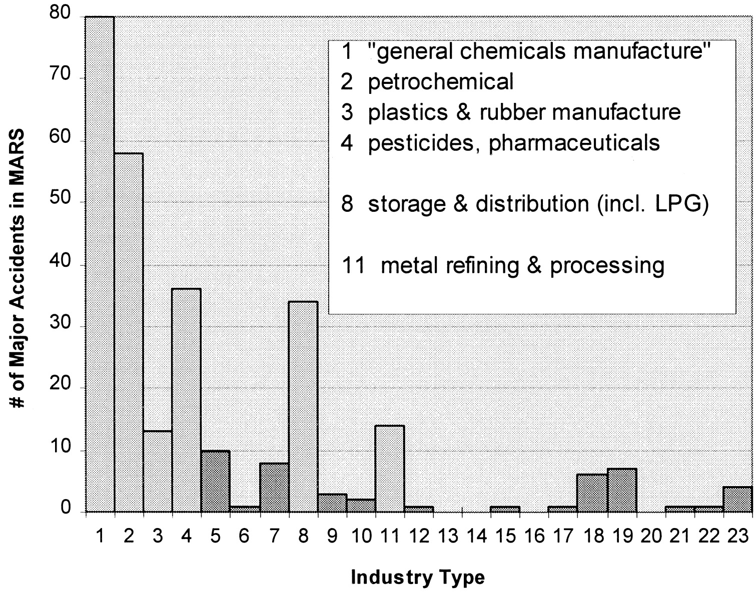

Fig. 6. Number of accidents notified to MARS as a function of type of industrial activity (status June 1997).

pesticides/pharmaceuticals (13%) and wholesale and retail storage and distribution (12%) (including LPG bottling and bulk distribution, tank storage farms, etc.). The remaining 55% of events originate mainly from 'general chemicals manufacture', which means that the information submitted to MARS has been sufficient to understand the industrial context in which the accident sequence occurred and thus the specific industrial activity relevant for the major accident notified. In only 1% of the events, the information was not sufficient to make any classification.

The *result*, mainly indicating the large contribution from petrochemical industries (codes 2 and partly 8), is useful to provide a potential user of the database with an indication from which type of industrial activities information can be retrieved.

3.5.4. Types of accidents

Fig. 7 shows the distribution of the number of accidents notified vs. the type of accident. As can be seen from this graph, 67% of the events are (gas) releases (to air), 10% releases (to water), 44% explosions and 48% fires. As can be expected for 'major accidents' which are likely to consist of complex event sequences with several accidental 'outcomes', there is significant overlap between these generic categories in individual major accidents.

Compared to Section 3.5.3 (number of accidents vs. industrial activity), this *result* is much less useful in terms of providing a potential user of the database with some guidance on the type of information included. The usage of the breakdown into relative contributions comes to its limit of application as soon as, e.g. relations between categories become strong: concerning accident types, it would, e.g. be necessary to

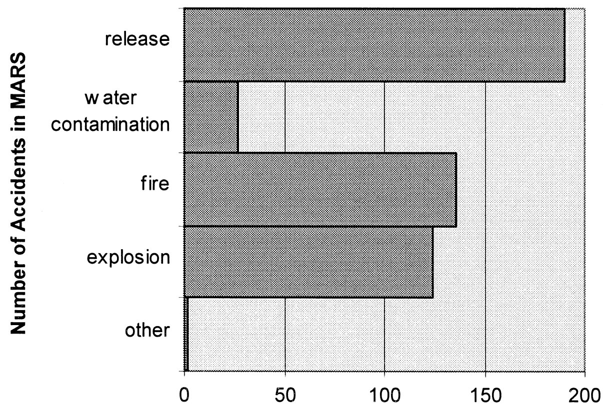

Fig. 7. Number of accidents notified to MARS as a function of accident type (status June 1997).

evaluate the strong impact of overlap of categories—in other words, the causal relations between them. Correlation analysis can, however, not be achieved by using such simplistic approaches.

3.5.5. Immediate consequences of accidents

Fig. 8 shows the distribution of the number of accidents notified vs. their immediate consequences. As for the accident-type categories in Section 3.5.4, there is significant overlap among the consequence categories (obviously, in most accidents with fatalities and/or injuries, there is also material loss involved, and—in case of larger numbers of fatalities—a significant community disruption is likely).

Apart from these trivial statements, which cannot be 'further analysed' by using the simplistic 'relative contributions' approach, there is only one number in this table which seems worth a bit of reflection: ∼ 18% of the accidents in MARS have environmental consequences. Again, this would be an interesting topic to be analysed in terms of comparing, e.g. the quantities of substances involved with the extent of environmental consequences. Again, this cannot be handled by using the simplistic approach. [5]

To develop our 'analysis' approaches, we have to realise that another main deficiency of the 'relative contributions' approach is, of course, its complete ignorance on the quantitative 'extent' of an event's characteristics. For example, an accident resulting in 100 fatalities gets the same weight as one resulting in one fatality. The large loss of valuable information related to such a procedure can be seen from Fig. 9, where the large variation in the quantitative 'extent' of the immediate consequences descriptor across the accidents in MARS, especially for the number of injuries, is clearly depicted.

[5] The reader should not begin to despair at this stage—more sophisticated data evaluation and analysis will be presented in Section 4 and in C. Kirchsteiger, A. Rushton, N. Kawka, Contribution of human errors to accidents notified to MARS, Seminar on Lessons Learnt from Accidents, Linz, Austria (October 1997).

fatalities	51
injuries	147
eco-harm	50
heritage loss	1
material loss	209
community disruption	84
other	45

Fig. 8. Number of accidents notified to MARS as a function of immediate consequences (status June 1997).

3.5.6. Immediate causes of accidents

In the MARS full report notification form (see Refs. [1,2] or MAHB's www homepage under http://mtrls1.jrc.it/mahb/MARS-FullReports.html), quite a complex coding scheme is provided: a total of ~35 different codes can be used for defining causative factors in major accident sequences with the possibility to make combinations of up to five individual codes. The following (Figs. 10 and 11) show the distribution of the number of accidents notified vs. immediate causes of accident, for technical/physical and human/organisational causes, respectively (status June 1997).

The main result here is that about twice as many immediate accident causes and combinations of causes due to human/organisational failures than due to technical/physical failures have been identified. This underlines the important contribution of the human factor to safety, not only in terms of 'adequate behaviour' of operators and maintenance staff, but also in terms of availability of appropriate operation and maintenance procedures, training, attitudes, etc. This essential element of adequate performance of the management in safety-related matters is one of the key elements of the new 'Seveso Directive', which gives significant attention to the aspect of Safety Management Systems.

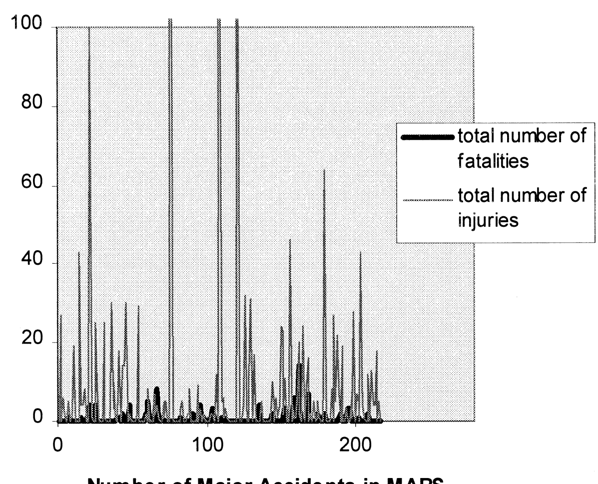

Fig. 9. Number of accidents notified to MARS as a function of the extent of immediate consequences (status June 1997).

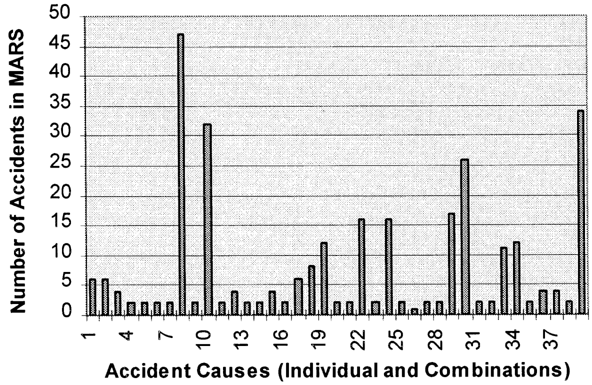

Fig. 10. Number of accidents notified to MARS as a function of immediate causes of accident (technical/physical failures).

Further, only a few causal factors are dominant in the occurrence of accidents.

For technical / physical failures		
Codes/code combinations	8	standing for component failures
	10	standing for component failures due to corrosion/fatigue
	30	standing for unexpected reactions
	39	for non-identified technical causes
For human / organizational failures		
Codes/code combinations	32	standing for lack of adequate procedures, training and thus operator errors (combination of three failure causes), thus inappropriate instructions and/or
	57	standing for inadequate process analysis and thus inadequate equipment design (combination of two failure causes)
	61	standing for inadequate design (without specification of underlying causes).

As can be seen from these *results*, besides runaway reactions, component failures, and especially those due to corrosion/fatigue ('equipment aging'), dominate failures due to technical/physical factors. Failures due to human/organisational factors are dominated by design errors (mainly due to inadequate process analysis) and lack of adequate procedures.

Although these results are not trivial any more, since they make first steps in *identifying patterns of accident causation*, they still rely, to a heavy extent, on often subjective assignments of codes. This problem can only be overcome by putting the analysis on the basis of those data fields in accident reports which include the most unbiased information—the free text descriptions. For detailed presentations of this new

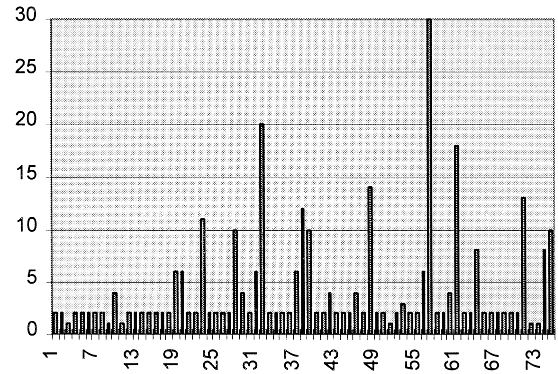

Fig. 11. Number of accidents notified to MARS as a function of immediate causes of accident (human/organizational failures).

analysis approach recently developed by MAHB and its applications to MARS data, reference has to be given to other publications, see Refs. [1,16].

3.5.7. Substances (in)directly involved in accidents

Fig. 12 shows the distribution of the number of accidents notified to MARS vs. the substances directly or indirectly involved in major accident scenarios.

The main result here is that, as can be seen from this figure, from about 290 named substances only ∼5% were contributors to more than five major accident occurrences.

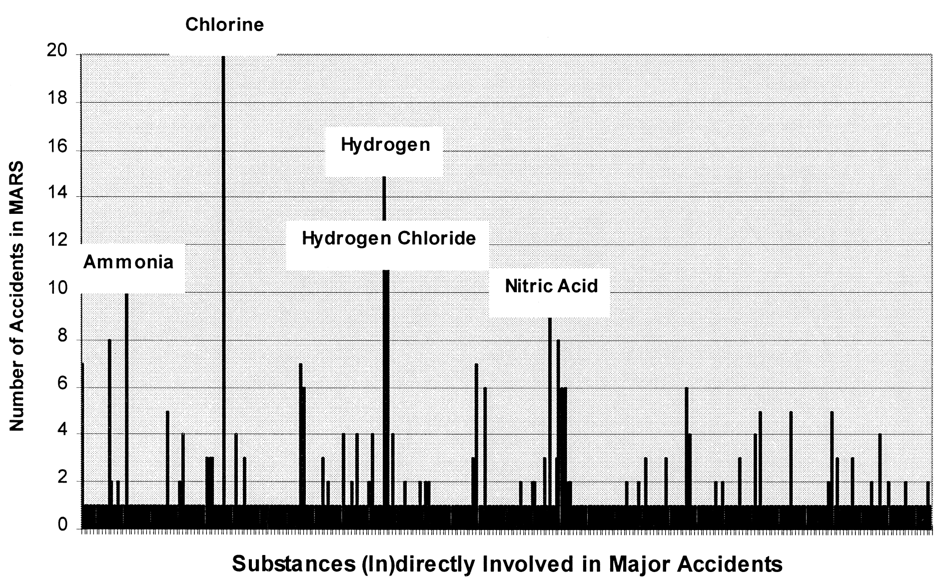

Fig. 12. Number of accidents notified to MARS as a function of substances (in)directly involved (status June 1997).

In other words, the number of dangerous substances, on which particular focus has to be given in the context of major-accident prevention, is relatively small. Again, this is reflected in the new 'Seveso II Directive' which significantly decreased the list of named substances included in 'Seveso I,' while providing on the other hand a comprehensive list of generic categories defining substances and preparations by means of their hazardous characteristics ('very toxic', 'toxic', 'highly flammable', etc., see Ref. [5]).

4. Some examples of correlation analysis of MARS data

4.1. The method of analysis

The MARS is evaluated by searching for significant correlations among certain descriptors of interest.

4.2. Quantities of dangerous substances involved as a function of the extent of consequences

As already mentioned in Section 3.2, the 'Seveso II Directive' follows a so-called two-tier approach which is based on the overall assumption that the risk of a major-accident hazard arising from an establishment in which dangerous substances are present increases with the quantities of substances present at the establishment. In the following, this assumption will be checked for three of the dominant substances in major accident scenarios as identified in Section 3.5.7 (status June 1997).

These *results* (Figs. 13–15) show that—quite independent of the substances—if a major accident occurs, then most of the quantities of the dangerous substances at the establishment are involved in the accident scenario where the total quantities are relatively small. This result does not hold for Fig. 14 where larger quantities are involved. These statements are relatively trivial since they, among many other dependencies of possible relevance, do not say anything about the extent of the consequences of such scenarios.

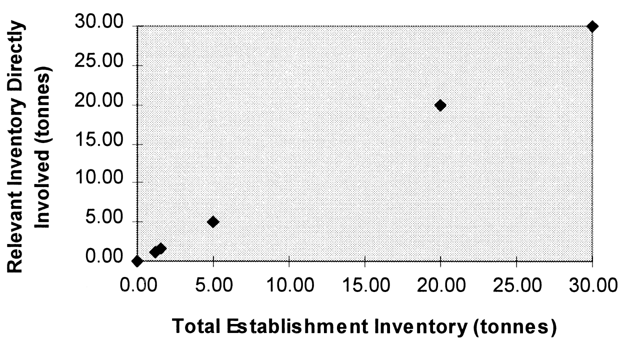

Fig. 13. Quantity of ammonia directly involved in major accidents as a function of quantity of ammonia present at establishment.

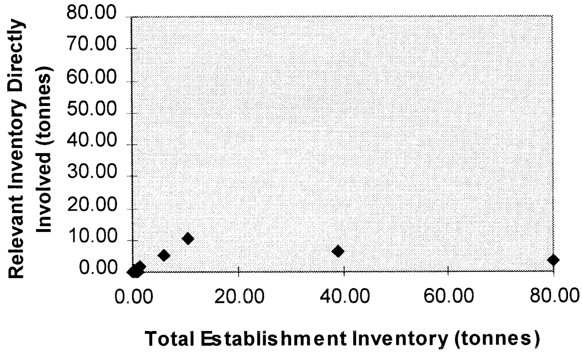

Fig. 14. Quantity of chlorine directly involved in major accidents as a function of quantity of chlorine present at establishment.

4.3. Relation between quantities of dangerous substances lost / released in a major accident and the extent of consequences

To take into account the extent of the consequences of major accidents, for all dangerous substances directly involved in major accidents (see Section 3.5.7), the number of hospitalising injuries is plotted as a function of the quantity of substances lost/released in percentage of the respective thresholds in the 'Seveso II Directive.' Using this easily observable consequence descriptor (thus having quite a high data 'credibility'), the following picture arises from MARS data (status June 1997).

As can be seen from this graph, there is no direct correlation between these two descriptors, but there seems to be a realisation of various underlying populations of dependencies: some accidents have practically no direct relation between quantity of substances lost and number of hospitalising injuries (the ones clustering close to the axes of the cartesian coordinate system) while others seem to follow an almost linear

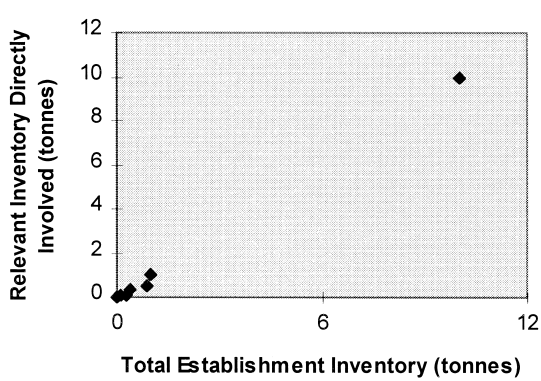

Fig. 15. Quantity of hydrogen directly involved in major accidents as a function of quantity of hydrogen present at establishment.

dependence. Similar graphs could be drawn for other, 'easily quantifiable' consequence descriptors, such as the number of fatalities, slight injuries or the costs related to material damages due to major accidents.

As already mentioned in Section 3.2, the new 'Seveso II Directive' assumes that the 'risk' of a major-accident hazard arising from an establishment in which dangerous substances are present increases with the quantities of substances present at the establishment.

However, the results of the above exercise do not show that this correlation exists for the quantity of substances lost/released in percentage of the threshold in the 'Seveso II Directive,' or for the quantity present at the establishment (a very similar graph could be drawn for this case).

Yet, this result has to be interpreted with some care. It does not 'prove' that the overall assumption in the Directive is 'wrong', but what seems to be clear is that—bearing in mind the appearance of the different event populations in Fig. 16—a simple two-dimensional correlation analysis (rather, a plotting of data on a two-dimensional frame) is insufficient to evaluate the complex variety of factors contributing to the eventual consequences of a major accident. In the examples in Section 4.2, this was not a problem since the two measures of interest, quantity of a substance directly involved and quantity of a substance present at establishment, are of course based on the same physical entity—the dangerous substance under consideration.

As a final note in this context, it shall be mentioned that studying 'relative statistical ranks' of MARS descriptor variables (which, essentially, consist of consequence descriptors, see Ref. [7]) can reveal patterns useful to graphically 'cream-off' events of specific interest.

As can be seen from Fig. 17, the overall impact of the quantity of substances lost or released on the overall 'unwontedness of an accident' (which corresponds to the maximum relative rank value of all its descriptors) is a collaborative effect of three quite distinct clusters of accident events.

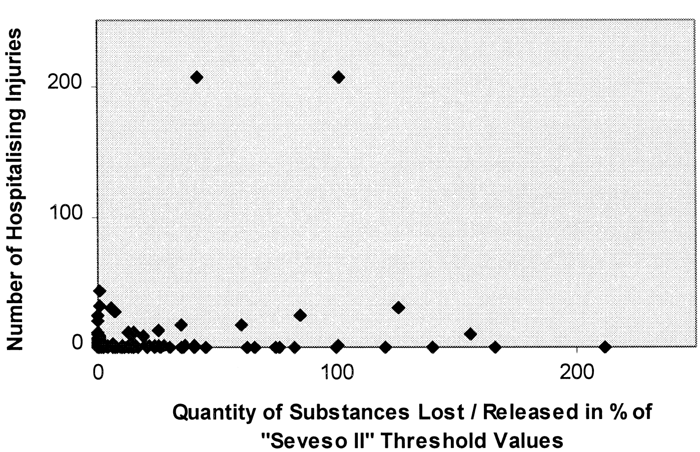

Fig. 16. Number of hospitalizing injuries as a function of quantity of substances lost/released in percentage of threshold in the 'Seveso II Directive.'

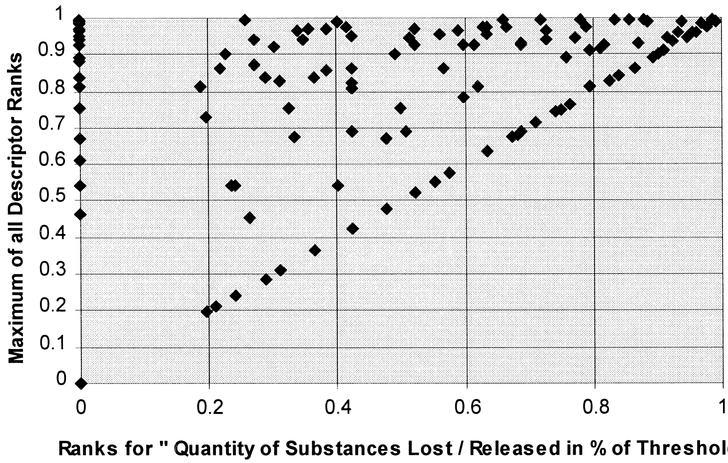

Fig. 17. Maximum of descriptor ranks as function of the ranks for 'quantity of substances lost/released in percentage of threshold in the Seveso II Directive.'

(1) Those events where *even negligible loss* of substances *may give rise to* 'spectacular' on-site or off-site *consequences, and where* the entire 'unwontedness' is thus independent of the quantities of substances lost or released, are clustered along the *y*-axis. Examples for this are large-scale explosions, etc. (2) The 'linear line' across the graph (45°) strings all those events whose 'unwontedness' is dominated by the quantities of substances lost or released, while, (3) all other events oscillate somewhere above this line. As can be seen from this simple result, plotting maximum descriptor ranks offers a nice tool to 'cream-off' events of particular interest with regard to a certain (*x*-axis) descriptor.

The main result here is that in situations where a large variety of contributing factors is involved in accident scenarios, methods have to be used which reduce data dimensionality by forming combinations of the original variables that explain most of the variability in the data. Such 'multivariate methods' are well-developed in mathematical statistics, but are clearly beyond the scope of this introductory paper and shall be presented in forthcoming publications on the matter. Further, an easy-to-apply method to cream-off events of particular interest by using statistical relative ranks has been demonstrated.

5. Summary

In this paper, following some shaky data analysis attempts in the last years, a first thorough overview evaluation of all MARS data has been performed on the basis of the new information exchange and analysis system MARS 3.0.

The following points of relevance have been identified.

(1) In ~ 10% of 'Seveso establishments,' a major accident occurred, highlighting the *importance of the information* included in MARS.

(2) MARS seems to cover to a *high degree of completeness* such major accidents.

(3) Two distinct populations of accident events are included in MARS: those which clearly meet the ‘Seveso II’ definition of a major accident and those which have negligible consequences but are regarded as being of particular technical interest for preventing major accidents and limiting their consequences, such as ‘near-misses’ (cf. emphasis in ‘Seveso II’ [5]).

(4) There seems to be a ∼ *constant rate of major accident occurrence* over the years, highlighting the importance of research on major accident prevention.

(5) The *delays in notification* of major accidents to MARS have improved over the years.

(6) A dominant portion of major accidents occurred in establishments of the *petrochemical industry*.

(7) A relatively large number of major accidents in MARS involved *environmental consequences* (cf. emphasis in ‘Seveso II’ [5]).

(8) *Inadequate Safety Management Systems* and *inadequate design* are dominant contributors to human/organisational failures resulting in major accidents (cf. emphasis on Safety Management Systems in ‘Seveso II’ [5]).

(9) *Equipment aging* and *runaway reactions* are important contributors to technical/physical failures.

(10) There is only a *small number of dangerous substances involved in major-accident scenarios* and thus only a few substances are particularly relevant for the purposes of major-accident prevention (cf. emphasis in ‘Seveso II’ [5]).

Concerning *methodological aspects of accidents data analysis*: (1) ‘relative contributions’ have been found to be usually without any real usefulness, except for presenting the contents of a database; (2) simplistic two-dimensional correlation analysis only makes sense if the variability of one data variable is determined to a large degree by the other variable; else, the more sophisticated methods of multivariate analysis have to be employed in order to produce results of relevance; (3) analysis of data from accidents databases has to focus on generating ‘lessons learned’, meaning identification of patterns of accident causation. Although this could in principle be achieved by counting corresponding code assignments from a consistent and well-developed coding scheme of accident causes, the usually large subjective element in code assignments requires the application of more advanced analysis techniques. Such approaches have to be based on those pieces of information in an accidents database which usually include the most unbiased information—the free text descriptions.

6. Outlook on the future use of MARS

With regards to the new requirements of the ‘Seveso II Directive,’ a new MARS information exchange network had to be designed and put into operation. In mid-1996, the detailed specification and design of this ‘MARS 3.0’ system have been defined and discussed with various international bodies, including all CAs, resulting in the network-type of database structure outlined above (Windows-part for the CAs, Windows/UNIXpart for MAHB). Having finished the actual software development in 1997, the entire database contents have been transferred to the new system. Following that, a workshop on the practical use of MARS 3.0 has been organised by MAHB for those CAs with an active short-term interest in the use of the new system for the purposes of exchanging and discussing information, experiences and analysis results on major accidents with the Commission. All 15 CAs of the Member States of the European Union have declared such a short-term interest in MARS 3.0 and thus received from MAHB their copy of the local Windows-part of the system.

Although there is an overall legal obligation to notify information on major accidents to the Commission, neither the 'Seveso I' nor the 'Seveso II' Directive give—for good reasons—a detailed technical specification how this should actually be accomplished. Therefore, Member States could in principle continue to send hardcopy reports on major accident occurrences in one of the 10 official languages of the EU other than the English language to the Commission.

However, many real benefits are related to a usage of the new system by the CAs:

- CAs can easily create and edit their MARS relevant accident events in MARS-consistent format;
- CAs can easily send the resulting electronic data files in standard ASCII-format to MAHB (on diskettes, via e-mail);
- CAs receive from MAHB periodic electronic updates of the contents of MAHB's central UNIX-based MARS database (i.e. all their own and all non-confidential data from all other CAs);
- CAs can build up their own local accidents database in MARS-format;
- CAs can make statistical evaluations of their accidents data and generate corresponding reports.

In accordance with the overall 'Seveso II' requirement of a more open access to all non-confidential information, possible participants in the MARS 3.0 information exchange system are not only the CAs of the Member States and the EC, but also all other interested parties in the area, such as industry or trade associations, trade unions, non-governmental organisations in the field of the protection of the environment and other international or research organisations working in the field. The long-term goal of MARS is to develop an information network that provides electronic access to all major industrial accidents knowledge and experience within the European Union to anyone (in different levels of detail, depending on the aspect of confidentiality of raw data), anytime, anywhere. Any such network is bound by successful communication, which is a precursor to more sophisticated structures and purposes of a system. For MARS, this purpose is improved policies and practices on industrial accidents prevention, mitigation and response through successful international co-operation and information exchange. Further, as the information society develops and expands, it can be expected that in the next few years more and more demands for 'instantaneous' on-line access to MARS data and analysis results are asked for (e.g. via the WWW). Therefore, by the end of 1997, exemplary parts of non-confidential MARS data have been put on the WWW on a trial basis (see MAHB's homepage under http://mtrls1.jrc.it/mahb/) and, depending on the interest shown by the user community, a complete integration of the MARS database in the WWW could be envisaged.

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