Working Paper

THE ROLE OF RISK ASSESSMENT IN FACILITY SITING: AN EXAMPLE FROM CALIFORNIA

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I. INTRODUCTION[1]

As the number and scale of energy facilities increase, government agencies are faced with more and more difficult decisions involving the management of societal risk. Since the risks can be complex and not well understood, risk management decisions can be extremely difficult to make. It would seem, then, that there should be an important role for formal analyses in assessing risks to aid those decisions. This paper explores that role in the context of the attempted siting of a Liquefied Natural Gas (LNG) facility on the California coast. While the first site application was filed in 1973, as of this writing (October 1980) no site has been approved. The story of those eight years, a fascinating case study in societal risk management, has been told and analyzed with insight by two of the participants in the process: William Ahern (1980a,b) and Randolph Deutsch (1980). This paper concentrates on one aspect of one episode in that siting process, taking the point of view of the frustrated decision analyst, trying to understand the role his tools play--and could play--in the political process of siting. After investigating that role, the paper concludes with some brief and very general recommendations as to what research is called for to make those tools more useful.

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In early 1977, state and federal regulatory agencies were favoring an LNG terminal site at Oxnard, California. As part of the site approval procedure, assessments of the risks to surrounding areas due to the LNG terminal had been done by the federal regulatory staff (Federal Power Commission, FPC),[2] and by consultants hired by the gas company (Science Applications, Inc., SAI). Both risk assessments estimated the probabilities of each of many possible accidents and derived from them various measures of the risk in probabilistic terms, such as expected numbers of fatalities, probability of fatality per exposed person per year, etc. The implicit goal of both of these assessments was to measure the risk in summary terms that could assist in the determination of whether or not the risk was low enough for the site to be acceptable. Both assessments indicated that the LNG risks to Oxnard were extremely low or negligible (SAI 1975; FPC 1976). The appropriate federal agency deemed the Oxnard terminal acceptably safe, and approved it in December 1977. Considering all of these events, things seemed to be moving smoothly toward approval for the Oxnard terminal. However, the city of Oxnard had commissioned another consulting firm, Socio-Economic Systems, Inc. (SES) to do an environmental impact report. As part of that effort, SES did its own risk assessment, which combined assumptions and model results from SAI, FPC, and U.S. Coast Guard studies to calculate about 5.7 expected annual fatalities as a summary measure of the risk of the LNG terminal (SES 1976). This was about 380 times higher than the corresponding estimate by SAI. However, according to Ahern (1980a) the politically more important part of the SES report was a set of descriptions of several deterministic worst case scenarios, with flammable vapor clouds covering up to 70,000 people, presented without estimated probabilities of occurrence. The publication of those scenarios "electrified opposition to the terminal," to quote Ahern.

In the face of opposition to the terminal based on concern for safety, the California state legislature passed the LNG Terminal Act of 1977 (S.B.1081, September), which excluded the Oxnard site. That bill may have passed with or without the SES worst case scenarios, but the fact remains that the SAI and FPC probabilistic risk assessments did not help the gas company or the regulatory agencies gauge the actual political acceptability of the Oxnard site. The assessments could have been intended for any of several purposes, among them two in particular: to warn the company away from a site where it would be imposing politically unacceptable risk, or to convince all appropriate government agencies that the site was acceptably safe. Measured against either of these two purposes, the SAI and FPC risk assessments failed. This paper presents and discusses four very general reasons for this failure:

[2]The FPC staff more or less became the Federal Energy Regulatory Commission (FERC) staff in the course of the creation of the Department of Energy in 1977. Their work will be referred to as the FPC assessment throughout this paper.

- differences in definition and evaluation of risk
- differences in approaches to risk management
- the nature of the role of analysis in the political process,
- the nature of the political process itself

The last section of the paper summarizes the lessons that can be learned from the discussions of these points, bringing them together in the form of very brief descriptions of the most promising areas for research directed at improving the usefulness of risk assessment in the political siting process.

II. DIFFERENCES IN DEFINITION AND EVALUATION OF RISK

Given the extent of controversy surrounding questions of societal risk, it seems odd that the debate goes on without a clear definition of what risk is. In fact, this section suggests that differences in definitions of risk are basic parts of the problem of managing societal risk.

A. FOCUSING THE DISCUSSION

An LNG siting problem, as discussed here, consists of two interdependent decisions: whether or not to have the LNG project, and if so, where to site the plant(s). A disinterested observer might view these decisions as involving the consideration of very uncertain benefits and losses, all viewed in relation to the alternative action (pipeline, oil, coal, nuclear, conservation, other site). The LNG plant could cause an uncertain reduction in the number and severity of supply interruptions, an uncertain change in the finances of the utility and its customers, an uncertain loss of flora and fauna, an uncertain degradation in people's enjoyment of the coast, an uncertain reduction in air pollution health effects, and an uncertain increase in accident-related loss of life and limb. While these statements suggest directions of LNG plant effects (reduction, increase, etc.), those directions depend on what alternative is assumed to take the place of the LNG project if it is not permitted, and on assumptions made in the related analyses. While it would be interesting to consider all of the factors listed, this paper focuses on health effects, including air pollution effects and accident-related loss of life and limb, factors central to the example given in the introduction. The word "risk" is used to denote some measure of those uncertain losses, reflecting the typical use of the word in such terms as risk assessment and societal risk. Even with this focus, uncertain health effects are many-dimensional things, so that any definition of risk must involve assumptions concerning how those losses are to be evaluated. That is the source of a key aspect of the societal risk management problem: There are two different types of definitions of risk, which arise from two basically different perspectives on risk, technical and societal. These two perspectives can lead to substantially different evaluations of the acceptability of the risk resulting from an LNG alternative.

B. TECHNICAL PERSPECTIVE

From the technical perspective, risk is some probability distribution over sets of health effects. For example, in one paper Keeney (1980a) defines the risk of a technology as a probability distribution over sets of probabilities $\{ p_i, i=1, \cdots, N \}$, each set denoted in short as $\{ p_i \}$, where p_i is the probability that the ith individual of a group of N individuals will die due to the technology before the end of the next time period. The probability sets $\{ p_i \}$ are constructed in such a way that within each set, each probability is independent of any other. The probability distribution over those sets is required to represent probabilistic dependencies between the fatalities. For example, in the LNG case the probability distribution over sets $\{ p_i \}$ could be essentially the probability distribution over accidents. To illustrate, suppose only one accident was possible for an LNG facility, that accident could occur with an annual probability of 10^{-7}, and it would expose each of the nearest 100 people to a very high fatality risk of 80%. While the possibility of such an accident results in an annual mortality probability of $.8 \cdot 10^{-7}$ for each of those people, that number alone does not reflect the fact that the fatalities would occur in one large accident of about 70 to 90 fatalities, if any occur at all. The probability distribution over sets $\{ p_i \}$ can be used to calculate both the probability of fatality per exposed person per year and the potential for high-fatality accidents. Past risk assessments have used these and other summary measures of that probability distribution. The SAI and FPC studies referred to earlier used among other measures the probability of fatality per exposed person per year, an index convenient for comparing individual risks from LNG to risks from other sources. In the Reactor Safety Study ("Rasmussen report"), the risk of nuclear power was represented by a reverse cumulative probability distribution over numbers of fatalities per year per reference reactor (USNRC 1975). One can read directly from a graph of that distribution the annual probability that the number of fatalities will exceed 10, will exceed 100, will exceed 1000, etc. It follows that such a distribution, often referred to as a Rasmussen curve, very directly indicates the potential for catastrophe. The same type of distribution has been used with LNG risk assessments (Hazelwood and Philipson 1977). Some risk assessments go one step further and reduce the distribution to the expected number of fatalities, a measure reported in the FPC and SES studies (see also Paté 1978).

C. SOCIETAL PERSPECTIVE

In contrast to the fairly straightforward technical-perspective risk measures listed above, extensive psychological research in the field of risk perception has suggested many more aspects to be included in a measure of risk that would be more sensitive to the concerns of political and societal processes (Fischhoff, et al. 1978; Linnerooth 1978; Otway and Pahner 1976). Some of these aspects are listed and briefly discussed here as a way of describing risk from a societal perspective. This section is not intended to cover these aspects in any detail, as they have all been treated at length in the cited papers. The aspects are listed roughly in order from the most easily adapted to a simple technical index to the most difficult.

1. Possibility of catastrophe

Some technologies cause fatalities that occur one at a time, scattered widely over a geographic area. An example would be the fatalities due to air pollution caused by burning substitutes for natural gas. While those effects are "spread out" over space and time, the fatalities from a major LNG accident would be "bunched" into a catastrophe at one place and time. That bunching can be very important for how society evaluates the risk. While the Keeney and Rasmussen measures reflect bunching, or possibility of catastrophe, the other technical-perspective measures listed above, probability of fatality per exposed person per year and expected number of fatalities, do not.

2. Inequity of impacts

An LNG plant that exposes people in its immediate neighborhood to a risk for the benefit of all Californians is a case where inequity is important. The air pollution due to a lack of natural gas would be a risk spread more widely over the benefiting population, and so would be more spatially equitable. A risk that may seem acceptable by an aggregate measure, such as expected number of fatalities, may not be politically acceptable if it is inequitably distributed.

3. Degree of control

This aspect is a much more general version of the voluntary/involuntary distinction made by Starr (1969). The central concept here is the level of participation of each potential impactee in each of two decisions: to expose himself to the risk, and to deploy the technology in the first place. Starr presented evidence which he interpreted as indicating that society has a much higher threshold of acceptability for risks involving voluntary exposure than for risks incurred involuntarily. Arguments against that hypothesis have appeared in the literature, most recently in the paper by Slovic, Fischhoff and Lichtenstein (1980), which concludes that apparent aversion to involuntary risk can be better explained by the higher potential for catastrophe and inequity that often accompany that type of risk. However, in another paper the same first two authors stress the importance of public participation in the second of the two decisions listed above, concerning the deployment of the technology (Slovic and Fischhoff 1979).

4. Attribution

This is an important aspect of societal reaction to a risk that is often overlooked because of the cause-specific way risk assessments are performed. There is no doubt as to the cause when a person has been injured or killed by an LNG accident. On the other hand, it may not even occur to someone when an elderly relative dies that he may have lived longer if there had been less air pollution. Beyond that, it would be impossible to attribute any death in particular to the increment in air pollution caused by a low share of natural gas in the energy mix. It may not seem reasonable in a narrowly prescriptive sense to evaluate easily-attributed health effects any differently than more subtly-linked health effects. However any more broad, strategic effort to assess the political acceptability of a project should take attributability into account.

5. Non- decision comparisons

The search for criteria for acceptable risk often falls back on comparisons not involved in actual decisions. For example, comparisons are often made between LNG or nuclear risk and risk of disease, or risk of the rest of the fuel cycle, or risk of smoking an extra cigarette. Yet very few people choose between living near an LNG plant and exposure to risk of disease. The latter risk is always there, as is the risk of the rest of the fuel cycle, so the LNG risk adds to it. Perhaps even fewer people choose between living near an LNG plant and smoking an extra cigarette, though that decision involves some interesting interactions. Yet the use of such benchmarks in evaluating societal risk may be helpful in placing assessments of risks in more meaningful terms than probabilistic measures (Lichtenstein et al. 1978).

6. Non- probabilistic evaluation

Perhaps the most serious mismatch between technical and societal perspectives lies in the societal sensitivity to descriptions of severe outcomes with no regard for the estimated probability for those outcomes. This aspect may have been a key one in the rejection of the Oxnard site mentioned earlier. Worst case scenarios, with uncalculated but extremely low probabilities, seemed to be effective in furthering opposition to the site. While it may be tempting to consider this an example of faulty information processing, of misuse of technical information, in fact there are reasonable justifications for this aspect of risk evaluation: doubt in the ability of probabilistic assessments to avoid underestimating probabilities of accidents, sensitivity to the feeling of dread that could accompany living in the shadow of a vividly described catastrophe, or desire for a resilient social system. However, this aspect of risk evaluation is directly incompatible with the probabilistic orientation of any of the technical-perspective risk measures listed above. One difficulty with any prescriptive evaluation incorporating this aspect is that the most severe outcome described is dependent upon the imagination and motivation of the analyst. Yet once again, any attempt to gauge the political acceptability of a risk should take this aspect into account.

7. Indirect effects

Some aspects of a technology having little to do with possible health effects may have a great deal to do with a societal evaluation of risk. Those aspects include the degree of centralization, how closely a new technology is linked with a high-consumption lifestyle, etc. While these aspects seem far removed from evaluating the risk to life and limb of LNG, they should be included in any effort to understand possible opposition to an LNG site.

D. IMPLICATIONS OF THE TWO PERSPECTIVES

The difference between the two perspectives on risk described above may have very direct relevance for the role of a risk assessment in a political risk management process. This is illustrated by the LNG siting example given in the introduction. The SAI and FPC risk assessments could be viewed as adopting the technical perspective. While parts of the SES assessment adopted that same technical perspective, other parts included worst case scenarios that caught the attention of people with a societal perspective. While the gas company and regulatory agencies were planning on the basis of the technical perspective of risk, the political process they had to deal with was quite naturally sensitive to the societal perspective. The result: probabilistic risk assessments were not effective in guiding the gas company and regulators, nor were those assessments persuasive in the political process. From the other point of view, the political process was not aided by the analytic effort that went into the SAI and FPC assessments. Clearly, no party was served by the mismatch between the technical perspectives of the probabilistic risk assessments and the societal perspective of the political process. Just as clearly, if risk assessments are to serve the applicant seeking to site a hazardous facility and the political process seeking to manage the resulting risk, then either the assessments should adopt more of a societal perspective of risk, or the political process should adapt itself to assessing risks from a more technical perspective.

As the previous paragraphs have made clear, there are many more aspects to the evaluation of societal risk than summary measures of probability distributions on health effects. The limited measures of past probabilistic risk assessments make it easy to suggest that adding more evaluation dimensions to an assessment will then provide more useful guidance to the parties in the siting process. In fact, decision analysts have proposed significant and interesting ways to expand probabilistic risk assessments to explicitly incorporate dimensions that represent societal concerns (Bodily 1980; Keeney 1980 a,b). These approaches are based on multiattribute utility analysis, which can generate evaluation functions that not only represent value tradeoffs between several dimensions, but also represent attitudes toward uncertainty (Keeney and Raiffa 1976). Such functions seem to hold great promise for bringing more of a societal perspective to risk assessments, making those assessments more useful and used. However, as the next sections demonstrate, there are more fundamental problems in the interface between risk assessment and the political process than a lack of dimensions.

III. DIFFERENCES IN APPROACHES TO RISK MANAGEMENT

Beyond differences in how risks are evaluated, political organizations cope with the uncertainties inherent in risk management in ways very different from that assumed in typical risk assessments. There are two types of uncertainty involved. First, there is uncertainty in the outcome of any action since the future is full of unknowns, accidents may or may not happen, physical processes are not completely understood, etc. Second, there is uncertainty in the results of any analysis. From a particularly narrow analytic point of view, looking only at a decision to be made immediately, there is no operational difference between these two uncertainties. But from a more strategic point of view, the second uncertainty reflects how likely the results of an analysis are to be subject to argument, or worse yet, how likely those results are to change. The possibility of analytic results changing within a few years gives very reasonable pause to a government agency about to commit resources to an action with effects spanning decades (e.g., setting a regulation or allowing a plant to be built). The next two sections explore how the analytic and political communities cope with these two uncertainties.

A. THE TECHNICAL APPROACH

Expected numbers of health effects is a risk measure that does not reflect outcome uncertainty, though it is sometimes reported with an error band indicating analysis uncertainty. The other technical-perspective risk measures reported above explicitly account for at least some aspects of outcome uncertainty, though often the analytic uncertainty is either not reported or is not clearly reported along with the risk measures, as was the case with the SAI and FPC assessments. Sometimes Rasmussen curves are reported with error bands reflecting analytic uncertainty, as in Hazelwood and Philipson (1977). In many cases analytic uncertainty is coped with by adopting conservative assumptions, then maintaining or implying that the reported risk measure is at the conservative end of the analytic uncertainty error bar. The fact that the SAI and FPC assessments differ in many of their measures, while both claim conservative assumptions, illustrates that there can be differences of opinion regarding what is an appropriate conservative set of assumptions.

While the technical-perspective risk measures discussed so far report uncertainty to varying degrees, evaluation is limited to observing how small the probabilities are, perhaps in non-decision comparisons as described above. In contrast, the decision analytic expansions to the technical perspective discussed before (Keeney 1980b; Bodily 1980) employ expected utility theory (von Neumann and Morgenstern 1947), which incorporates attitude toward outcome uncertainty in the risk measure itself. In this type of approach, the risk measure is the expectation of an index (utility) that is a nonlinear function of the outcome measures. On any one dimension, then, if the utility function is concave downward, the expected utility risk measure will discount the value of an option with high outcome uncertainty relative to another option with the same expected outcome but less uncertainty. In such an approach, analysis uncertainty can be gauged by a sensitivity analysis which adds error bars to the risk measure.

In the technical approach, then, outcome uncertainty is reflected in all but one of the risk measures, and attitude toward outcome uncertainty is incorporated within the expected utility risk measures. Analytic uncertainty is represented, when it is at all, by error bars or bands around any of the measures, or is dismissed by maintaining or implying that the reported measure is at the conservative end of the error bar. It follows that each technical approach to coping with uncertainty is based on one of two assumptions. The approaches not based on expected utility assume that once outcome and analytic uncertainties are measured and presented, the political process will know what to do with them. The expected utility approach incorporates attitude toward outcome uncertainty directly in the risk measure, assuming that the political process will want to trade off outcome uncertainty with expected outcomes in the way prescribed by von Neumann and Morgenstern (1947).

B. THE POLITICAL APPROACH

The political process, to the extent that one can generalize, often takes a markedly different approach to coping with uncertainty than that assumed by the expected utility risk analyst. Three brief examples illustrate this. When the Office of Technology Assessment did a study on LNG in 1977, it concluded that, in the face of the large analytic uncertainties, "... decisions about LNG systems should be made on the basis of nonquantitative approaches... " (USOTA 1977). When the FPC staff assessed the risks of two California LNG sites (Oxnard and Point Conception), it found the two resulted in different but very low risks. It decided that both sites resulted in an acceptable level of risk, then dropped risk as a factor and favored the more risky Oxnard site on other grounds. When the California state legislature drafted the LNG Terminal Act of 1977, it set a stringent remote siting constraint intended to preclude a worst case scenario anything like the ones SES published concerning Oxnard.

All of the above examples point to the same conclusion: these political decision making processes do not take the probabilistic perspective of the risk analyst, are not ready to incorporate uncertainty into risk evaluation in any way resembling the expected utility approach, and refuse to explicitly trade off risk to life and limb against any other dimension. It is misleading to refer to a political process as risk averse in the expected utility sense, since the thinking evidenced in the processes cited above has very little to do with the expected utility model. The thinking is basically non-probabilistic. In reference to the California remote siting provision and the SES worst cases for Oxnard, one legislative staff member stressed that the California legislature could not allow a site that could kill 40,000 people. The remote siting provision was a constraint used to avoid any explicit trading off of safety with environmental quality, cost, etc. The FPC staff employed similar reasoning in determining that the risk was less than some level, then dropping it from consideration. In each case, the setting of a constraint was effectively an heuristic employed to simplify a difficult decision. Of course, the level at which the constraint was set involved implicit tradeoffs between safety, environment, and cost, as well as judgments concerning the nature of sites available on the California coast, but those tradeoffs and judgments were never considered in an explicit manner.

As with any heuristic, the remote siting constraint imposed a probable cost. Ahern, representing himself and not his agency, has maintained that it almost certainly precluded sites that would be deemed more desirable by any reasonable evaluation (personal communication 1979). More generally, a desire to preclude the possibility of a disaster, no matter how improbable, can lead to decisions that impose financial and environmental costs. Ahern (1980b) describes two cases of this in recent California decisions.

IV. THE ROLE OF ANALYSIS IN THE POLITICAL PROCESS

It is interesting to consider various modes of risk assessment on their own merits. But no analysis exists in a vacuum. Its effectiveness depends critically on the process of which it is a part. Three critical features of that process which can cause problems for the use of risk assessments are briefly reviewed here. We first consider the disaggregated nature of the political process, then examine the two typical ways in which analyses are used in siting procedures: in drafting legislation or regulations, and in hearings.

A. DISAGGREGATED NATURE OF THE PROCESS

The most serious problem in the use of a decision analytic siting evaluation model, such as the one proposed by Keeney (1980c), is that the decision structure assumed by the model does not match the institutional structure making the siting decision. For example, the most basic assumption made by the above model is that there is some single, self-aware process somewhere making tradeoffs between conflicting objectives, such as between safety, cost, and environmental quality. In fact, the actual process may be such that those tradeoffs are not made by any identifiable agency, but are made in the interaction between agencies, with each agency only looking at a part of the problem.

The California LNG siting process is a good example of disaggregation. Three agencies were centrally involved in the state level decision making: the state legislature, the California Public Utilities Commission (CPUC) and the California Coastal Commission (CCC). The state legislature set up the siting process, including a single-agency licensing provision intended to ensure a timely decision, and a remote siting requirement to ensure public safety. As part of that process, the CCC ranked alternative sites, considering primarily environmental quality subject to the remote siting constraint. Then the CPUC selected a site, not necessarily the site ranked highest by the CCC, considering primarily cost and how quickly the site could be developed, relative to the state's need for LNG. The major relevant objectives were cost, safety, environmental quality, and need for LNG as a function of time. Each agency would maintain that it considered all factors, yet the mandates of each are such that each paid special attention to a subset of those objectives. Complicating the picture still further, two agencies within the federal government were also part of the process: one looking at all of the major objectives, the other attending to questions of national import policy. Add to this the state and national courts, and it becomes very hard to identify any single self-aware decision making process where all the tradeoffs were made. To be sure, the overall process results in some decision, which can be analyzed as being consistent with particular implicit tradeoffs, but any similarity between tradeoffs consciously made and those inferred is likely to be simply fortuitous. It is not clear where a decision analytic evaluation model would fit into such a process, whose tradeoffs should be used to set the parameters, or even to whom the analysis should be delivered.

B. ROLE OF ANALYSIS IN FORMING SITING LEGISLATION, REGULATION

One of the observed roles of analysis in siting procedures is in guiding the drafting of the relevant legislation and regulations. Consider, once again, the California LNG Terminal Act. That act established several interesting aspects of the siting process, but here we will focus on the remote siting constraint mentioned above. While it could be described as an heuristic, it is set in very technical language (at most 10 people per square mile within one mile, at most 60 per square mile within four miles), with numbers that were based on analyses. A decision analyst would be inclined to measure the probabilistic costs and benefits of each of various levels of the remoteness constraint, and pick the most favorable. But in this case, while the legislative staff had an entire range of analyses to look at, from each of several different studies and experts, none of them assessed in any direct way the costs and benefits of any level of constraint. Instead, each analysis indicated the maximum distance a flammable methane cloud could travel from an LNG plant. The state of the art in understanding the physical process was weak enough that any of a number of acceptable sets of assumptions could drive an analysis to any of a number of results. In fact the results of the analysis varied from 1 mile to 50 miles for maximum cloud distances. It was not clear which set of assumptions was "neutral", or which was most appropriate for use in drafting legislation. No analysis was used in turn to aggregate this range of analyses into summary measures to guide the setting of the remote siting constraint. The drafting of the legislation was a matter of examining the range of analyses, then making direct intuitive judgments as to the most appropriate constraint. In this case, then, analyses were used in the drafting of legislation, but only for very low-level inputs that were not very directly related to the costs and benefits involved in the actual decision.

C. ROLE OF ANALYSIS IN HEARINGS

The second observed role of analysis in siting procedures is in presenting the various cases before a hearing process. There have been several hearings in the California LNG siting process, ranging from quasi-judicial to legislative in nature, at the local, state, and national levels. The hearings considered every aspect from energy need to safety to cost to the relative merits of the various sites. Take as one example the CPUC hearings to determine the need for LNG in California. Several different agencies presented testimony, each supported by an analysis of a slightly different character, as described by Ahern (1980b). But once again, as in the previous subsection, the several analyses showed several different conclusions, and they were aggregated into the CPUC decision to approve the terminal without any traceable analytic link back to the testimony analyses.

D. SECTION CONCLUSIONS

The key feature in each of the previous two subsections is that in the California siting example, there was not *an* analysis, but many analyses, all suspected of one bias or another, and those analyses were aggregated into risk management decisions in a non-analytic way. There did not seem to be a single objective risk, but rather more than one analysis indirectly assessing risk. There are analytic tools that could be used to combine several analyses into a single source of advice for the decision making process. However, those tools, based on Bayesian statistical inference, would require subjective judgments that would explicitly set the weight given to each analysis, or to each set of assumptions adopted. While this would be a promising avenue to pursue, it may not be politically feasible to collect those judgments. Beyond that, it may not be seen as appropriate to extend analysis to that level, as it would involve political considerations that are seen as properly treated only in legislative and hearing processes.

V. CONCLUSIONS: FUTURE RESEARCH DIRECTIONS

The previous sections of this paper have presented basic problems with the interface between risk assessments and the political siting process. Those problems involve differences in how risk is defined and evaluated, how uncertainty is coped with, how analyses are used in the political process, and the nature of the political process itself. While the discussions of those problems are interesting in and of themselves, they also provide insight into the most promising directions for research to improve the usefulness of risk assessment in the political risk management process. To begin with, there are of course two sides to the interface between risk assessments and the political risk management process. However, the problematic features on the political side of the interface seem either extremely difficult to change or not desirable to change. It seems most appropriate, then, to address the problematic features on the assessment side of the interface. A review of the previous sections indicates the most promising areas for improvement:

- Extend the scope of risk evaluation measures to account as much as possible for societal concerns.

Section II described basic differences in the technical and societal perspectives on risk, and the implications of those differences. Risk assessments typically adopt a technical perspective, and so provide very straightforward, single-number evaluations of risk that do not incorporate societal concerns very well. Political processes are sensitive to the societal perspective, but research describing that perspective is not oriented toward evaluations of risk that provide clear guidance for risk management decisions. Future research should seek to close that gap by developing hybrid risk evaluation aids that are sensitive to societal concerns, yet provide clear risk management decision aids. Work has begun in that direction (Bodily 1980; Keeney 1980 a,b), but should be extended.

- Develop risk management decision aids that are compatible with the essentially non-probabilistic orientation of the political decision maker.

Section III described basic differences in the technical and political approaches to risk management. The most significant difference is the essentially non-probabilistic orientation of many political decisions. That is very problematic for most risk assessments, which tend to be probabilistic in nature. Yet if risk assessments are to be useful, ways must be found for their results to be expressed in a language that the political decision maker can understand.

- Examine analytic techniques for aggregating the results of several different analyses, and select and adapt the most promising ones for use in the political process.

Section IV identified the need for developing analytic tools with which to aggregate results of analyses, then went on to enumerate the problems involved in implementing those tools. Yet not enough is known at this time to assess the feasibility of those tools. That feasibility must be tested by applying the most promising aggregation techniques in actual case studies.

Certainly, none of the research tasks described here is easy. However, the potential usefulness of improvements in any of the areas would justify the research effort many times over.

REFERENCES

Ahern, W. 1980a. "California Meets the LNG Terminal", *Coastal Zone Management Journal* 7, p. 185-221.

Ahern, W. 1980b. "The Role of Technical Analyses in California Energy Siting Decisions". Paper prepared for the LEG Case Study Task Force Meeting, IIASA, Laxenburg, Austria, September.

Bodily, S.E. 1980. "Analysis of Risk to Life and Limb", *Operations Research* 28(1), Jan.-Feb.

Deutsch, R.W. 1980. "Siting an LNG Facility in California: The Regulatory Framework and the Factors Involved in the Decision Making Process". Paper prepared for the LEG Task force Meeting, IIASA, Laxenburg, Austria. September.

Fischhoff, B., P. Slovic, S. Lichtenstein, et al. 1978. "How Safe is Safe Enough? A Psychometric Study", *Policy Sciences* 8.

FPC. 1976. Pacific Indonesia Project, Final Environmental Impact Statement, Federal Power Commission. December.

Hazelwood, R.N. and L.L. Philipson. 1977. Survey of LNG Risk Assessment, Report for the California Public Utilities Commission,Socio-Economic Systems, Inc., Los Angeles.

Keeney, R. L. 1980a. "Evaluating Alternatives Involving Potential Fatalities", *Operations Research,* 28 (1), Jan.-Feb.

Keeney, R. L. 1980b. "Equity and Public Risk", *Operations Research* 28(3), May-June.

Keeney, R. L. 1980c. *Siting Energy Facilities*, New York: Academic Press (in press).

Keeney, R. L. and H. Raiffa. 1976. *Decisions with Multiple Objectives*, New York: Wiley and Sons.

Kunreuther, H. 1980. "Societal Decision Making for Low Probability Events: Descriptive and Prescriptive Aspects", (forthcoming IIASA working paper).

Lichtenstein, S., P. Slovic, B. Fischhoff et al. 1978. "Judged Frequency of Lethal Events", *Journal of Experimental Psychology: Human Learning and Memory*, 4 (6).

Linnerooth, J. 1978. "Reevaluating the Value of Life: Practical Considerations", invited paper presented at ORSA/TIMS Conference, Los Angeles, November.

Otway, H. J. and P.D. Pahner. 1976. "Risk Assessment", *Futures*, 8 (2).

Paté, M.-E. 1978. "Public Policy in Earthquake Effects Mitigation", Technical Report 30, Blume Earthquake Engineering Center, Stanford.

SAI. 1975. LNG Terminal Risk Assessment Study for Oxnard, California. Prepared for Western LNG Terminal Company, SAI-75-615-LJ. La Jolla, California: Science Applications, Inc.

SES 1976. Environmental Impact Report for the Proposed Oxnard LNG Facilities, Socio-Economic Systems, Inc., Los Angeles, California. September.

Slovic, P. and B. Fischhoff. 1979. "How Safe is Safe Enough? Determinants of Perceived and Acceptable Risk", in L. Gould and C. A. Walker (Eds.), *Too Hot to Handle: Social and Policy Issues in the Management of Radioactive Wastes*, New Haven: Yale University Press.

Slovic, P., B. Fischhoff and S. Lichtenstein. 1980. "Perceived Risk", in R. C. Schwing and W. A. Albers (Eds.), *Societal Risk Assessment: How Safe is Safe Enough?* New York: Plenum Press.

Starr, C. 1969. "Social Benefit Versus Technological Risk", *Science*, 165: 1232-1238.

USNRC. 1975. *Reactor Safety Study*, ("Rasmussen Report"), WASH-1400, Washington, D.C.: U.S. Nuclear Regulatory Commission.

USOTA. 1977. Transportation of Liquefied Natural Gas, Washington, D.C.: U.S. Office of Technology Assessment.

von Neumann, J. and O. Morgenstern. 1947. *Theory of Games and Economic Behavior*, Princeton: Princeton University Press.