The use of field experience to assess the probabilities of major accidents

Yann Flauw, Clément Lenoble

The use of field experience to assess the probabilities of major accidents

Yann Flauw[a*], Clement Lenoble[a]
[a]INERIS, Accident risks division, Parc Technologique Alata BP2, F-60550 Verneuil-en-Halatte

Abstract: In France, a law published the 30th of July, 2003 introduced prevention and repair of damage caused by industrial and natural disasters. This law has initiated the use of frequencies and probabilities in the risk assessments performed in safety reports. The French legislation requires to assess the probabilities of major accidents when doing a risk analysis. Several approaches are available to estimate the probabilities of accidents. One of the most famous is the bow-tie method. Another approach is also authorized: the use of field experience. For example, a duty holder who has experienced one fire in his installation during the last ten years can use this information to assess the probability of a fire within the following year. This approach is indicated in the French legislation, however no methodology is given or advised on how to use that experience collected by operators. In most cases, one will merely calculate the ratio between the number of accidents and the database timeframe. Unfortunately, doing so barely gives a gross approximation of the expected value, without taking into account the size of the dataset, nor any potential uncertainty implied by it. This paper develops the methodology proposed in France through a series of formulas making it possible to assess the probabilities of major accidents by using field experience and taking the above considerations into account. These formulas mostly depend on the work context – assessing an ignition probability and assessing a leak frequency require different mathematical hypothesis and models – and on the quality of the field experience data considered – with a conservative approach: using a very reliable database should lead to a lower probability than using an incomplete one.

Keywords: Probability assessment, Frequency, Field experience.

1. INTRODUCTION

In France, regulations regarding risk prevention and risk management in industrial facilities are the result of more than 200 years of legislation, the evolution of which has often been consecutive to industrial accidents. Two years after the industrial accident of AZF in Toulouse (French initials for AZote Fertilisant), a new law was introduced on July 30, 2003. It deals with both prevention and repair of the damage caused by industrial and natural disasters. Since then, regulations have been made considerably tighter and the entire approach towards risk assessment has changed.

This law has developed new tools for risk assessment and risk management. One of the evolutions implemented is the use of probability/frequency based risk assessments for safety report and land-use planning issues. This is a major change in France: consequence based risk assessments had been used for more than ten years. Lenoble and Durand [5] have developed the subject further.

With regard to risk assessments performed in the framework of the safety reports (SEVESO Directive), industrialists are asked to assess the probability of each possible major accident in their facilities. To achieve this objective, they have to assess in most cases the frequencies of initiating events given by a fault-tree analysis or the probabilities of secondary events. For example, industrialists are often required to assess a leak frequency (annual, or per operation), a blowout or an ignition probability, a probability of failure on demand for a safety instrumented function, etc.

Data and methodologies to be used are free as long as they are justified. Most of the methodologies used are based on event and/or failure trees or bow tie diagrams. Data such as loss of containment frequencies, ignition probabilities, failure of a safety measures and human error are most of the time extracted from generic data sources. Some examples of them are the Bevi, OREDA, EREIDA, etc. However, the French regulation allows them to use their own field experience to assess the probabilities and frequencies of accidents, without giving specific guidelines.

The French National Institute on Industrial Environment and Risks (INERIS) is developing a methodology which aims at helping industrialists in the use of field experience for events frequency assessment.

Such a methodology needs to address two specific issues:

- the uncertainties linked to the lack of experience: initiating events of major accidents are hopefully rare;
- the quality of data: high quality data is rare as long as it needs systematic record of events that occur in facility. This may be hard and expensive to implement in some facilities.

The methodology proposes a set of formulas depending on the characteristics of the studied event (whether it can occur all the time: continuous mode, or at fixed moments: on demand mode) – and on the quality of the field experience used to assess the frequency.

It is worth noting this methodology can be used to assess the frequency or probability of any kind of event, as long as the required hypotheses are met.

2. CONTINUOUS MODE

2.1. Notations and hypotheses

The objective is to assess the annual frequency of occurrence of an event which can occur at any time, given a fixed field experience. Let A be this event. Let E be the experience. E is defined as the sum of all the lengths of observation, and is expressed in units of time. For example, if A is a warehouse fire and 100 warehouses are observed during 5 years, E is equal to 500 years. Let N be the number of occurrences of A during E. N has no dimension. Let f_A be the real annual frequency of occurrence of A. f_A is unknown and cannot be calculated. This methodology aims at giving a relevant estimator of f_A. This relevant estimator is noted $<f_A>$. f_A and $<f_A>$ are expressed in / unit of time.

The frequency of occurrence of A is supposed to be homogeneous within the field experience sample and constant during the observation timeframe. This hypothesis is questionable but common in this field of application (see Procaccia [2]). INERIS has chosen not to take aging into account in the current version of the methodology; that would have lead to using Weibull distributions and resulted in much more complicated formulas. This is not the objective of the methodology. This choice is discussed in section 6.

Under the above assumption, the random variable N(t) – number of occurrences of A during a time t – follows a Poisson distribution with parameter $f_A t$. The time between two consecutive occurrences of A follows an exponential distribution with parameter f_A.

2.2. Frequency assessment

Under the previous assumptions, this methodology proposes to select the upper bound of the γ one-sided confidence interval. With the notations of section 2.1., this leads to (IRSN, [4]):

$$<f_A> = (1/2E)\text{Chi-squared}_{\gamma}(2N+2), \tag{1}$$

where $\text{Chi-squared}_{\gamma}(2N+2)$ is the γ-quantile of a Chi-squared distribution with 2N+2 degrees of freedom.

The choice of a one-sided interval rather than a two-sided interval is based on a conservative approach due to the French regulation. Two-sided intervals contain more information than one-sided intervals. However, the lower bound will be useless in a safety report. In fact, the French regulation demands industrialists to justify the frequencies of major accidents are not higher than a threshold value. In this context, one-sided intervals seem more relevant.

The equation (1) implies that using a field experience with inputs N and E to assess the frequency of A according to this methodology is equivalent to using a field experience with inputs N’ and E and selecting the unbiased estimator, where $N' = 0.5\ \text{Chi-squared}_{\gamma}(2N+2) > N$:

$$\langle f_A \rangle = N'/E \quad (2)$$

Using a confidence intervals amounts to overestimating the number of occurrences of A reported by the field experience. The table below gives some values of N' depending on N and γ.

Table 1. Values of N' used in equation (2)

γ\N	**0**	**1**	**2**	**3**	**4**	**5**	**10**	**15**	**100**	**500**	**1000**
90%	2.3	3.9	5.3	6.7	8	9.3	15.4	21	114	530	1042
80%	1.6	3	4.3	5.5	6.7	7.9	13.7	19	109	520	1028
70%	1.2	2.4	3.6	4.8	5.9	7	12.5	18	106	513	1018
60%	0.9	2	3.1	4.2	5.2	6.3	11.5	17	103	507	1009
50%	0.7	1.7	2.7	3.7	4.7	5.7	10.7	16	101	501	1001

Table 1. underlines the impact of parameter γ on the selected estimator, especially when N is low. For N = 0, $\langle f_A \rangle$ is more than tripled between γ = 50% and γ = 90%. The choice of γ is therefore essential. Recommendations on how to choose it are given in section 4.

3. ON DEMAND MODE

3.1. Notations and hypotheses

The objective is to assess the probability of occurrence of an event which can only occur at specific times, given a fixed field experience. Let A be this event. Let E be the experience. E is defined as the total number of observations, and is dimensionless. Let N be the number of occurrences of A during E. Let p_A be the real probability of occurrence of A. p_A is unknown and cannot be calculated. This methodology aims at giving a relevant estimator of p_A. This relevant estimator is noted $\langle p_A \rangle$. p_A and $\langle p_A \rangle$ are dimensionless.

The probability of occurrence of A is supposed to be homogeneous within the field experience sample and constant for each observation. Under this assumption, the random variable N(e) – number of occurrences of A during e observations – follows a binomial distribution with parameters e and p_A.

3.2. Probability assessment

Under the previous assumptions, this methodology proposes to select the upper bound of the γ one-sided confidence interval. With the notations of section 2.1., this leads to:

$$\text{If } E < 30 \text{ or } N > E - 5, \text{ then } \langle p_A \rangle = 1, \quad (3)$$
$$\text{If } (E > 30 \text{ and } N < 5) \text{ or } (E > 50 \text{ and } N/E < 0.1), \text{ then } \langle p_A \rangle = (1/2E)\text{Chi-squared}_\gamma(2N+2), \quad (4)$$
$$\text{Else, } \langle p_A \rangle = (N+u_\gamma \text{Sqrt}(N(E-N)/E))/E, \quad (5)$$

where u_γ is the γ-quantile of the standard normal distribution.

These formulas lead to three zones depending on N and E. Equation (3) is associated to zone 1, equation (4) to zone 2 and equation (5) to zone 3. The zones are drawn on the figure below:

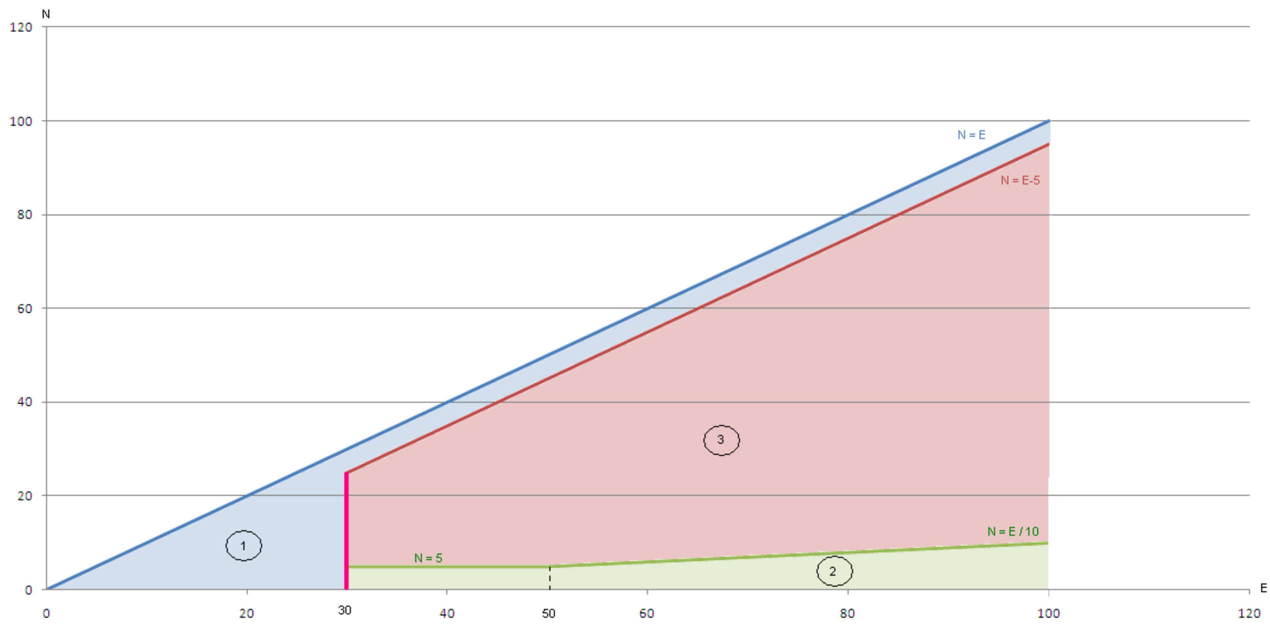

Figure 1. Domains of definition for formulas (3), (4) and (5)

It is worth noting that equation (4) will be used in most cases. In fact, this methodology aims at assessing accidents and failures probabilities, therefore N/E is likely to be smaller than 0.1. In this case, the formula for the on demand mode is the same than equation (1), except $<p_A>$ is dimensionless.

As underlined in section 2.2., the choice of parameter γ is essential. Equations (3) through (5) are monotonically increasing with γ. γ can therefore be interpreted as an indicator of the degree of reliability of the used field experience. A higher γ decreases the chances of underestimating p_A by leading to a higher value of $<p_A>$. Recommendations on how to choose it are given in the following section.

4. DATABASE QUALITY

This methodology proposes 3 degrees of quality for a field experience database. Each case will be associated with a value for parameter γ and N will be artificially increased in the worst case. Databases are considered to be either very reliable, reliable or moderately reliable. A very reliable database means the user has a total confidence in parameters N and E: all failures are reported; the observation timeframe is homogeneous; reporting methods have not been modified; the same group of people does the reporting; the database is not too old, etc. A reliable database means we are almost sure all failures have been reported, but the user cannot guarantee it. For example, the failure has extreme consequences (meaning lack of reporting is very unlikely), but the database is old and does not cover a continuous timeframe. At last, a moderately reliable database means we strongly suspect some failures have not been reported, or the characteristics of the failure have been modified during the observation timeframe; for example, a pipe leak database where the minimal diameter of the reported leaks has decreased over time.

If the field experience is very reliable, choosing $\gamma = 90\%$ might be unnecessarily restrictive. On the other hand, choosing $\gamma = 50\%$ is questionable: the real value of the assessed frequency or probability is underestimated half of the time. In addition, when N is low, this underestimation can be huge. According to table 1., if N = 0 and we choose $\gamma = 50\%$, $<f_A> = 0.7/E$. With $\gamma = 70\%$, $<f_A> = 1.2/E$. This means that in 30% of the cases, $f_A > 1.2/E$ which is almost two times the “relevant estimator” $<f_A>$. With a conservative approach, choosing $\gamma = 50\%$ cannot be allowed. INERIS proposes the value $\gamma = 70\%$ when using a very reliable field experience.

If the field experience is reliable but the user cannot guarantee a complete exactness of parameters N and E, this methodology proposes the value $\gamma = 90\%$. This choice increases the value of $<f_A>$ or $<p_A>$. It therefore covers any small uncertainty that might exist on the value of N or E. In fact, choosing $\gamma = 90\%$ with the values N and E is equivalent to choosing γ = 70% with a slightly higher value of N, or a slightly lower value of E.

At last, if the field experience is moderately reliable, using this field experience to assess a probability or a frequency is very questionable. In those cases, using a generic database is recommended. However, if there is no other option, INERIS proposes to choose γ = 90% and to increase artificially the value of N to cover the uncertainties. This methodology does not propose a new value of N since it is very dependent on the bad quality of the database. This is a subjective decision operators have to take.

5. NUMERICAL EXAMPLES

5.1. Continuous mode

An industrialist owns 100 identical warehouses. He points out no fire has been signaled within the 5 years of use of each warehouse. He is completely certain of this information, since a fire cannot go unnoticed. In this case, N = 0, E = 500 years and the database is very reliable: γ = 70%. Equation (1) leads to the following estimator for the annual frequency of occurrence of a fire for one warehouse: $\langle f_A \rangle$ = (1/1000)Chi-squared$_{70\%}$(2) = 2.41 10^{-3} / year.

5.2. On demand mode

An industrialist wants to use his field experience to assess the probability of leakage of a decant pipe when it is used. He has observed 12 leakages in 10 years. Each year, 30 decanting are carried out; each decanting uses only one pipe. The decant pipes are all the same and are checked out by the same operator at fixed intervals. However, the leakages are mostly reported by the truck drivers; more precisely, it might be possible that some limited leakages have not been reported. In this case, N = 12, E = 300 operations, the database is reliable: γ = 90%. Since E > 50 and N/E < 0.1, equation (4) leads to the following estimator for the probability of occurrence of a leakage during a decanting operation: $\langle p_A \rangle$ = (1/600)Chi-squared$_{90\%}$(26) = 5.93 10^{-2}.

6. DISCUSSION

The methodology developed in this paper has some drawbacks, which will lead to complementary works in the upcoming year. Firstly, the methodology supposes the field experience data are homogeneous and the failure rate is constant over time. This is obviously false in reality. Beauzamy [3] explores new methodologies to take uncertainties, lack of homogeneity, missing data, etc. into account. However, the methodology developed in this paper leads to simple formulas that can be easily used by industrialists for their safety reports. This is mainly why it has been favored over other methodologies, more realistic and precise but far more complicated to implement.

Secondly, the choice of γ = 70% for a very reliable database is questionable. At the moment, this value is very subjective: it is the lowest round percentage for which N' (as defined in section 2.2.) is over 1 when N = 0. The idea is to reward very reliable database by allowing lower frequency and probability estimator, while complying with the French conservative approach (thus not taking a too small value for γ). Works will be conducted in 2012 to discuss the relevancy of γ = 70% and propose adapted values for γ.

Another difficulty when using this methodology is to decide whether a field experience is reliable or not. Right now, there is no clear criterion to help an industrialist decide which degree of quality he has to select. INERIS will focus on clarifying this aspect of the methodology. Complementary works will be carried out in 2012.

At last, it is worth noting the mathematical aspects of the methodology can be extended to any type of database, as long as the hypotheses are met: natural risks, functional safety, human reliability, etc.

7. CONCLUSION

The methodology developed in this paper can be used for frequency and probability assessment of events in the context of French risk assessments of facilities. It allows industrialists to use their own field experience to assess frequencies and probabilities, rather than extracting generic values from aggregated databases. These generic values can be very restrictive for the operator if he has a lower N/E ratio.

Equations (1) through (5) give the operators an alternative: selecting the upper bound of a particular one-sided confidence interval as the estimator of the frequency or probability they want to assess. However, the degree of reliability of the field experience used in the assessment greatly impacts the results. At the moment, INERIS proposes to distinguish very reliable, reliable and moderately reliable databases, each associated with a different approach as exposed in section 4.

In 2012, INERIS will work on these quality criteria. The objective is to propose the operators a set of questions which will lead to a notation of the used database. This system of notations is associated with a set of formulas, with a main idea: a certain range in the notation equals one formula. The development of this new methodology relies on two steps. Firstly, the questions must be defined. To do so, the parameters defining the reliability of a database must be identified. Some options are: its age; its homogeneity; its sufficiency, etc. Secondly, the impact of each of those parameters must be studied. The objective is to decide how to modify the formulas (increasing γ, increasing N, decreasing E) when a parameter varies.

References

[1] IEC 61508-1 ed2.0. Functional Safety of Electrical/Electronic/Programmable Electronic Safety-related System.

[2] Henri Procaccia. Introduction à l’analyse probabiliste des risques industriels, Tec et Doc - Lavoisier, 2009.

[3] Bernard Beauzamy. Nouvelles méthodes probabilistes pour l'évaluation des risques, Société de Calcul Mathématique S.A., 2010.

[4] IRSN. Rapport DSU n°223, Avis sur les intervalles de confiance à retenir dans le cadre des études de sécurité des canalisations de transport, 2010.

[5] Clement Lenoble, Clarisse Durand. Introduction of frequency in France following the AZF accident, Journal of Loss Prevention in the Process Industries, 24-3, 227-236, 2011.