GROSS DISPROPORTION, STEP BY STEP – A POSSIBLE APPROACH TO EVALUATING ADDITIONAL MEASURES AT COMAH SITES

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The European Council Directive 96/82/EC of 9 December 1996 on the control of major-accident hazards involving dangerous substances requires, at Article 5, that 'Member States shall ensure that the operator is obliged to take all measures necessary to prevent major accidents and to limit their consequences for man and the environment'. In the Great Britain (GB) this requirement has been taken as equivalent to the pre-existing legal requirement to reduce risks 'so far as is reasonably practicable' (SFAIRP). A key concept of SFAIRP is gross disproportion. Although this pre-existing concept has been recognised for 30 years, a method by which a value for gross disproportion can be derived for a specific situation has seldom been the topic of significant debate or formal publication.

The objective of this paper is to show how this might be done in the context of the GB regulations which implement Directive 96/82/EC and start that debate. It is based, in part, on the experience of the author as an assessor of safety reports produced in accordance with this directive and its predecessor.

The paper sets out in a clear procedural manner a series of individual steps that can be taken to derive a value for gross disproportion for each specific risk reduction measure being considered. It can be applied to relatively minor retrofitting of measures as well as more radical options such as complete substitution by non hazardous processes. It will provide a systematic approach which tries to be 'fit for purpose' rather than so burdensome that it leads to 'paralysis by analysis'. The framework can be made more sophisticated in order to support judgments in borderline cases.

The author was, until recently, head of a group of 25 specialist staff having responsibility for technical inputs to work by the GB competent authority for the directive in a wide range of topics in the field of safety and loss prevention. The group is responsible for the major inputs to decisions on the adequacy of COMAH demonstrations at the most complex installations subject to the directive. The author has worked in safety and loss prevention for almost 30 years, and currently works in HSE's process safety corporate topic group.

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BACKGROUND

Regulatory controls in GB have been based on a series of prescriptive Factories Acts and associated Regulations setting out specific requirements for particular safety problems or, sometimes, industry sectors. Such legislation is ill equipped to respond to fast changing industries and the safety issues arising from them. The style of legislation changed following a review by Lord Robens, a well known industrialist. This 'Robens Report'[1] set the template for future legislation with 'goal setting' requirements rather than 'prescriptive' requirements, largely based on the requirement that operations be 'safe, so far as is reasonably practicable'. Although 'reasonably practicable' was not a new concept in GB law, this made it the foundation stone of most subsequent health and safety law. The most relied upon definition of 'reasonably practicable' is to be found in the court decision in the case of Edwards -v- National Coal Board[2]. The most quoted part of the decision is:-

> *'Reasonably practicable' as traditionally interpreted, is a narrower term that 'physically possible' and implies that a computation must be made in which the quantum of risk is placed in one scale and the sacrifice, whether in money, time or trouble, involved in the measures necessary to avert the risk is placed in the other; and that if it be shown that there is a gross disproportion between them, the risk being insignificant in relation to the sacrifice, the person upon whom the duty is laid discharges the burden of proving that compliance was not reasonably practicable. This computation falls to be made at a point of time anterior to the happening of the incident complained of.*

The Seveso II directive was implemented in GB as the Control of Major Accident Hazards Regulations 1999[3], (COMAH). Seveso II took the existing law beyond the requirement for risk information. Demonstration takes that information and uses it, in further analysis, to show that additional measures are 'not reasonably practicable' (in Seveso terms 'not a necessary measure'). The decisions made are almost inevitably based on some form of cost-benefit analysis (CBA) with gross disproportion as the decision function. There is gross disproportion, according to the definition above, when the costs of a potential safety measure grossly exceeds the value of the safety benefits obtained should the measure be implemented. The proportion factor (which may or may not be gross) is simply the ratio of the costs to the benefits. In low risk situations the CBA may be entirely qualitative and barely recognisable as CBA.

HOW GROSS IS GROSS?

A wide range of authoritative documents[4][5][6][7][8][9][10][11] have made reference to gross disproportion either directly or indirectly. These should be considered necessary background reading before any attempt is made to apply the material that follows.

From these references a number of broad indications can be extracted, albeit with some contradictions. They include the following:-

- Even at the low end of risk, disproportion must always be gross to reflect an intended bias in favour of safety[2]. Care must be taken not to introduce this bias more than once and hence make decisions unduly precautionary. This is a particular danger when valuing human harms averted.
- Gross disproportion factors (GDF) greater than 10 are unlikely, but not ruled out. The higher the risk the higher the GDF[11].
- Where the severity of the predicted consequences is high, more emphasis should be given to the magnitude of those harms[5].
- HSE has not formulated an algorithm which can be used to determine the proportion factor for a given level of risk. The extent of the bias must be argued in the light of all the circumstances. It may be possible to come to a view in particular circumstances by examining what factor has been applied in comparable circumstances elsewhere to that kind of hazard or in that particular industry[8].
- It is further assumed that the value of the proportion factor will increase in some way as risk increases[6].

STEP BY STEP

The suggested scheme of calculation for a situation specific value of gross disproportion considers three factors which might be summarised as 'how bad?', 'how risky?', and 'how variable?'. These factors are not intended to be fully independent and, therefore, introduces some element of non-linear weighting. For example 'how bad?' and 'how risky?' together provide a degree of double counting of the harm. This is intended.

In order to apply this approach the only necessary input information is that contained in an FN curve representation of societal risk such as that shown in figure 1. During the formulation of this approach, three similar schemes of analysis have been considered. They have been named *'integer'*, *'equivalent integer'* and *'suggested'* for identification purposes.

The starting point for all three, are values extracted from the FN curve and the analysis that precedes it. These values are

- The sum of the failure rates for all the events in the scenario list (ΣFR) in events per year.
- The expectation value (EV) which is the average number of deaths per year that might be expected. It is a numerical value representing the area under the FN curve. It is sometimes referred to as potential loss of life, or rate of harm.
- The number of deaths ($Nmax$) predicted from the worst outcome arising from all the events in the scenario list.
- The number of deaths (Nav) calculated from EV divided by ΣFR giving deaths per event. The point (ΣFR, Nav) can be shown on the FN plot from which it is derived, as in figure 1.
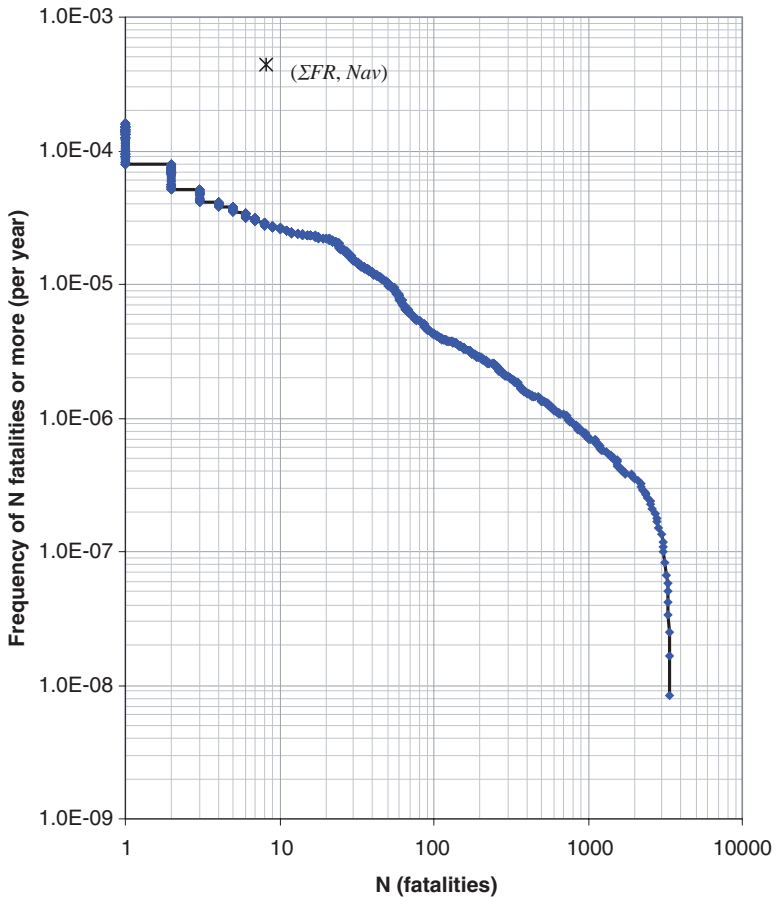
Figure 1. FN Plot for a hypothetical bulk chlorine installation

The *integer* option for GDF represents the actual numerical value of each 'how factor' with a value of either 1, 2 or 3. The three integers representing the three 'how factors' are multiplied together and then a final 3 is added to give the suggested GDF. This gives a potential range of GDFs from 4 to 30. The boundary values adopted to determine the integer values of the three factors are given below.

The *equivalent integer* option is an attempt to overcome the discontinuities of using only integers by replacing the 3 integers and pairs of boundary values with a direct logarithmic relationship. The logarithmic relationships are derived from an approximate

'curve fit' using the geometric mean value (or an equivalent) within each band coupled with the integer value of that band. This leads to relationships of the form:-

$$\text{`how factor'} = (4/3) \times \log_{10} (\text{`value'})$$

where each 'how factor' is as defined below and each 'value' is the corresponding parameter extracted from the FN curve analysis (*Nav, EV*, and the ratio of *Nmax* to *Nav*, respectively)

This was tried because the discontinuities with the *integer* option are particularly severe at high values of GDF, although this should seldom be a problem with 'real' cases.

The *suggested* option is a recalibration, downwards, of the *equivalent integer* option. This reduction serves to reduce the number of cases where a GDF of greater than 10 is produced. This gives a better match with the 'broad indications' identified above.

All the options are presented below for debate.

HOW BAD?

'How bad?' is a representation of the average number of fatalities per event (*Nav*).

In the *integer* option the boundary value between 1 and 2 is 10 fatalities per event, and the boundary between 2 and 3 is 100 fatalities per event.

In the *equivalent integer* option the how bad factor is calculated by taking the base 10 logarithm of *Nav* and multiplying it by four thirds. Values less than 1 are then rounded up to 1. Applying this minimum of 1 to all the how factors ensures that, overall, gross proportion calculated for any situation cannot be less than 4. In this option, values are not capped at 3. This is a response to the limitation of the 3 band system of the *integer* option.

The *suggested* option is just the *equivalent integer* option without the multiplication by four thirds.

HOW RISKY?

'How risky?' is a representation of the expectation value (*EV*).

In the *integer* option the boundary value between 1 and 2 is 10^{-4} fatalities per year, and the boundary between 2 and 3 is 10^{-3} fatalities per year.

In the *equivalent integer* option the how risky factor is calculated by taking the base 10 logarithm of $100{,}000 \times EV$ and then multiplying it by four thirds. Values less than 1 are then rounded up to 1. In this option, values are not capped at 3.

The *suggested* option is just the *equivalent integer* option without the multiplication by four thirds.

HOW VARIABLE?

'How variable?' is a representation of the ratio of *Nmax* to *Nav*.

In the *integer* option the boundary value between 1 and 2 is a ratio of 10, and the boundary between 2 and 3 is a ratio of 100.

In the *equivalent integer* option the how variable factor is calculated by taking the base 10 logarithm of the ratio and then multiplying it by four thirds. In this option, values are not capped at 3.

The *suggested* option is just the *equivalent integer* option without the multiplication by four thirds.

HOW IT MIGHT WORK IN PRACTICE

Because gross disproportion is the decision function for 'not reasonably practicable' it might be thought that it need only be calculated as the penultimate step in a safety demonstration. As gross disproportion reflects the significance of the risk, its numerical value can also be used at an earlier stage. It can be used to set the breadth and depth of the search for, and evaluation of, possible additional measures in which it will finally be used. If this approach is adopted then the GDF(s) should be calculated once the existing risks have been predicted. In the context of a COMAH report this would be after the information on extent, severity and likelihood has been produced. Put another way, the value of the GDF sets the proportionality that runs throughout the demonstration as well as being the decision function.

Toxics installations, and other installations having very directional effects, can produce high ratios of *Nmax* to *Nav*. The largest encountered by the author being 2,400. This was part of the reason for not capping any factor at 3 in the *equivalent integer* and *suggested* options.

Some example calculations may serve as an illustration. In order to base them on publicly available data, they are taken from HSE research report 283 'development of an intermediate societal risk methodology'[12] including the addendum [13].

THE WHOLE PLANT

Using chlorine installation number 2 which has 2×80 tonne chlorine tanks, the input data for the whole plant (scenarios 1-51, high population) are

- ΣFR (events per year) 2.62×10^{-3}
- *EV* (deaths per year) 6.59×10^{-3}
- *Nmax* (deaths)   4515
- *Nav* (deaths per event)   2.52

These input data are used to derive the 'how?' factors as follows:-

'How bad?'
Nav is 2.52.

This is below the lower boundary value of 10 (boundary values are 10 and 100) so gets a 'how bad?' factor of 1 under the *integer* scheme. With the *equivalent integer*

scheme, $(4/3) \times \log_{10}(Nav)$ gives 0.54 which is rounded up to 1. With the *suggested* scheme, $\log_{10}(Nav)$ gives 0.4 which is again rounded up to 1.

'How risky?'
EV is 6.59×10^{-3}.

This is above the upper boundary value of 1×10^{-3} (boundary values are 1×10^{-4} and 1×10^{-3}) so gets a 'how risky?' factor of 3 under the *integer* scheme. With the *equivalent integer* scheme, $(4/3) \times \log_{10}(EV \times 10^5)$ gives 3.8. With the *suggested* scheme, $\log_{10}(EV \times 10^5)$ gives 2.8.

'How variable?'
Nmax is 4515 and *Nav* is 2.52. So *Nmax/Nav* is 1792.

This is above the upper boundary value of 100 (boundary values are 10 and 100) so gets a 'how risky?' factor of 3 under the *integer* scheme. With the *equivalent integer* scheme, $(4/3) \times \log_{10}(Nmax/Nav)$ gives 4.3. With the *suggested* scheme, $\log_{10}(Nmax/Nav)$ gives 3.3.

The corresponding indicative GDFs are the products of the 3 'how?' factors plus 3.

- *integer* $(1 \times 3 \times 3) + 3 = 12$
- *equivalent integer* $(1 \times 3.8 \times 4.3) + 3 = 19.3$
- *suggested* $(1 \times 2.8 \times 3.3) + 3 = 12.2$

The GDFs in the examples that follow are derived in the same way.

Using the LPG distribution depot example the input data for the whole plant (scenarios $1-24$, general + housing + school) are

- ΣFR (events per year) 2.21×10^{-2}
- *EV* (deaths per year) 5.16×10^{-2}
- *Nmax* (deaths)   148
- *Nav* (deaths per event)   2.34

The corresponding indicative GDFs are

- *integer*   9
- *equivalent integer*   14.9
- *suggested*   9.7

BULK TANKS
Using chlorine installation number 2, the input data for the 2×80 tonne chlorine tanks (scenarios $22-31$) are

- ΣFR (events per year) 1.24×10^{-4}
- *EV* (deaths per year) 2.46×10^{-3}
- *Nmax* (deaths)   4515
- *Nav* (deaths per event)   19.81

The corresponding indicative GDFs are

- *integer*   21
- *equivalent integer*   20.3
- *suggested*   10.3

Using the 2×80 tonne propane tanks in the LPG distribution depot example (scenarios $7-11$) the input data are

- ΣFR (events per year) 4.12×10^{-5}
- *EV* (deaths per year) 3.00×10^{-3}
- *Nmax* (deaths)   148
- *Nav* (deaths per event) 72.77

The corresponding indicative GDFs are

- *integer*   9
- *equivalent integer*   11.2
- *suggested*   7.6

TANKER OFFLOADING
Using chlorine installation number 2, the input data for the tanker offloading (scenarios $1-5$) are

- ΣFR (events per year) 1.25×10^{-3}
- *EV* (deaths per year) 3.29×10^{-3}
- *Nmax* (deaths)   352
- *Nav* (deaths per event)   2.63

The corresponding indicative GDFs are

- *integer*   12
- *equivalent integer*   12.5
- *suggested*   8.4

Using the road tanker delivery to the propane tanks in the LPG distribution depot example (scenarios $1-3$) the input data are

- ΣFR (events per year) 4.77×10^{-3}
- *EV* (deaths per year) 1.55×10^{-3}
- *Nmax* (deaths)   27
- *Nav* (deaths per event)   3.25

The corresponding indicative GDFs are

- *integer*   6
- *equivalent integer*   8.2
- *suggested*   6.2

POINTS TO NOTE

Given the significant limitations of the 3 options it is important to judge whether they 'behave' in a reasonable way. In order to provide some further information for the reader to make their own judgement, it is worth providing the full range of GDFs for both plants used as examples above in the form of tables for easier comparison.

To the author, these seem to be reasonable values, and I would personally use the *suggested* option. However, the process of smoothing, which is part of the *suggested* and *equivalent integer* options, does risk introducing spurious accuracy (that is the temptation to quote, and worse still rely on, more significant figures than can by justified by the uncertainties inherent in the method as a whole). Numerical values may be quoted above to 3 significant figures, but I would only use the rounded integer part.

The options presented in this paper for deriving a GDF are based on fatality risk alone. It must be remembered that the scope of the CBA analysis for a 'not reasonably practicable' judgement is much wider than fatality and includes a range of other harms averted. In the case of an 'all measures necessary' demonstration, it includes averted harm to the natural and built environment. HSE has published its policy on this[11].

KEEPING IT SIMPLE!

In the simplest cases, where there is only one significant hazardous event leading to essentially a single outcome, *Nav* equals *Nmax* and ΣFR becomes the single frequency of that event. These data then come directly from the severity and likelihood information in a COMAH report. This situation might apply when, for example, considering the necessity for fire protection on a pressurised LPG storage vessel.

Another simplification is to assume that the possible additional measure being considered is 100% effective and 100% reliable. Using this as an initial assumption can often lead to clear cut decisions that would not be affected by debates about efficacy and values of 'failure on demand' etc.

Table 1.

For the chlorine installation number 2	Integer	Equivalent integer	Suggested
whole plant	12	19.3	12.2
road tanker offloading coupling	12	12.5	8.4
pipework 25 mm diameter	5	5.6	4.9
2nd pipework section	9	7.3	5.4
2 × 80 tonne chlorine vessels	21	20.3	10.3
pipework, vessel outlet, pre ROV	7	6.2	4.8
pipework, ROV to plant	9	9.1	6.4
pipework in plant	9	8.2	6.0

Table 2.

For the LPG distribution depot	Integer	Equivalent integer	Suggested
whole plant	9	14.9	9.7
road tanker propane delivery	6	8.2	6.2
road tanker butane delivery	6	7.4	5.7
propane storage, 2×80 tonne	9	11.2	7.6
butane storage 2×60 tonne	9	10.4	7.2
outlet manifold	4	4.0	4.0
transfer line	4	4.2	4.0
cylinder filling	9	10.8	7.4
propane export tanker mini-bulk	6	8.1	6.3

OTHER BENEFITS

Clearly a major benefit of having a systematic approach to SFAIRP, 'reducing risks ALARP', 'all measures necessary', etc., is that, not only can a duty holder claim to have met those legal requirements, but can also show why that claim is soundly based. Having a systematic approach ensures that the right amount of resource, whether it is *money, time or trouble*, is being expended rather than expenditure based on serendipity. Good risk management is good business management.

One additional benefit of having identified a range of possible additional measures, and having shown that they are not reasonably practicable, can arise should there be pressure to develop land near the duty holder's installation. Experience shows that major development proposals can come forward at relatively short notice. Developers will have expended considerable effort on preparing the financial business case for the proposal and are likely to have paid little regard to any adverse financial effect on the duty holder's installation. This is likely to carry great weight with planning authorities in the absence of a well argued case about adverse effects. Having a list of additional measures, of known cost, which were not quite reasonably practicable in the existing situation, provides the basis of a quick response to planners on the potential costs to the duty holder should the development go ahead. A swiftly delivered, well argued case, with illustrative costs, and their effect on the business, is much more likely to be effective than generalised protest.

AUTHORS NOTES

The views expressed in this paper are those of the author; and, except where the context indicates otherwise, not necessarily those of the Health and Safety Executive.

This paper makes no claim to there being any underlying scientific truth in the options proposed. What is offered is a workable method for the practitioner, that attempts to follow the spirit of the relevant policy statements.

An industry approach arising, in part, from discussions with this author has already been published[14].

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