

# Reflections on Planning and Analysis for Extreme Events

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Three and a half decades as a practicing consultant in the emerging field of decision analysis has given me a sense of optimism in what I believe can be accomplished in planning for extreme events. It has also given me a strong appreciation for how hard it is to accomplish and implement a rational approach to such planning in our democratic society.

I have three main messages that I wish to present to my fellow participants. I do not claim that these messages are particularly original. My three messages are as follows. First, DO NOT rely exclusively on statistical analysis using available data. Second, DO use judgmental methods to construct models for assessing the probabilities and consequences of extreme events. Third, when uncertainties and consequences are large, the value of further information is often high. Look for and evaluate alternatives to gather intelligence, to carry out research, and to develop technological alternatives to reduce the uncertainty and/or mitigate consequences.

I think we could find analogs for these messages from long before the scientific method and probability theory emerged in the Age of Enlightenment. Homer's *Iliad* describes how Cassandra's warning of impending catastrophe was ignored, even though she was the Trojan King's daughter. Human history is not reassuring that leaders will listen to and act on timely warnings or the urging of analysts to seek means for mitigating potential disasters. Reflecting on history and my perception of our current society causes me to add a fourth "meta-message" at the end of the paper.

Message #1: *DO NOT rely exclusively on statistical analysis using available data.* I am weary of so-called analysts whose probabilistic methodology is limited to using historical data as a probability distribution. This approach gives a probability of 1/100 to the "hundred-year flood" by calling up from the data base the highest level of the river that has occurred in 100 years of available data. We should have learned by now to be skeptical of such simplistic methods. The data base for extreme events implies a small sample size, by the definition of "extreme event." The past is not necessarily a good predictor of the future. Modification of the watershed through removal of natural vegetation, land use changes, and changes in the catchments and channels in the river system may have caused very large changes over 100 years in how upstream rainfall relates to downstream changes in the river level. Further, rainfall events may reflect climatic changes such as El Nino patterns and year-to-year shifts in the jet stream. Let's look at tree rings, dry lakes once filled, and the geological record. The earth's climate has changed a lot during human history, and maybe during the past hundred years.

Nearly forty years after I first learned about Bayesian analysis, I find that many people in the scientific community are still relatively ignorant about such probabilistic reasoning. Want a quick test? Ask the following question: "A fair coin is flipped three times, and at least one of the outcomes is a head. What is the probability of all heads?" Even people well trained in probability

and statistics have difficulty answering this question, because they have been taught to assume that available data reflect independent, identical trials. The test question is a simple example of how partial knowledge about outcomes negates statistical independence. Moreover, as noted in the paragraph above, scientists often assume that the available data come from a process that is stationary in time. The assumptions of independence and of a stationary process make statistical analysis easy, but these assumptions may not be appropriate! Consider what we know about geological processes, climatic processes, or human behavior as we confront some extreme event. What factors influence the probability of a flood, an earthquake, the failure of a complex engineered structure, a terrorist attack, etc.? We should make use of available knowledge and informed judgment about what factors may make an extreme event more likely, or less likely, or how the likelihood of the extreme event may change over time. Such reasoning leads us to build models as a way of refining our analysis. And this leads to my second message.

*DO use judgmental methods for assessing the probabilities and consequences of extreme events.* A good start may be obtained by simply recognizing that probabilities might be conditional, in the sense that probabilities change over time or as underlying conditions change. We can test the available data to determine if there appear to be changes in the probability with time, or in relation to other factors. Must we use a model, in which the extreme event is predicted from knowledge of a causal sequence of events that lead to the extreme event? For most of the extreme events that concern us, we do not have validated causal models. We can, however, work with sequences of events in which the probability of events later in the sequence are conditioned on the occurrence of events (or underlying factor values) earlier in the sequence. Good statistical data may be available as a basis for estimating the conditional probabilities for some of the events in the sequence. For other events, data may be sparse or unavailable, because we do not have direct historical experience. So, as the basis for making decisions to deal with extreme events, the best we can about do is to assemble and use the best available expert judgment. Expert judgment may be based on analogies to similar events or processes where we do have experience, or on theoretical reasoning, including use of models. Often the best available experts will not agree, and their disagreements may relate to differences in the models or analogies used in their reasoning. It will often be useful to make sure the full range of responsible expert viewpoints are available for the assessment, and by sensitivity studies, we can ascertain how important are the differences in expert judgment for overall conclusions. Peer review, clear statements of the information base, and making explicit the reasoning underlying the probability judgments are excellent ways to help assure quality in the assessment process. Probabilities change as the underlying state of information changes. Further investigation and research may confirm or disprove lines of reasoning and reduce, or sometimes, increase, the uncertainty of an extreme event.

Now I am an advocate and practitioner of this type of analysis. I expect there will be others at our meeting who feel very much as I do. I am happy to share lessons from my experience, and I continue to try to learn from the experience of others in the risk analysis community. One of my early projects led to a briefing for President Nixon's Science Advisor and a publication in *Science* magazine [1]. It concerned the effect of cloud seeding on the intensity of hurricanes. The probabilistic methodology involved combining historical observations on hurricanes with subjective judgment in the form of probabilities on different theories for how seeding would affect the intensity of a hurricane. Another example from about thirty years ago involved calculating for NASA the probability that microbial life from Earth transported to Mars on the Viking spacecraft would lead to microbial contamination on Mars and potential interference with any indigenous life forms there [2,3]. The methodology was assessment of conditional probabilities over a sequence of events describing the landing of the spacecraft, the release of the microorganisms, transport of these microbes, and whether the microbes could successfully reproduce if they reached a hospitable location on Mars.

There is a lot of other analysis of extreme events that follows the same approach of assessing conditional probabilities for a sequence of related events, leading to the extreme event of concern. Nuclear safety analysis, and more generally, the experience with safety analysis of engineered structures such as airplanes, manned space vehicles, bridges, and buildings, uses this approach. I have listened to lectures on medical diagnosis at the Stanford Medical School that involved essentially the same approach. I chaired a National Research Council review on the relation of the weight of automobiles to the frequency of fatal accidents [4]. The heart of this problem lies in the relationships among conditional probabilities: driver age, driver behavior, and vehicle weight are not independent variables! In the 1980s I was involved in assessment of toxic waste sites, and for the last twelve years I have been dealing with a particularly difficult kind of toxic waste: spent nuclear reactor fuel, and the high-level radioactive waste from reprocessing such fuel. Again, I chaired a National Research Council committee [5]. A central issue in the management of such waste is the methodology of assessing the likelihood of releases of significant amounts of radioactivity into the environment. There is no historical data base for many of the key issues, and yet there is a great deal of available knowledge. The assessment methodology must summarize scientific knowledge in a way that is both credible and useful for guiding decisions on site selection and repository design. I am pleased that our committee, composed of scientists from a number of countries and disciplinary backgrounds, reached consensus on how to deal with the difficult and controversial issues involved.

I believe similar issues lie at the heart of many other controversies involving safety with respect to extreme events, including genetic modification of food materials, threats of natural pandemics or pandemics from biological warfare, and alteration of climate from changing the composition of the atmosphere. While some argue for a “precautionary principle” of avoiding a technology or policy that involves the possibility of harm, I will argue from an analogy with medicine, that in practice, one must balance the probabilities of beneficial consequences against the probabilities of harm. There is no easy way to determine how much precaution or prudence is enough. The decision context is important. I believe that probabilistic methods give us tools to sharpen and extend our thinking beyond the historical admonition, “First, do no harm.”

Message #3: *When uncertainties and consequences are large, the value of further information is often high. Look for and evaluate alternatives to gather intelligence, carry out research, and develop technological alternatives to reduce the uncertainty and/or mitigate consequences.* Decision analysis, a combination of modern economics and probabilistic risk analysis, gives us tools to evaluate uncertain situations, and one of the most useful of these is value-of information analysis. It is explained in textbooks used in most of our business schools and engineering schools, and yet it is rarely used, especially in a public safety context. The hurricane analysis in [1] was, I believe, one of the first applications of this concept in a major public policy context. An analysis my colleagues and I did on arsenic [6] is the sole reference on value of information in a recent report about toxic substances in the environment by a Presidential/Congressional Commission on Risk Assessment and Management [7]. Value of information analysis is an excellent tool for gaining insight on which uncertainties are most important. It can help in evaluating whether further research is justified before deciding on a policy or deploying a new technology.

*Concluding Caveat: a “Meta-Message.”* We in the US live in a most unusual and fortunate time, when an adequate food supply, good health care, and protection against natural disasters and foreign enemies are essentially assumed to be certain -- our “birthright” in this modern age. Our forefathers viewed life as much more uncertain, and this view prevails today over much of the rest of the world. Common-sense survival skills involve recognizing when

situations are risky and doing things to reduce the risks: store food against the possibility of a lean year, know your potential adversaries, and construct defenses against foreseeable attacks. I worry that many of us in our affluent American society have lost these survival skills. Instead, we make the unwarranted assumption that we should have certainties. When something goes wrong, our society seems to want to find the “bad guys” and hold them responsible. Rather than always seeking “bad guys,” we should recognize that bad things may happen as the result of our well-intended actions – or inaction. We should seek to do a better job of making difficult choices in the face of complex uncertainties and to learn from our past mistakes. This is a basic underlying message in many reports from our leading scientific institutions [5,7,8]. I worry about whether this message is reaching our public and our political leadership. If this meta-message isn’t getting through, technical analysis capabilities may not help much in improving our preparation for extreme events.

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