SOCIETAL RISK CRITERIA IN LAND USE PLANNING – THE SCALE OF 'SCALE AVERSION'

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The current UK land use planning (LUP) regime near major hazard (MH) installations is based on modelled hazard or risk to hypothetical individuals at specified locations. These straightforward and transparent model outputs are convenient for drawing Consultation Distance (CD) and zone boundaries, and for comparisons. True, they are "blind" to population density and, partially, also to differences in vulnerability (though allowance can be and is made, for example, for slower escape by vulnerable people). However, these objections are addressed[1] by assigning each development type a sensitivity level, which takes into account both density and vulnerability, and restricting more sensitive developments to zones further from the installation. The LUP regime thus implicitly takes account of societal risk (SR). How it is to do this explicitly remains unclear, however, even after HSE's recent consultation (HSE 2007).

There are conceptual as well as practical problems with a comprehensive SR assessment. Not only is it relatively complex and expensive to carry out, but the results, even plotted as an FN graph[2], can be difficult to interpret, especially in terms of tolerability criteria. If a line is drawn to demarcate the region where the risk is deemed intolerable from that where it is tolerable-if-ALARP (As Low As Reasonably Practicable), it is unclear whether a graph that is above the intolerable threshold in one place but well below it elsewhere should be judged intolerable. Again, it can be difficult to compare FN graphs for different sites, or for different risk reduction options at a given site. Internal contradictions and potential inconsistencies are clearly set out by Evans (1997).

Partly for these reasons, efforts have been made by HSE and others to organise or manipulate the data underlying the FN graph to generate a single characteristic number. Unfortunately, this is to trade transparency for convenience: such risk indices are convenient for comparisons, but their meaning can be far harder to discern than that of the originating graphs. In the case of the Scaled Risk Integral (SRI), even the dimensions are baffling (no matter that they are logically derived):

$$(\text{people}^2 + \text{people})/\text{hectare}.$$

Probably the simplest numerical index is obtained by multiplying the frequency of each component incident by the number of fatalities it would cause and summing the results over all components. The result is the calculated annual fatality rate or Potential Loss of Life (PLL) from all accidents at the major hazard facility.

An important disadvantage of this natural approach is that it does not acknowledge the putative aversion of the public to multiple fatalities, also known as scale aversion. HSE and other industry experts have debated whether a single accident killing, say, fifty people is, or is considered by society to be, a worse outcome than fifty individual fatal accidents; and whether, if such aversion does exist, it should be incorporated in SR criteria (see e.g. Stallen, 1996; Jonkman, 2002 and detailed discussion in Appendix 6 of HSC, 1991). HSE now has a published policy not to use scale aversion (HSE, 2010).

Much HSE guidance cites its landmark publication (HSE, 2001), affectionately known as R2P2, in recommending an *ostensibly* scale-neutral slope of -1 for SR criteria on logarithmic FN axes. Note that R2P2 does not independently endorse this value for the slope, but refers to another report commissioned by HSE (Ball, 1998) – which also does not endorse a particular value for the slope. Nevertheless, HSE guidance and publications by others cite R2P2 as an authority for the -1 slope. The tolerability line passes through the R2P2 "anchor point", namely a frequency of 2×10^{-4} per year (= 200 chances per million, or cpm, per year) for single events causing 50 *or more* deaths. On this basis, accidents causing 5 *or more* deaths would be tolerable at 2000 cpm/yr, those causing 500 *or more* deaths at 20 cpm/yr, and so on.

The reason I have laboured the word "ostensibly" and stressed "or more" in the above paragraph is that, contrary to appearances, an FN criterion slope of -1 incorporates a considerable degree of scale aversion, concealed within the words "or more". This is explained in detail in several publications, including HSC (1991).

The dotted line in Figure 1, labelled F(N), is the tolerability criterion described above, which I shall loosely term the R2P2 criterion. The curve below it, labelled f(N), is plotted to pass through 100 points representing accidents in which *exactly* N people die[3]. It is important to realise that the two curves correspond to identical risk profiles. Thus, the condition that the risk of 50 or more deaths from a single event should have a predicted frequency of one-tenth (10%) that of 5 or more, corresponds to the condition that the risk of exactly 50 deaths should be no more than approximately one eighty-fifth (1.2%) of the risk of exactly 5 deaths.

According to HSC (1991) "it is a matter of judgement whether and if so to what extent an FN limit curve of slope

[1]Within PADHI (Planning Advice for Developments near Hazardous Installations).

[2]Frequency F of events causing N or more deaths; F *v* N plotted on log-log scales.

[3]Strictly, the curve should be dotted, since fN is not a continuous function: it is defined only for integral values of N.

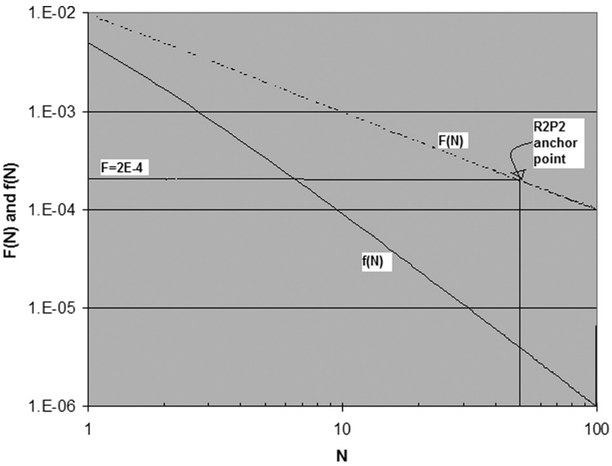

Figure 1. Scale aversion implicit in apparently scale-neutral FN criterion

minus 1 is indeed risk averse: that is, shows extra repugnance to deaths of large numbers. We consider that it does include some risk aversion." The reason for the authors' hesitation is that "one might think in terms [not of exact numbers of victims, but] of the chance of killing 'about 10' (say, 9–11), 'about 100' (say, 90–110), and 'about 1000' (say, 900–1100). The frequency of events would indeed be in the ratio 1:10:100."

However, the scale aversion definitely exists and can be objectively measured. To begin with, the ratio quoted by HSE is not quite correct. The just-tolerable frequency of events killing about 1000 (900–1100), about 100 and about 10 (the HSE sequence is back to front) is in the ratio 1:10:137. If we include in our survey the just-tolerable frequency of killing one person[4], the ratio, which would be 1:10:100:1000 without scale aversion, turns out to be 1:10:137:2465.

For the criterion to be truly scale-neutral, the maximum tolerable PLL should be directly proportional to the maximum number of fatalities (N_{max}). In the hypothetical situation where at most one fatality could be caused, ie $N_{max} = 1$, the value of PLL consistent with the R2P2 anchor point is 5.00×10^{-3}. Table 1 compares calculated just-tolerable PLLs that are truly scale-neutral, ie proportional to N_{max}, with those derived from the R2P2 graph. A marked scale aversion is clearly apparent.

It must be conceded that the gap between the curves in Figure 1 tends to decrease, together with the degree of scale aversion, for sparser sets of N values – rather than a continuous spectrum (Ball, 1998).

The SRI was originally applied in the LUP context, prior to the introduction of PADHI. It therefore dealt originally with risks of dangerous dose (or worse); however, there is no objection, in principle, of using it to express fatality risks, as is appropriate in the present context.

[4]Since we are dealing with integers, "about 1" = 1.

The derivation of the SRI is set out in Carter (1995) and further explained in Hirst (1998), Carter (2000) and elsewhere. The SRI is calculated from IR values:

$$SRI = (P \times R \times T)/A$$

where:

P = population factor
= ½[mn + (mn)^2], where
m = population modifier:
m = 1 for house residents
2 for a sensitive/vulnerable population
0.25 for people at a workplace
n = population of development
R = IR (at the proposed development near the MH site) (cpm/yr)
T = proportion of time for which the development is occupied
A = area of development (ha)

The population factor P represents an enormous scale aversion, with the aversion factor growing at approximately half the rate of the number of fatalities. Thus, it is implied that society is as averse from an accident in which 50 people are killed as it is to $½(50 + 50^2) = 1275$ separate fatalities.

I have been unable to find any justification for this weighting, beyond the observation made by Hirst (1998) that it falls within the range of weightings used by others. In fact, as Hirst himself demonstrates, the SRI scale aversion grows with N in parallel (beyond approximately N = 10) to the system in use in the Netherlands, which HSC (1991) branded "extreme" – and which has caused "some local difficulties of implementation which have necessitated permission for derogations" (Ball, 1998). Indeed, it appears to outdo in severity of aversion the distantly related "worst-case" screening tool, the Approximate Risk Integral (Carter, 2000; Hirst, 2002); though perhaps not the recently proposed risk integral for land-use planning (Saw, 2009).

It is instructive to pit R2P2 and SRI against one another – instructive, though perhaps somewhat mischievous: R2P2 is concerned with regulatory compliance of hazardous installations and SRI is used in the management of residual risk through LUP; therefore, strictly, we are not comparing like with like. For simplicity, let us do this

Table 1. Comparison of scale-neutral PLL values with those derived from R2P2

	Maximum tolerable PLL	
N_{max}	Truly scale-neutral	R2P2 (FN slope = −1)
1	0.005	0.005
10	0.050	0.020
100	0.50	0.042
1000	5.0	0.065

in the context of a planning application near a MH installation which has no other neighbours within the CD. Let us start from the R2P2 anchor point: the SR is intolerable if the calculated frequency of accidents causing 50 or more fatalities exceeds 2×10^{-4} per year.

The same document suggests that the ALARP zone should encompass two orders of magnitude; whence, if the frequency of such accidents is no more than 2×10^{-6} (2 cpm) per year, then the risks (at least from such large accidents) are deemed broadly acceptable, with no immediate need for further risk reduction measures.

Now, suppose the application is for a nursing home with 100 residents on a 1ha site in the outer zone of the CD.

$$P = \tfrac{1}{2}[mn + (mn)^2] = 20100$$

R = 0.3 cpm per yr (characteristic of outer zone)

T = 1

A = 1

Whence

$$SRI = (P \times R \times T)/A = 6030$$

This is more than double the value of 2500, which triggers an Advise Against (AA) decision.

Re-stating: the SRI would trigger AA in a situation where 100 people are exposed to a risk of 0.3 cpm of receiving a dangerous dose. Since a dangerous dose is reckoned to be fatal to roughly 1% of the exposed population[5], the situation equates to 0.3 cpm per year of one fatality.

But we have seen that R2P2 considers 2 cpm of 50 or more fatalities per year, i.e. more than 300 times the above risk, to be not merely tolerable, but broadly acceptable without the need for further risk reduction.

I repeat the health warning given above: regulatory compliance and land use planning require different approaches, so may not be entirely fair to contrast their criteria.

The knotty issues of scale aversion have aroused a great deal of debate in recent years. A satisfactory resolution of the many strands – science, ethics/philosophy, socioeconomics – still appears elusive. Meanwhile, the available choice is not "for" *v* "against" scale aversion, but between moderate and severe expressions of scale aversion.

[5]This is uncontroversial if we assume that the hazard is toxic rather than flammable (Rushton, 2009).

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REFERENCES

Ball, D.J. and Floyd, P.J., 1998, Societal risks – a report prepared for the Health and Safety Executive.

Carter, D., 1995, The scaled risk integral – a simple numerical representation of case societal risk for land use planning in the vicinity of major accident hazards, *Proc 8th Int Symp Loss Prevention and Safety Promotion in the Process Industries, Antwerp*, 2: 219–224.

Carter, D. and Hirst, I.L., 2000, "Worst-case" methodology for the initial assessment of societal risk from proposed major hazard installations, *J Haz Matl*, 71: 117–128.

Evans, A.W. and Verlander, N.Q., 1997, What is wrong with criterion FN-lines for judging the tolerability of risk? *Risk Anal*, 17: 157–168.

Hirst, I.L., 1998, Risk assessment. A note on F-n curves, expected numbers of fatalities, and weighted indicators of risk, *J Haz Matl*, 57: 169–175.

Hirst, I.L. and Carter, D.A., 2002, A "worst case" methodology for obtaining a rough but rapid indication of the societal risk from a major accident hazard installation, *J Haz Matl*, A92: 223–237.

HSC, 1991, Major hazard aspects of the transport of dangerous substances – Report of the Advisory Committee on Dangerous Substances.

HSE, 2001, Reducing risks, protecting people – HSE's decision-making process.

HSE, 2007, Proposals for revised policies to address societal risk around onshore non-nuclear major hazard installations, *CD212*.

HSE, 2010, Status summary of 23 issues February 2010, http://www.hse.gov.uk/societalrisk/technical-policy-issues.pdf (item 3).

Jonkman, B., van Gelder, P. and Vrijling, H., 2002, An overview of quantitative risk measures and their application for calculation of flood risk, *ESREL 2002 European Conference*.

Rushton, A.G. and Carter, D.A., 2009, "Total risk of death" – towards a common and usable basis for consequence assessment, *PSEP*, 87: 21–25.

Saw, J.L. et al., 2009, Societal risk: initial briefing to Societal Risk Technical Advisory Group, *HSE RR703*.

Stallen, P.J.M., Geerts, R. and Vrijling, H.K., 1996, Three conceptions of quantified societal risk, *Risk Anal*, 16: 635–644.