Risk Matrix Basics

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Abstract

There is a growing volume of discussion on the value or otherwise of the ubiquitous "Heat Maps", which have become de facto, the weapon of choice in discussing and comparing corporate, national and global risks, whether for regulation, governance, or political justifications. This note sets out to remind us of the strengths and limitations of blindly following standard recipes and blithely extrapolating into inappropriate areas or applications. It all depends on understanding the basis of their derivation and the limitations of inherent approximations from dumbing them down.

Introduction

Risk management is an increasingly important task in managing enterprises, companies, countries and societies. The most prominent risks, which attract the public eye the most, are risks that involve human life or health or the state of the environment. But in many cases the stakes are of a different nature. In the financial markets risk usually is associated with losing money as a consequence of investments turning bad, mortgages not being paid back or fraudulent bookkeeping. In construction the risks are associated with completing a railroad in time and within budget or a building collapsing. All these have in common that the outcome of an action, a decision or an activity is to a certain level uncertain. The uncertainty not only pertains to the magnitude of the potential loss but also to the question of the likelihood of a particular loss.

The political debate is often laden with confusion about the representation of risks, the magnitude of risks and the decision-making tools and mechanisms. A typical example is the discussion about the validity of risk matrices. In this discussion the presentation of the risk as points or lines is confused with the decision mechanism - usually some red, yellow, green coloring scheme – and the choice of the demarcations between these areas.

In this report we try to take away at least some of the confusion in the hope that the discussion will depart from discussion about methods and focus on what should be important, which is the discussion about acceptability. The latter discussion is completely and utterly political (Ale, 2003).

The need for graphical representations of risk often stems from the need to get around the physical, chemical and mathematical instruments that play a role in safety science. This unfortunately introduces many misconceptions, even about what has been published earlier. In order to understand the discussions and to take away these misconceptions the reader is invited to bite the bullet. In the following things will be kept as simple as possible but also be made as complicated as necessary. The mathematical formulas are there to illustrate a point and sometimes give mathematical proof for those who otherwise would not be convinced. They can also be skipped by those who are willing to believe that everything stated as being fact in this report can be proven.

Risk management

In order to deal with uncertainty in an organised way the concept of probability is introduced. Probability is the measure the likelihood that something will happen. It has an exact mathematical definition. Organised risk management starts with the estimation of the "magnitude" of the risks involved followed by some process of decision making. The first – known – form of a decision making principle was formulated by A. Arnaud in 1662

> *Fear of harm ought to be proportional not merely to the gravity of the harm, but also to the probability of the event*

Risk therefore is a combination of consequences and probabilities. In Arnauds view the true measure of risk is the multiplication of probability and consequence. Risk is probability times effect. What in mathematical terms is designated by the expectation of the consequences. We will see that

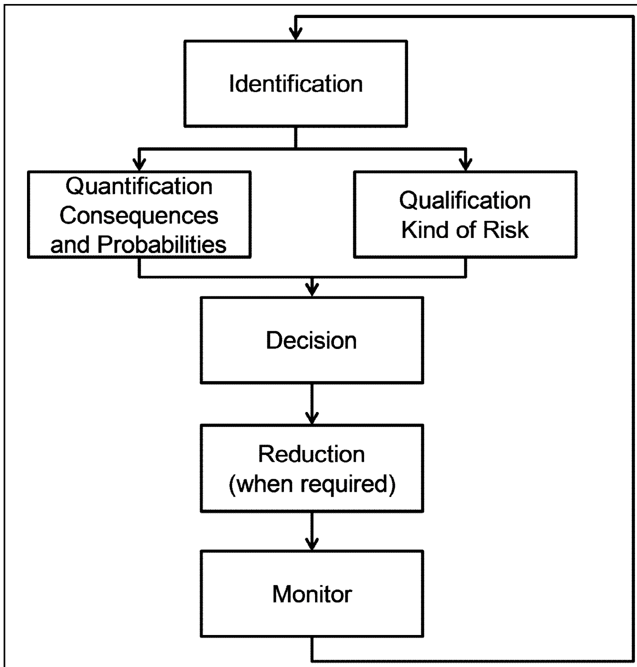

Figure 1: Steps in the risk management cycle

decisions that follow Arnaud's rule in having the acceptability of an activity directly proportional to this measure of risk are common in economics. However the more contentious decisions, and these are often related to issue of life and death, do not seem to follow this rule. Many attempts have been made to capture apparently different relationships between acceptability, probability and consequence.

Therefore the process of risk management can be summarised as in figure 1 (van Leeuwen en Hermens, 1995). After identification of all the potential adverse events, the probabilities and consequences are modelled and quantified. The risks are also qualified. Qualification in this context means establishing other attributes of the activity with which the risk is associated and which are important for the decision to undertake the activity. These attributes are often value laden especially when the risk involves potential harm to human life or health. Although it may seem that establishing the magnitude of risk is value free, it often is not, because, as we will see later, the way this magnitude is expressed may itself contribute to the framing of the decision. After this work has been done the information is ready for use in a decision making process. After it has been decided whether the risk is acceptable or has to be reduced, the risk is monitored and a new cycle may start depending on whether the risk seems to remain acceptable or not. Although decision is only a small block in the diagram of figure 1, this usually is takes the most time and the most discussion. Especially the discussions about the use of nuclear power, about the risks of chemical industry and the associated transport and about the long term effects of human activities on the climate of the earth have shown that in decision making there is often more than consequence and probability alone (Gezondheidsraad, 1993)

In real life the risk management process is not as clean as the schematic suggests. As said before, value judgements are often made in the steps where information is assembled and in this way the gathering and presentation of information becomes a part of the decision making. As Harry Ottway (1973, 1975) put it:

> *Risk estimation may be thought of as the identification of consequences of a decision and the subsequent estimation of the magnitude of associated risks.*
>
> *Risk evaluation is the complex process of anticipating the social response to risks; … this could be termed as the "acceptability of risks"*

We could also make a distinction between risk management and risk governance. Risk management may be thought of as keeping risk within defined limits against define costs. Risk governance is the process in which we deal with a problem that involves risk, but also many other things.

Risk

In the sometimes heated discussions about risk acceptability, risk has been defined and redefined countless times, often to reflect those aspects or arguments that a proposer or author deemed important. This is not discussed here any further but serves as the argument why for this report a number of definitions need to be given, as they will be used in this report, without prejudice about the validity of any other definition one can give. Let event be an occurrence or happening resulting from a decision.

Consequence (c) is the outcome of an event

Probability (p) is the chance that the event will occur. Probability is a number between 0 and 1.

Frequency is the average rate per unit time (usually a year) that an event will happen. It is often also called the probability per year. The latter is mathematically imprecise and leads to much confusion. As an example take car accidents. There a few hundred of these each year. Therefor the probability of a car accident is 1. (At least 1 has already happened so the probability cannot be smaller). For the future one might think that form tomorrow there is a chance that no more accidents will happen. In that case the probability of car accidents is smaller than 1. These probabilities however are highly uninformative. It is much handier to work with the (expected) number of accidents per year.

Riskpoint is the combination the outcome and the probability/frequency of an event

Riskset is the set of riskpoints all possible events of a decision.

Risk (R) is the magnitude of riskset. R can be evaluated in various ways.

In many cases the discussion about risks involves an argument of uncertainty. This will be dealt with later. For now it is sufficient to assume that consequences and probabilities can be established or estimated.

In its simplest form the magnitude of risk is the total value of the expected outcomes or expectation value. This is also referred to as risk is probability times consequence or

$$R = p * c$$

If there is a range of consequences and the probabilities for the different outcomes are different then the risk in general is

$$R = \sum_{i=1}^{n} p_i * c_i$$

This definition of Risk is used in finance and insurance. It is a single number. Therefor risks measured in this way can easily be compared.

Unacceptable consequences

The problem with measuring risks in the simple way described earlier is that it implies that the decision maker will attach equal value to risks for which the R is equal; that it does not matter whether there is a 1/100 chance of winning 100 euro or a 1/1000 chance of winning 1000 euros. In normal life betting games this is often the case. However if the consequences are very high this might no longer be the case. As an example after 9/11 insurance companies were no longer prepared to insure losses in excess of 1 billion euro's regardless of the probability. In such circumstances the consequences and the probabilities or frequencies have to be presented and considered separately.

Intermission: presenting risks

At this stage in this report it is necessary to introduce the various ways risk can be presented and how uncertainty can be taken into account leading to even more complications.

The presentation of R as product of c and f or the sum of the products of c's and f's is a single number. The R of 100 euro's with is probability of 1/100 is 1. This presentation is necessarily a two dimensional picture. Usually f (frequency) is given as a function of c (consequences).

FN diagrams

Suppose the following list of events with consequences and frequencies is known:

c	f
1	0.85341
3	0.104124
4	0.057345
10	0.010761
25	0.001552

50	0.000376
1000	1.01E-06
10000	1.06E-08

The R for this set is 1.56. A graph using linear scales depicting these points looks like figure 2.

This is a very unfortunate representation as most points seem to be on the vertical axis. Therefor a smarter way of presenting these numbers is in a so-called “double logarithmic” diagram in which the value at the “tick marks” increase exponentially instead of linearly as given in figure 3..

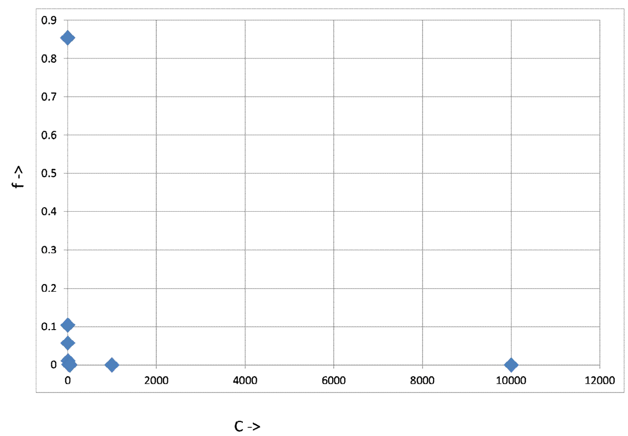

Fig 2 Frequencies and consequences on a linear scale

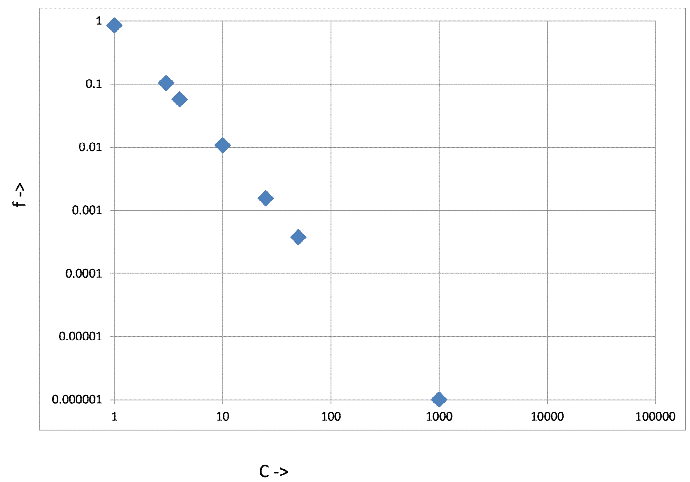

Fig 3 Frequencies and consequences on a double logarithmic scale

The frequencies in this example have been chosen to decrease with increasing consequences, but that does not have to be the case. Suppose we have a list of events as follows:

c	f
1	6.04E-01

3	5.16E-01
4	6.47E-01
10	7.64E-01
25	9.93E-02
50	3.94E-01
1000	4.46E-01
10000	4.43E-01

That would on a double log scale look like figure 4

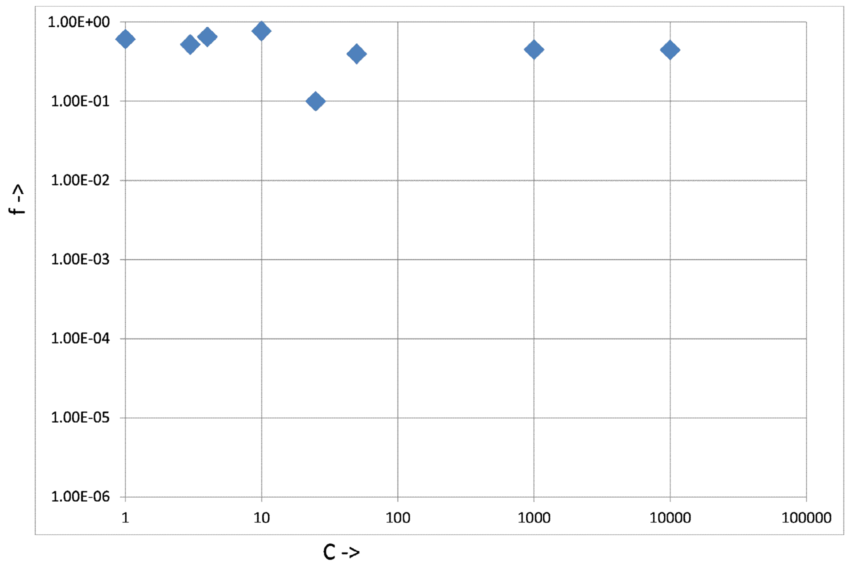

Fig 4 Frequencies and consequences on a double logarithmic scale

The graph would sort of wander about. A much neater way of doing this is to add the frequencies up from the largest consequence to the lowest. This always leads to a decreasing line (figure 5)

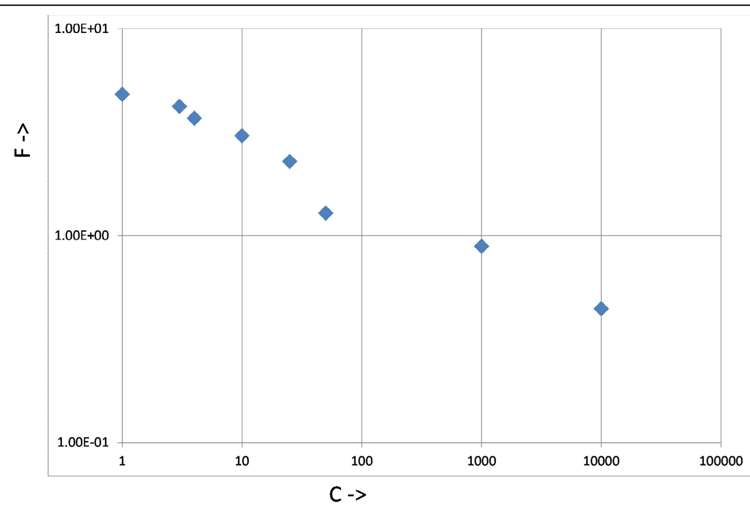

Fig 5 Cumulative Frequencies and consequences on a double logarithmic scale

It should be noted that the frequency axis in figures 2-4 have f and in figure 5 it says F, making the difference between regular and cumulative frequencies. However this is not always done and especially in the older literature, when the typesetting options were much more limited one has to refer to the original paper to know. The graph with cumulative frequencies is called a complementary cumulative distribution function (CCDF) and is the regular form of the FN diagram.

It should also be noted that there is no line drawn in any of these diagrams. That is because if the consequences would be number of people killed, such a number could only be an integer. Before an FN diagram can be converted into an FN curve a few further steps have to be taken.

This will be done after the histogram representation has to be dealt with

Histograms

In many cases the potential consequences are not precisely known. In such cases a number is presented as a range of numbers and all events having consequences in that range are put in the same bin.

Suppose that in total 40 accidents have been found with the following numbers of people affected:

1-9	11
10-99	13
100-999	12
1000 - …	4

This could be presented in a bar chart: (Fig 6 left)

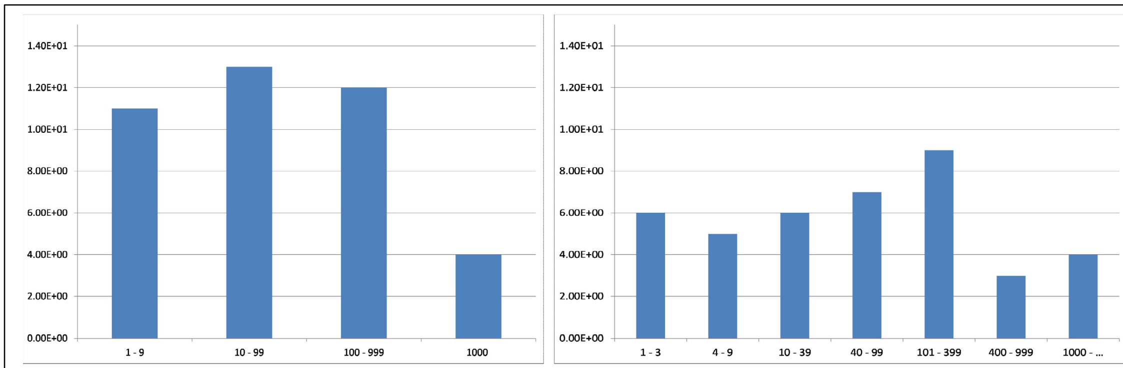

Figure 6: Bar charts for numbers of events.

Now suppose that these numbers could be refined to the following table:

1 - 3	6
4 - 9	5
10 - 39	6
40 - 99	7
101 - 399	9
400 - 999	3
1000 - …	4

Then the bar chart would look like figure 6 right. It should be noted that the numbers in each of the bins on the right hand side are lower than that on the left hand side. This has implications when these numbers are used in any measure of acceptability, but that will be dealt with later.

If on would convert both diagrams into curves one could plot them in the same plot as given in figure 7. The advantages of this representation are immediately obvious. The plot is invariant for the size of the bins. Even if every bin would only be one person wide i.e N = 1; N= 2 etc even then the figure would look the same. That is why in risk presentations the FN diagram or CCDF is the preferred presentation.

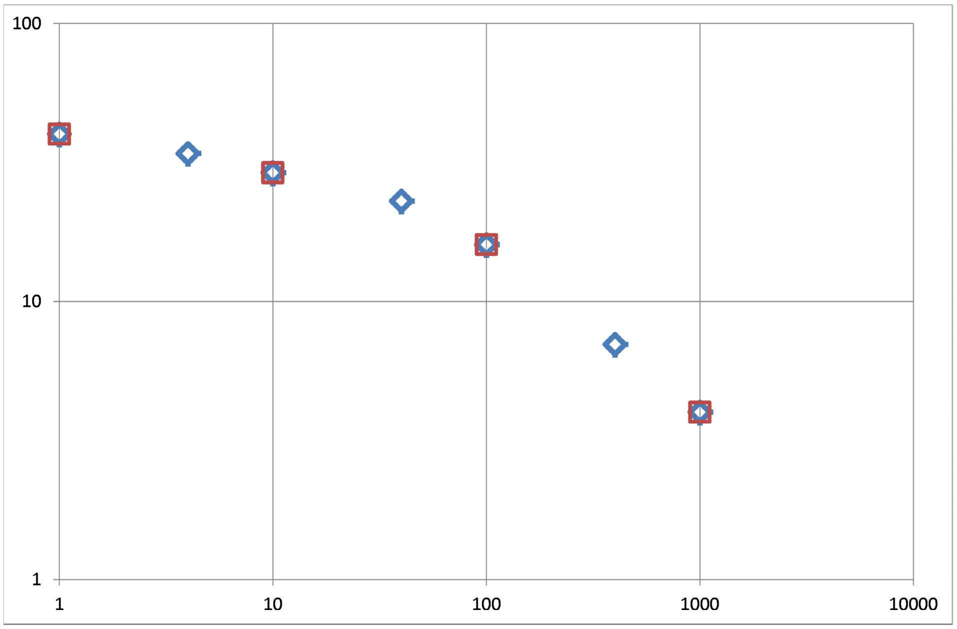

Figure 7 FN diagrams for numbers of events.

It can be easily seen that should these numbers be found in a period of 1000 years the only thing left to do is divide the values on the vertical axis by 1000 to get the number of events per year.

If one were to represent this data as continuous curves one could end up with curves such as in figure 8. It is only for the reason that the numbers of cases do not decrease with increasing N that one can see that the “bargraph” curve cannot be an FN diagram. Therefore these representations of discrete data are dangerous for later interpretation and uses, but this habit is nonetheless

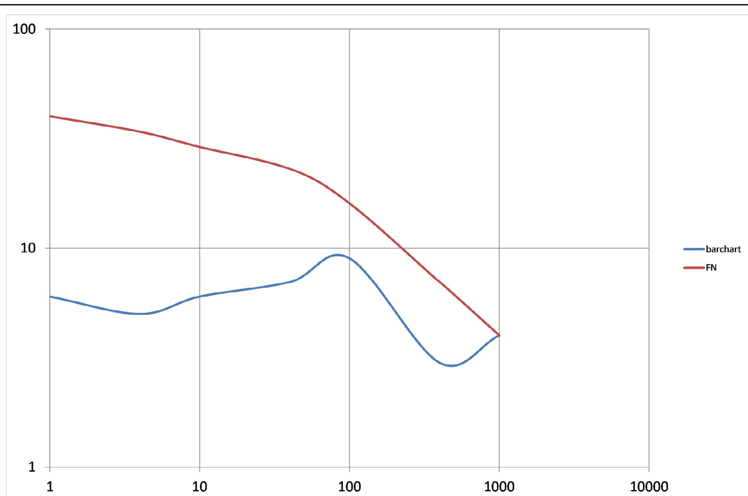

Figure 8: curves.

widespread.

A math trick

There is one trick however that does not change the shape nor the values in the presentation of an FN diagram, but increases its useability. This trick is to define the FN curve for non integer number as follows:

For r N < M < N+1 F(M) = F(N). This converts the FN diagram into a stepwise continuous function. This means that it can be integrated. As has been shown by Ale (1996) and by Jongejan (2008) the integral under the curve is equal to the expectation value of the risk. Another advantage is that the summation and abstraction rules for functions apply.

Risk Criteria

In the previous section nothing has been said about criteria. Until now, all diagrams were just representation of risk calculations, be it simple invented ones just for illustration.

It is obvious that the simplest way of limiting a risk is to set a maximum to the expectation value R. The simplest way to compare risks is on the basis of their expectation value. There are however two

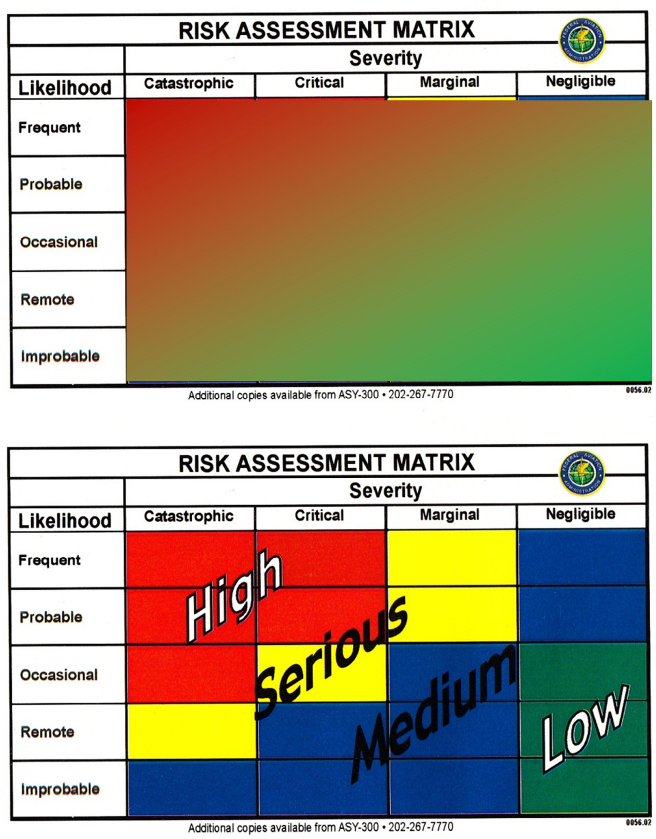

Fig 9: Examples of risk matrices

persistent problems with this approach. One is that in political choices higher consequences sometimes weigh heavier than smaller consequences and that it is sometimes desirable and sometimes necessary to do something about the so called “high consequence low probability” risks. Since the accident with the Deepwater Horizon this is also referred to as ruin prevention.

The other is that consequences are often multidimensional. They involve money lost, environment damaged, people killed and injured.

To deal with the latter first it is obvious that that depicting all these dimensions separately would result in an dimensional diagram. Given the problems people already have understanding a two dimensional diagram – as will be seen later – people often choose to translate the consequences in a single entity. The magnitude of that entity then is no longer a defined number expressed in definable measures. It is a brew of all the consequences together. What is often forgotten is that making this brew implies value judgments with respect to the mutual valuation of all the dimensions involved. As it was put in judgments about airports in which people killed figure next to noise levels: it implies the answer to the question how much dB a dead person is worth. That is one of the reasons why larger companies refrain from brewing a one dimensional consequence thingy and treat these kinds of risks separately.

The qualifications given to these consequences are often in terms of severe or mild and the

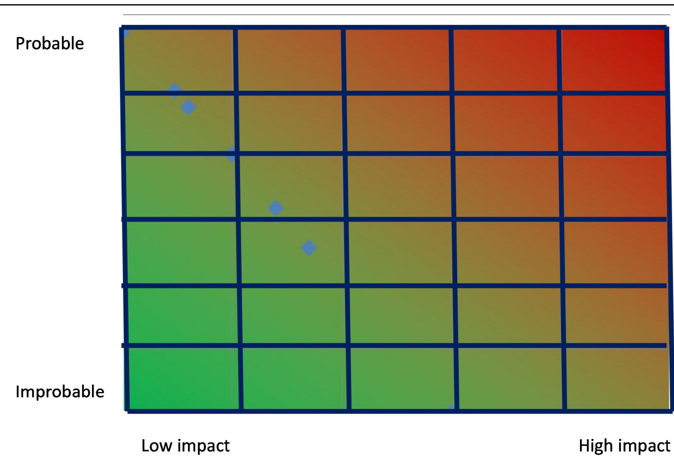

Figure 10: Figure 3 made into a risk matrix

frequencies in terms of often or rare, which than can be put nicely into a diagram such as in figure 9.

In the top half of figure 9 it is only indicated when things get worse (redder). In passing it is noted that the direction of the consequence axis runs from right to left, which is in mathematical terms at least non-intuitive. In the lower half the suggestion already is made that the yellow boxes have about the same “value” in terms of risk.

Unfortunately there are numerous examples of these risk matrices where the suggestion of equal value is implied.

It is likely, but not certain, that the frequency axis is thought of to be non cumulative.

Risk matrices

With these ingredients one can convert figure 3 into a risk matrix as in figure 10. However it is very difficult not to interpret the boxes as having some numerical value. Obviously the demarcation between acceptable and unacceptable can be put anywhere. But be aware: the frequencies are not cumulative. Neither were they in the often cited Farmer curve (Farmer, 1987, Ball, 1998). That Farmers curve looks like an FNH curve is purely by accident. In nuclear energy industry High dose events are less frequent that low dose events and thus Farmers curve is descending.

Every attempt to make a qualitative risk matrix into a quantitative one, in which the surface area actually stands for a value and a constant valuation is assumed along some diagonal is asking for trouble. In every step therefor implied weightings should be made explicit and probably debated in a political arena.

Risk Criteria

The development of Fault Tree and Event tree techniques, from Second World War logistics, through to high risk/consequence applications such as space flight and nuclear reactor reliability, is the source of much of the modern risk manager's repertoire. Some of the early ground breaking work included comparisons of nuclear risks to "normal" risks, such as natural disasters and transportation. This was displayed as a log/ log plot of frequency (of an event) versus the Consequences (as number of fatalities caused) of that event, as seen in Figure 11 (Rasmussen, 1975).

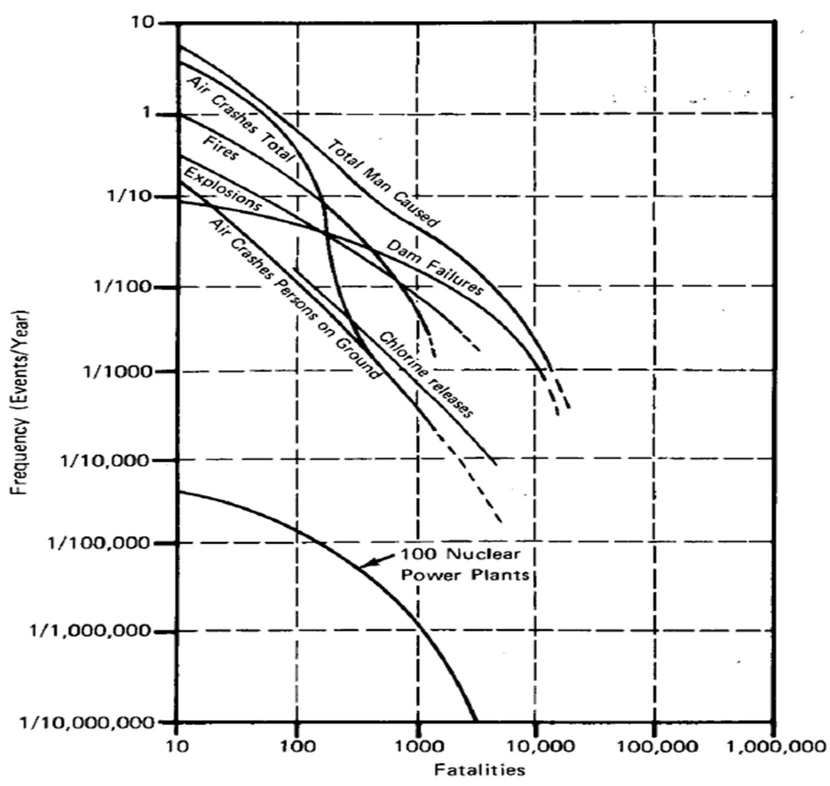

Figure 11: **fN** curves for manmade risks (from Rasmussen 1975)

In the UK, Farmer (Farmer, 1987, Ball, 1998) utilised the frequency / dose plot to assess the likely exposure of the public to the operation of a nuclear reactor. (Figure 3)

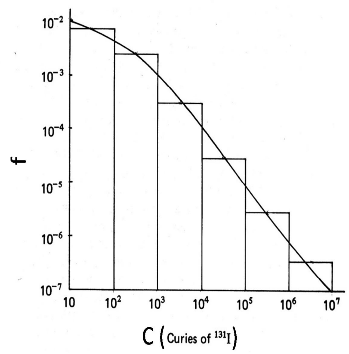

Figure 12: The Farmer curve (from Griffith (1982)

This gave him a total level of exposure, (societal dose, risk) normalised to specific local population distributions. This was another form of PIG but capable of quantitative derivation of individual and total (societal) fatality risk levels for specific sites. The consequences were calculated from representative “model” loss of containment events, but the plot allowed an envelope of total impact to be assessed.

As will be discussed later, there were a number of disadvantages associated with this representation. That is why, in a further development, cumulative risk curves were developed in which the vertical axis did not represent the frequency of a certain consequence, but rather the frequency of **exceeding** a certain consequence.

These cumulative **FN** curves are usually concave curves. There is generally a finite intercept on the N axis and as N tends to 0, the cumulative risk frequency tends to increasingly large numbers as the impact becomes more and more trivial.

FN curves have been used in all kinds of industries, where quantitative risk analysis was introduced as a means to gain insight into these risks and as a basis for subsequent decision making. Examples are the Canvey Island study (HSE, 1978) and the COVO study (Cremer and Warner, 1981) (see Figure 4). The propagation of quantified risk analyses led to the further development of comprehensive techniques, by which detailed fault-tree and event tree analyses could be summarized in information ready form, for decision making (Cox, 1982; Ale, 1986, 1987)

These techniques were introduced back to the nuclear industry (full circle) in the independent risk assessment done for the Sizewell B public Inquiry (Slater 1982), and were clearly more helpful than the reams of computer generated Fault tree submissions (Westinghouse 1982). Finally some ten years later the UK Nuclear Inspectorate published their own version. (Harbison NII 1993))

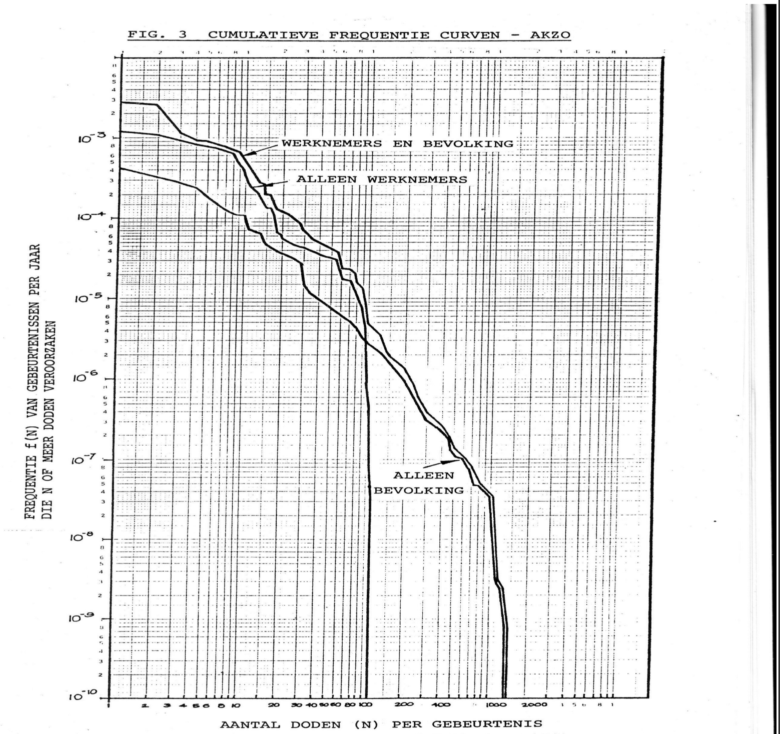

Figure 13, FN curves from the COVO study

In fact as early as 1976 the province of Groningen in the Netherlands published their views on the acceptability of risk, given in figure 18. as an FN plot. In this diagram, there weren't any colours (yet), but the areas of acceptable, conditionally acceptable and non acceptable can clearly be seen. It can also be seen that they thought that a consequence of 1000 people killed was too much. The numbers killed below 1 were included (and rated) because they counted an injured person as 0.1 of a kill. The figure shows that they were less risk averse when people were not killed.

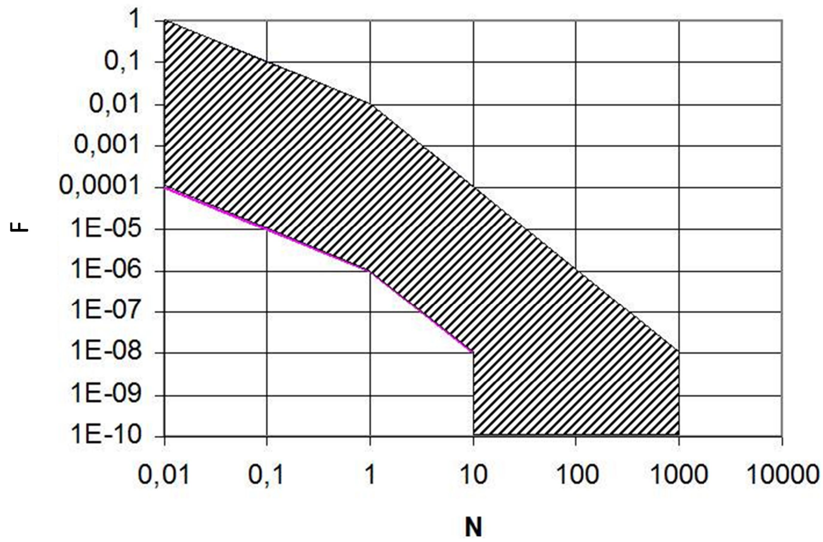

Figure 14. The risk map of the province of Groningen

In most of the later diagrams published by HSE, the Governments of the Netherlands, Switzerland, Australia and Hong Kong, only one straight line was given (the demarcation of unacceptability or intolerability) and in some cases also a maximum as an anchor point. (As a straight line can then be drawn given its anchor point and its slope). The slope is the expression of the risk aversion index described above. The limits of acceptability can be summarised in a table as below: (Pikaar, 1995; Ball, 1998)

Table 1 Selection of National Risk criteria

Year	country	Anchor N	Anchor F	Slope	MAX N	details
1976	UK	10	10^{-4}	None		ACMH– UK HSE Advisory Committee on Major Hazards
1978	NL	10	10^{-4}	-2	1000	Groningen -NL
1982	UK	10	10^{-4}	-1	None	Kinchin – UK Nuclear Industry
1988	HK	10	10^{-4}	-1	1000	Hong Kong
1988	NL	10	10^{-5}	-2	None	TK (1988); acceptable line factor 100 lower
1991	UK	500	10^{-4}	-1	1000	ACDS
1993	UK			-1 and -1.3	?	HSE Off shore
1993	UK	10	10^{-4}	-1	1000	
1995	NL	10	10^{-5}	-2	None	As 1988 but acceptable line removed
1995	NL	10	10^{-4}	-2	None	For transport per km
1997	HK	10	10^{-4}	-1	1000	For transport per instn.

The bodies setting these standards have been numerous and diverse; but the methods of presentation have been the same, with the one exception of Farmer's original curve, which was non-cumulative, hence an **fN** curve rather than an **FN** curve. Demarcations (limit lines), between acceptable and non acceptable regions, are given as straight lines or steps following the gridlines or as curves. Areas in between such as "conditionally acceptable" can be given as well. With the improvement of typesetting techniques, colours were added. The colouring scheme of traffic lights are universally recognised, so that naturally, the unacceptable area became red, the acceptable area green. With the introduction of fading colours in the Microsoft drawing packages, continuous coloration made these diagrams look like heat maps. (As in Figure 10).

As discussed previously, in an FN curve, the total risk set is depicted as a cumulative frequency distribution presentation. This means that the "risk" is not a single point in the diagram, but a line that may or may not cross the limit line (figure 15).

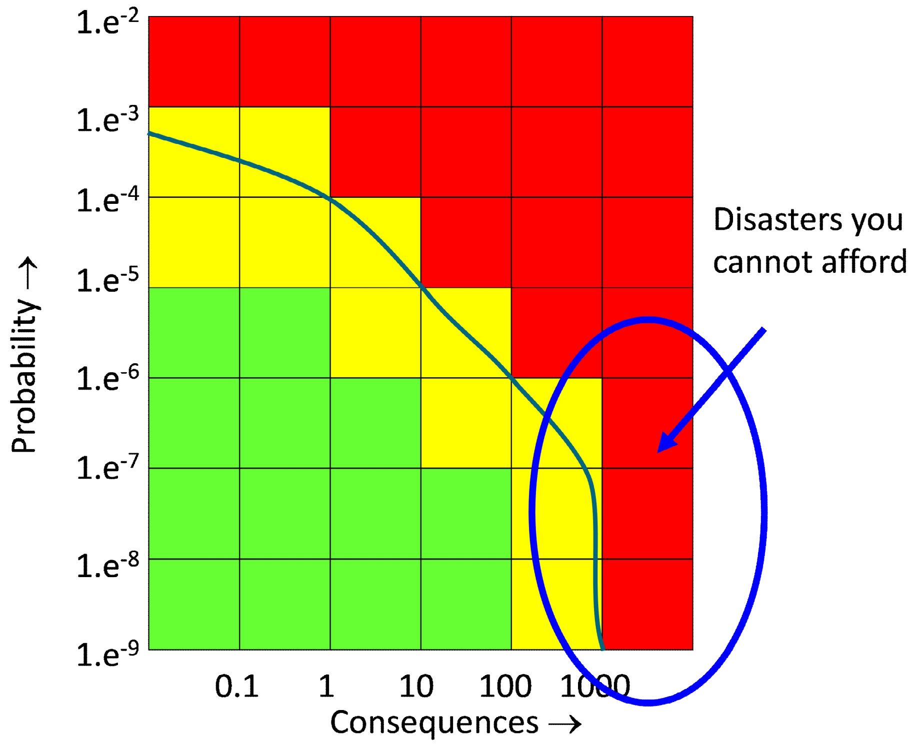

Figure 15: Unacceptable disasters.

There is however no real reason why the demarcations should follow the gridlines that happen to result if one uses a base 10 number system and a logarithmic scale. If the demarcation between acceptable and non acceptable is plotted as a straight line on a double log graph, the line represents the equation F (M>N) = $C/N^{-\alpha}$. Alpha is also called the aversion factor. Several attempts have been made to derive this factor in a scientific way. The results vary from 1.2 (Okrent, 1981) to 2 (Hubert, 1990). In these cases, such a risk averse demarcation does not follow the economic rule that f*c should be constant. Many arguments against risk aversion, explicitly or implicitly, are rooted in the assumption that they should (Evans). Nevertheless even if an alpha of 1 is chosen there is an element of risk aversion, sometimes reflected in setting a maximum number of people affected or a maximum acceptable loss. It should also be borne in mind that a so called "risk neutral" limit (when interpreted as the acceptable F (cumulative) is equal to A/N (A = constant) for each of the (f,c) points in the riskset. . It is also pointed out that even an F=1/N limit implies some aversion (in these terms) as f = dF/dN. So for F = A/N, f would be A/N^2

This could give rise to, in principle, an unlimited expectation value as the area under the curve grows with increasing N without limit (The integral of 1/N is log(N)). That is probably one of the reasons why all the 1/N curves have an upper limit. A variety of criteria lines is shown below in Fig 16 showing the range of slopes and maxima.

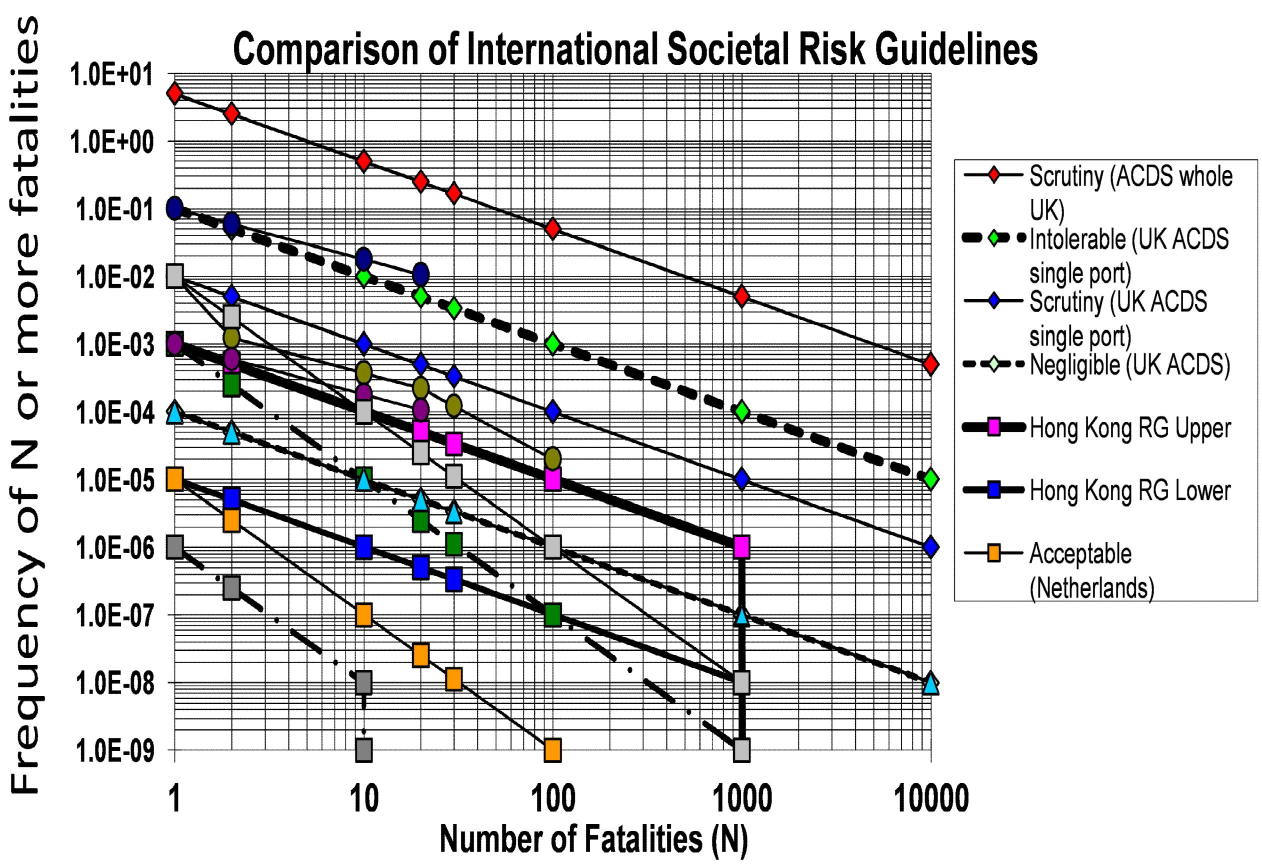

Figure 16: graphs in FN of acceptability criteria. (from Cox R.A.)

The technique is still applied (Fig 17) to industrial installations (onshore and offshore) worldwide and developments of this fully quantitative approach are still valid, available, but now sadly little used in the UK due to resource considerations (time, cost and expertise availability).

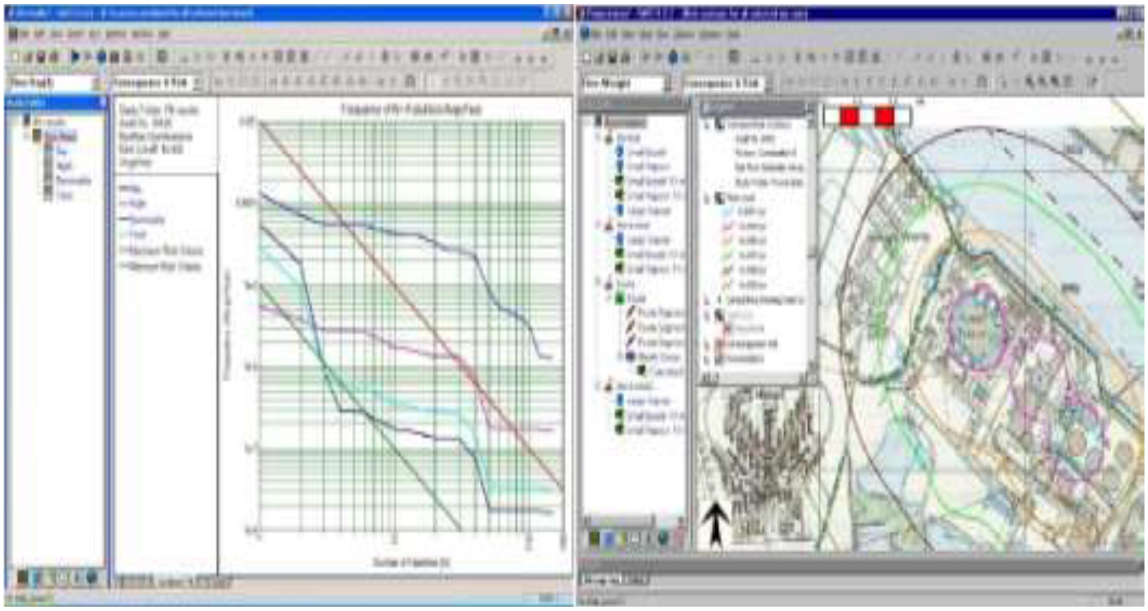

Fig 17 – FN plots and Risk Contours from the SAFETI package.

What has emerged is the increasing use of the visual image of a plot that is helpful in picturing where the seriousness of risks are perceived to be – a so called "heat map" to identify hot spots. Currently, the requirements of corporate governance (Cadbury) and many regulatory bodies (HSE) include risk registers and often some form of "risk matrix" to display the perception of risk exposure and measures (justified) to prevent, minimise or manage them. In its most basic form, a corporate group discusses a list of potential threats and assigns notional likelihoods and estimates of seriousness (consequences), often against guidelines, (e.g. examples in classes, say 0 – 5 for each identified candidate threat). In order to assess the relative importance of these "risks", (and perhaps to prioritise responses), they are often plotted on a two dimensional "heat map". This is an example of a probability impact graph, often referred to as a PIG (see Figure 5).

As qualitative visualisation techniques to aid decision making, these PIGS have been found by many to be very helpful and by some indispensible. The problems arise when additional, often quantitative outputs are required or attempted. (Creswell) Such as:-

- What are the correct ordinates? – Probabilities, frequencies, of events, outcomes, etc.?
- One or both linear scales, or Logs, Powers?
- Discrete points or area averages?
- Single points or distributions?
- Completeness?
- Uncertainties?
- "Level of Risk" (Total, components)
- Criteria, Acceptability, Tolerance, Appetite.
- Calibration with records, reality?

Discussion

So far we have concentrated on the historical development and original intent of Probability Impact Graphs (PIGs). We have seen that they do have a legitimate mathematical basis and that their utilisation without awareness of the “rules” can be at best misleading and at worst disastrous. But the main driver for their continued use is that, as a way of assessing the relative positioning of identified risks (from the Risk Register), in terms of qualitative seriousness (notional relative immininence and scale?), it has proved useful in stimulating discussion, awareness and even action from non specialist, but crucial decision makers in an organisation.

Recent work on the neuroscience of risk (Burke 2011)), seems to support this innate ability of people to process and make decisions on risk in a relatively sophisticated way. At the neuron level, mammals seem to have a “hard wired” ability to handle very rapidly and effectively, probability, uncertainty, size of risk and promise of reward. This is a basic survival evolutionary skill: and it is claimed (Linked in ref) that an analysis of the neuroscience data indicates a “risk aversion/ incentivisation factor of N to the 1.54.(Fig 18)

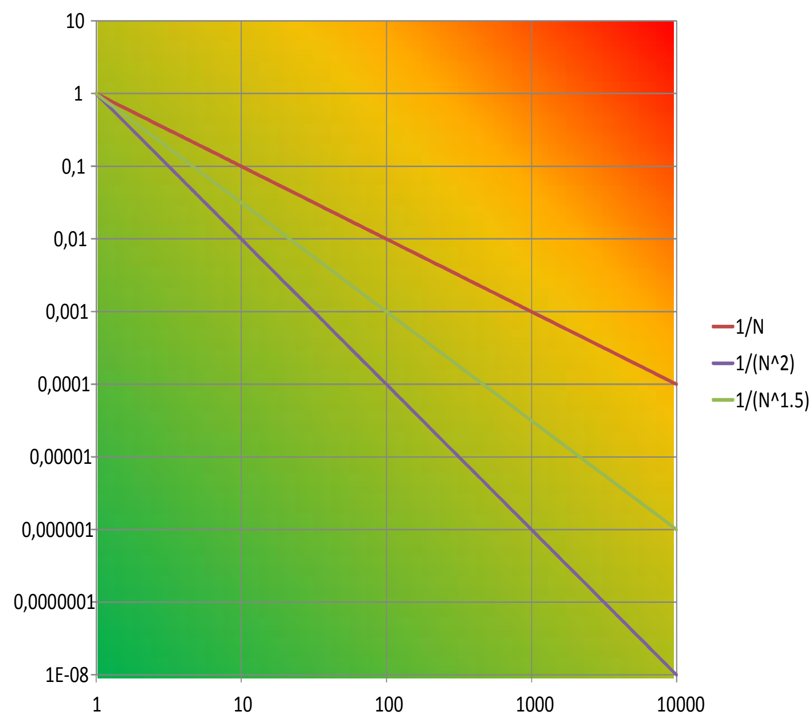

Figure 18. An Intelligent PIG with Aversion Criteria

All of these factors as we have seen, can be accommodated in the risk matrix approach. Can we therefore continue to utilise legitimately, what has become an integral part and some think, that indispensible tool in the armoury of corporate Risk Management (and ISO standards) – the PIG? How can we build useful plots in a resource efficient way and still get the added value from their construction?

Group assignments of frequencies and consequences, while subjective, have some basis in proven Delphic techniques. So there is no reason to stop employing PIGS as long as the limitations and necessary assumptions are documented and understood. (Note ISO 31010 fails to comment on whether the frequencies plotted are cumulative or not - **fN** or **FN**). But can we get more? We believe the answer is to set out the rules of their utilisation, explicitly in the standards.

- Recognise there are two distinct categories –
    1. The" Post it" or "heat map" (Qual) Pig
    2. The "Intelligent" or "Groningen" (Quant) Pig.
- If we wish to rank individual risks on a presentation plot that allows us to appreciate the implications of a group discussion on their (relative) importance and seriousness, then a Post it PIG is helpful.
- Any discussion on their individual acceptabilities, needs, however to be done on a risk by risk basis and generalisations are difficult, (not allowed) unless some further quantification and standardisation is employed.
- Quantification is not difficult, but we should follow the rules. Currently most benchmarking, or guides as to scale of consequence and likelihood, are given as implicit log scales. Some actually quote frequency ranges. It helps presentation to ensure that the underlying scale is actually logarithmic.
- For simple comparisons and heat map ranking, **fN** plots are OK. Maxima in allowed consequences (**Nmax**) are always a good idea. Risk aversion can even be incorporated by multiplying the consequence scale by say 1.2, 1.5, or 2, (or whatever the corporate risk appetite indicates).
- For more ambitious outputs such as criteria and risk levels the (Intelligent) cumulative FN plot is needed,
- On the FN plot the group can look at a more rigorous definition and assignment of frequencies and consequences, but risk aversion, Maximum allowed risk and acceptability criteria are all now real and really useful outputs.(Figure 22)
- The area under the FN curve is then the **RISK** or **EXPECTATION LEVEL**. This cannot be legitimately derived from the qualitative versions
- a Risk "Level" can be derived as - the area under the CCDF curve –

  i.e The Risk Level is approx $= \frac{1}{2}(N_{max} - N_1) \times (F_1 - F_{max})]$

The inference from this is that, we can use these plots and derive significantly more information, as long as we are very careful. Spreadsheets can make the required mathematical transmutation of the raw "post it" sessions relatively painless and provided the basis is understood and regularly queried we could produce useful results

Conclusion

Risk matrices are perceived as a convenient and understandable way of presenting risk and displaying limits. In today's management and policy making arena, this simplicity is preferred over the perceived complexity of more mathematical expressions. The presentation of risk as an **FN** curve is seen as exceptionally difficult to understand. In addition consequences tend to be valued as single factor impacts, rather than the multidimensional effects, which they usually are in practice. This development has led to an increasingly strident debate about risk matrices and methods of risk management, to the extent that that there seems to be a call to give up on using them at all in risk management.

With recent disasters in mind, we think they can make a real contribution, but it would be helpful to appreciate what is behind traditional **FN** representations of risk and thus enable a more intelligent (pre incident?) discussion of the dimensions and implications of risk decisions; of such things as appetite, accountability and its limits of acceptability/tolerability (societal and corporate), in whatever form helps; even in such **FN** diagrams, if it helps us manage these risks more responsibly and effectively.. (Casting PIG's before-----!)

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Timeline(approx)

!967 - Farmer, F.R. (1967) Siting criteria – a new approach, atom (128) pp 152-70

1976 – Groningen Criteria (FN (∑fn) plot with limits)

197? - Rasmussen Comparisons with natural disasters (fn curves)

1981 - Rijnmond Risk Output (risk contours and (log axes)fn curves)

1982 - Sizewell B – (Cox - independent” Farmer” type fn curve)

1984 - Technica - SAFETI (“All” Failure cases generation) uses Groningen criteria

!985 - Dutch External Safety Criteria (Individual and Societal Criteria, SAFETI Fn curves and contours)

!980’s - Slovic Risk Aversion (fxn2, fxn1.2)(note on log scales)

!988 - Risk Lite - “Semi quantitative” Risk estimation (still fxn Matrices))

1990 - Corporate Risk Management (Red Amber Green Traffic Lights /Matrices)

1992 – Big Four discover Risk Matrices and move on from mere quantified inputs

1995 - Cadbury Corporate Governance Risk required Registers and produced Matrices based on Board discussions.

2000 - Enterprise wide Risk Management tools include Risk lite graphics

2010 - ISO 3100 – PIGS - organized guesses

2011 – Linked in groups - How do we get a Level of risk from this? How do we get the total summed risk?

2012 – back to Farmer?