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The Effect of Default Values in Regulation Matters

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Abstract

Both performing and validating a detailed risk analysis of a complex system are costly and time-consuming undertakings. With the increased use of probabilistic risk analysis (PRA) in regulatory decision making, both PRA practitioners (usually, licensees) and regulators have generally favored the use of defaults because they can greatly facilitate the process of performing a PRA in the first place as well as the process of reviewing and verifying the PRA. The use of defaults can also ensure more uniform standards of PRA quality. However, different regulatory agencies differ in their approaches to the use of default values, and the implications of these differences are not yet widely understood. Moreover, large heterogeneity among licensees makes it difficult to set suitable defaults. This paper will focus on the effect of default values on estimates of risk. In particular, the following questions will be explored: "How should defaults be set?"; and "What are the implications of choosing different default values?" Some insights on the effects of different levels of conservatism in setting defaults will be provided. This can help decision makers evaluate the levels of safety likely to result from regulatory decisions.

1. Introduction

Today probabilistic risk analysis (PRA) is being productively applied to a variety of engineering technologies, and is being more extensively used in regulation. The increased use of PRA in risk-informed regulation (also sometimes called risk-based regulation or performance-based standards) seems to be due to its potential to yield both improved safety and improved economic efficiency.

Even though both regulators and licensees recognize the potential benefits of risk-based regulation, this approach has been slow to be adopted in practice. The first nuclear power plant PRA was published in 1975 [1], but the U.S. Nuclear Regulatory Commission (NRC) did not issue draft regulatory guidance for risk-informed regulation until 1997 [2,3]. The barriers to the implementation of risk-informed regulation are largely the same as the barriers to the implementation of quantitative safety goals, and were well discussed by Griesmeyer and Okrent [4]. In particular, they note that “there will always be lack of assurance about the estimates of low frequency, high consequence events” and that “the subjectivity, the subtlety and the novelty of risk analysis open to the unintended bias, as well as to outright abuse”. As a result, they conclude: “there will always be conflict in the management of risk due to the variation of both societal values and societal risks, as well as the uncertainties in the estimation of those risks”.

Why is this? Essentially, the problem has to do with asymmetries in information between regulators and licensees. Performing a comprehensive and rigorous risk analysis of a complex system is a costly and time-consuming undertaking that requires detailed site-specific knowledge. Even verifying or validating a PRA is costly; if the verification process is to generate high confidence in the results of the risk analysis, the levels of effort and expertise required are comparable to performing the analysis in the first place. Since regulators will rarely have either the staff time or the site-specific knowledge to undertake such analyses, they are generally dependent on analyses performed by licensees.

Here the uncertainties and subjectivity involved in risk analysis become a problem. Even if one is willing to assume that licensees will not engage in "deliberate bias or abuse" [4], there is typically enough room for judgment (both in structuring the PRA model itself and in estimating key parameter values) that licensees can easily "shade" their analyses in the most favorable possible direction without departing from the range of credible assumptions. As just one example of this, there is a natural tendency to review the dominant risk contributors identified in a PRA and "sharpen one's pencil" to see whether the risks from the dominant contributors have been overestimated. It is much less common to do the reverse, even though regression to the mean would suggest that these are likely to have been *underestimated*.

Note also that licensees and regulators have systematically different goals or utility functions. In particular, regulators have a natural incentive (and in fact often a mandate) to seek large safety margins (e.g., by ensuring that risks have not been underestimated); the costs of compliance with regulations are at best a secondary consideration, and in some cases regulators are actually precluded from taking compliance costs into account. Licensees also have an incentive (in face, a direct financial incentive) to ensure the safety of the facilities that they own and operate, but in their case this is balanced by a competing desire to minimize costs. Given the changes taking place in some industries (e.g., the effects on the nuclear power industry of increased competition due to electric utility deregulation), the urgency of cost minimization is if anything likely to increase in the next few years. Therefore, once licensees have achieved a level of safety that is acceptable from a corporate point of view, they will generally have an incentive to ensure that the risks disclosed to regulators are not *overestimated*, in order to avoid additional burdensome regulation.

2. The Use of Defaults

PRA results must be derived from high-quality, validated risk analyses in order to be used in regulatory decision making, while both performing and validating a detailed risk analysis of a complex system are costly and time-consuming undertakings. With the increased use of PRA in regulatory decision making, and because of the difficulty of validating a PRA, there is an incentive to standardize PRA's by specifying default modeling assumptions and default parameter values for many uncertain and/or subjective quantities. The adoption of officially approved default modeling assumptions and parameter values can greatly facilitate the process by which regulators review and verify a PRA. Moreover, the use of defaults also facilitates the process of performing the PRA in the first place, and can help to ensure more uniform standards of PRA quality, particularly in industries where licensees differ widely in their levels of technical expertise and sophistication.

However, the use of defaults also poses a significant challenge. In particular, the promise of risk-informed regulation to achieve improved safety and economic efficiency is greatest in fields where licensees are highly heterogeneous, since in such cases risk-informed regulation will allow regulations to be tailored to the specific conditions of each facility, as opposed to a "one size fits all" approach. However, it is precisely this large heterogeneity among licensees that makes it difficult to set suitable defaults; in extreme cases, such defaults may not even be within an order of magnitude of site-specific values at some facilities.

Currently, different agencies differ widely in their approach to this problem, and the implications of these differences are not yet widely understood. Two illustrations are discussed here.

The Environmental Protection Agency (EPA) generally sets defaults very conservatively [5]. For example, in assessments of hazardous waste sites, the default assumption may be that children are exposed to the site 24 hours a day, 365 days a year, even if the site is near a schoolyard rather than near children's homes, and even if it is covered with snow for several months of the year. Use of such conservative defaults may ensure safety, but certainly does not yield an economically efficient regulatory outcome. Nominally, the intent may be to encourage licensees to develop more accurate site-specific information, and in fact licensees would clearly have an incentive to develop such information when faced with highly conservative default assumptions. However, regulators may be quite reluctant to approve departures from the default, since in many organizations (including regulatory agencies), making a decision is potentially more risky to one's career than doing nothing. In fact, the extent of their reluctance is likely to be directly related to the conservatism of the default (since the perceived cost of foregoing a large safety margin would be correspondingly great), so the insistence on using default assumptions may be greatest precisely when those defaults are least realistic. Thus, when defaults are chosen conservatively, some form of management incentive system may be needed to ensure that individual regulators are willing to approve appropriate departures from the defaults.

At NRC, by contrast, the situation is quite different. There, defaults have generally been set at or near the mean value achieved by the nuclear power industry. This creates a risk that licensees may choose to use the approved defaults when they think their own facilities are likely to be worse than average, and use plant-specific data when their plant's performance is likely to be better than average. If this approach is used by an individual plant (e.g., if they choose to use default failure rate data for their relatively unreliable diesel generators, but plant-specific data for highly reliable pumps and valves), the overall results of the PRA will be non-conservative. However, such selective use of plant-specific data may create red flags for regulatory reviewers of the resulting PRA, providing a mechanism for identifying and correcting such non-conservatism.

More importantly, those plants with the highest overall risk are the most likely to use default assumptions in their PRA's, for two reasons. First, those plants may recognize that their own risk performance is likely to be worse than the industry average, and hence may strategically choose to use default assumptions in order to "put the best face on things" and avoid undesired and costly regulatory intervention. In addition, the plants with the highest risks may be high-risk in part because of inadequate attention to the collection and trending of plant-specific failure rate data, and hence may not even have high-quality plant-specific data readily available for use in the PRA. This suggests that when defaults are set at or near the population mean, the plants whose risks are underestimated the most may be precisely those high-risk plants about which regulators have the most reason to be concerned.

3. Effect of Default Values

Fortunately, the implication of how defaults are chosen is a topic that is amenable to fairly rigorous mathematical analysis. In particular, if the actual value of an uncertain quantity is represented by a random variable *X* and the default value accepted for use by the relevant regulatory agency is given by a constant *c*, then it is reasonable to assume that the value licensees will choose to use in their PRA's is given by

$$Y = \min(X, c) \qquad (1)$$

In other words, our model assumes that licensees will prefer to use plant-specific data when doing so yields more favorable results than the approved default, and will use the default value when that is more favorable. Basically, our concern is the effect of the default value on the estimated risk. That is, where should the default be set? What are the implications of choosing different default values?

The effect of the default can be measured by the expectation of $T = Y/X$; that is, $E(Y/X)$. The expectation of *T* can be obtained by the Reimann-Stieltjes integral as the following closed form.

$$E(T) = \int_0^1 \frac{c}{t} \cdot f_X(\frac{c}{t})dt + F_X(c) = \int_c^\infty \frac{c}{t} \cdot f_X(t)dt + F_X(c) \qquad (2)$$

This model has been analyzed for a wide variety of choices of $f_X(x)$, either analytically where possible (e.g., for the uniform or exponential distributions), or by simulation for less tractable distributions. The results of the simulation analyses suggest that if the default *c* is set equal to $E(X)$, then *Y* will be on average 4% to 15% lower than X (see the first column of Table 1). This would seem to indicate that the use of mean values as defaults is not a serious problem, since risk estimates are typically much more uncertain than this to begin with. Moreover, the results presented in Table 1 are likely to be upper bounds on the effect that might be observed in the real world. However, upon further reflection, two potential problem areas emerge, as described below.

The first problem is that estimates of the form of equation (1) may appear in parallel with each other (i.e., multiplicatively) in the PRA. If three or four independent estimates (each of which is low by about 15%) are multiplied, the resulting product can be low by a factor of about 2. Moreover, the various estimates may not be independent; presumably, finding out that a plant is worse than average on one measure will increase the likelihood that it will be worse than average on others as well. Such positive correlation increases the amount by which the average risk can be underestimated, if licensees behave as postulated.

Table 1. Underestimation of Risks Using Mean Value Defaults*

Distribution	E[Y/X]	E[min(Y$_i$/X$_i$), i=1, ..,100]
Exponential	0.85	0.20 ¡ ¾0.01
Weibull (shape parameter 2)	0.88 ¡ ¾0.02	0.40 ¡ ¾0.01
Weibull (shape parameter 3)	0.90 ¡ ¾0.02	0.51 ¡ ¾0.01
Weibull (shape parameter 5)	0.92 ¡ ¾0.01	0.66 ¡ ¾0.01
Uniform (lower bound=0)	0.85	0.505 ¡ ¾0.001
Lognormal (range factor=3)	0.88 ¡ ¾0.02	0.24 ¡ ¾0.01
Lognormal (range factor=10)	0.90 ¡ ¾0.02	0.10 ¡ ¾0.01
Lognormal (range factor=30)	0.93 ¡ ¾0.01	0.06 ¡ ¾0.01
Lognormal (range factor=100)	0.96 ¡ ¾0.01	0.07 ¡ ¾0.01

*Error bounds for simulation results are ¡ ¾two standard errors.

The second problem is even more important. In particular, even if one assumes that the estimated average risk across all plants in the population is low by only a small percent, the risks at the worst facilities will be underestimated by much more than that. With a population of n plants, the risk at the worst plant will be underestimated by an amount equal to $E[min(Y_i/X_i,\ i=1,2,..,n)]$. As before, simulation analyses for a variety of distributions $f_X(x)$ have been undertaken. The results suggest that for a given functional form of distribution $f_X(x)$, the risk at the worst facility will be underestimated the most when X is highly uncertain (i.e., when the population of plants is highly heterogeneous with respect to their levels of risk). Moreover, the results show that for a population of 100 plants, the risk level at the worst plant can easily be underestimated by a factor of 2, and in some cases by an order of magnitude or more (see the right-hand column of Table 1).

4. Conclusions

The results presented here suggest that it will frequently be desirable to set defaults at least somewhat conservatively (although the use of extremely conservative defaults also has disadvantages, as pointed out in Section 2). Moreover, the simple model presented here can also be used to provide guidance on how conservatively the default c ought to be chosen; e.g., at what percentile of the distribution $f_X(x)$ should c be set if we wish to ensure that risk (either the average for the population, or the risk at the worst plant) is underestimated by no more than α%?

If defaults are *not* set conservatively, then particularly careful attention must be paid to the crafting of regulatory incentives so that licensees nonetheless have an incentive to generate risk analysis results based on realistic plant-specific data (and to reveal those results to the regulatory authorities). For example, put oneself in the position of a utility executive who has just been successful in obtaining regulatory relief based on a PRA performed using default assumptions, and then discovers that plant-specific data are substantially less favorable than the defaults. Clearly, there will be an incentive not to disclose the less favorable results. More significantly, there may be an incentive not to even generate plant-specific data in this situation, due to a perception that there is little to be gained beyond the regulatory relief that has already been obtained, but much to be lost.

Presumably, however, the regulator has an ongoing desire to encourage licensees to generate high-quality plant-specific data, especially when it may turn out to be substantially worse than the defaults used in previous risk analyses. Figuring out how to responsibly provide such incentives is likely to require careful thinking and creativity. For example, regulators may wish to consider allowing more relaxed timetables for compliance and/or greater flexibility in how to meet regulatory requirements and safety goals as rewards for licensees who voluntarily disclose unfavorable risk results. Such strategies may simultaneously achieve the competing goals of encouraging licensees to reveal unfavorable risk results while still ensuring adequate levels of safety and regulatory compliance in the long run.

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