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Howard Kunreuther

I. INTRODUCTION*

Society has become increasingly concerned with the appropriate procedures for evaluating projects which promise to yield long-run benefits, but also create potentially catastrophic consequences. Recent examples of such problems are the siting of energy facilities such as nuclear power plants or liquefied natural gas (LNG) terminals.

This paper has two principal purposes. Utilizing recent theoretical and

*This paper, prepared for the IIASA Task Force Meeting on Liquefied Energy Gases, reflects many helpful discussions with IIASA colleagues—John Lathrop, Joanne Linnerooth, Michiel Schwarz, Craig Sinclair, and Michael Thompson. Randolph Deutsch, John Lathrop and Ralph Keeney provided helpful comments on an earlier draft of this paper.

empirical contributions to the literature on choice under uncertainty, it proposes a descriptive model as to how such decisions are reached in the United States. On the basis of this descriptive model, suggestions are made for improving the process. The paper thus attempts to integrate descriptive and prescriptive components for analyzing these societal problems.

Section II sketches the elements of a descriptive model of the societal decisionmaking process. This model describes the process of choice by individual parties, each of whom have specific goals and objectives, limited information which are guided by these objectives, and scarce computational resources. It is thus in the spirit of what Simon (1978) terms procedural rationality. The model extends these notions to the case where there are several interested parties who must interact and arrive at a solution for a particular problem. Hence there is an additional layer of complexity imposed on the structure—the interaction between stakeholders who may have different objectives and hence differential information bases.

Section III illustrates the descriptive model with empirical evidence from the LNG siting decision process which has been studied extensively (see Ahern 1980a; Deutsch 1980; Lathrop 1980; and Linnerooth 1980). The paper also utilizes material from studies by Davis (1979) and the Office of Technology Assessment (1977) on the nature of the LNG controversy in the United States. Section IV indicates how we might improve the current situation by recognizing that the descriptive process is based on a number of institutional and legal constraints which may be difficult to change. In developing these prescriptive measures, I will build on the concepts of decision analysis as applied to siting decisions (Keeney 1980), the concepts of assumptional analysis developed by Mitroff, Emshoff and Kilman (1979) as well as policy analysis. Section V provides a brief set of conclusions.

II. DESCRIPTIVE MODEL OF SOCIETAL DECISIONMAKING

Relevant Concepts

In contrast to most textbooks analyses of decisionmaking under uncertainty, where there is a well specified set of probabilities of certain events occurring and potential gains or losses from them, the problems discussed in this paper have grave uncertainties about them. For one thing, there has not been a long history with which to build a statistical database. The technologies are relatively new and in many cases past experience provides us with limited guidance as to the chances of severe accidents occurring. In a similar vein one has to speculate as to what the losses might be should a particular catastrophic event occur in a given location. These two elements of uncertainty represent a challenge for both risk analysis and decisionmaking.

On the analysis side, there is a need to systematically estimate probabilities and consequences from both past data and judgmental studies. There is an extensive literature from controlled laboratory experiments over the past decade which have uncovered a set of biases and heuristics that individuals utilize in dealing with low probability events (Fischhoff, et al. in press; Tversky and Kahneman 1974). Other studies have suggested that the context in which a problem is framed plays a key role in how people make their decisions (Hershey, et al. 1980; Tversky and Kahneman in press). These findings, partly due to computational limitations on the part of individuals, present a challenge to the analyst who would like to improve the decisionmaking process. An attempt in this direction has been taken by Fairley (1977) who provides a detailed set of guidelines for estimating "small" accident probabilities based on a consideration of catastrophic risk analyses for LNG marine transportation. His motivation for suggesting systematic analyses, is that there is a great danger that many sources of an accident will otherwise be omitted. In addition, there are numerous opportunities for bias with respect to judgmental estimates of accident probabilities when there is *not* a long history of past events. Similar reasoning would apply to the analysis of losses from a given accident, such as a major breach of an LNG tank.

On the decisionmaking side, the lack of a detailed database implies that different stakeholders or interested parties will have different estimates of the probabilities and the losses that guide their own judgments. I will look at the process in terms of a scenario involving a number of different decisions, which taken together resolve a particular problem. Some of the decisions may be solved in parallel by different parties; others may be dealt with sequentially.

The *decentralized and sequential nature of the process* are key concepts which guide the descriptive analysis. March (1978) characterizes this process as one of limited rationality, whereby individuals and groups simplify a large problem into smaller pieces because of the difficulties they have in considering all alternatives and all information. Support for these concepts at the level of governmental, firm and consumer decisionmaking comes from several quarters. Lindblom (1959, 1965) emphasizes the incrementalism in decisions made by bureaucracies where there is a tendency for government agencies to "muddle through" by making small changes from the status quo rather than attempting to structure and solve a larger problem. Cyert and March (1963), in their classic study of the behavioral theory of the firm, provide empirical evidence on this behavior by showing how organizations decentralize decisions and attend to different goals and objectives at different times. Bettmann (1979) integrates findings from a number of studies and suggests that the consumer simplifies the decision making process by decompartmentalizing the problem, utilizing limited search, and behaving sequentially with appropriate feedback loops.

Another important concept, which also relates to the uncertainty of information on probabilities and losses, is the ***importance of exogenous events*** in influencing the decision process. Random events, such as disasters, play a critical role in triggering specific actions to "prevent" future crises. The small data base for judging the frequency of low probability events, coupled with systematic biases of individuals in dealing with concepts of chance and uncertainty, increases the importance of a salient event in the decisionmaking process. Tversky and Kahneman (1973) describe this phenomenon under the heading of availability, whereby one judges the frequency of a event by the ease with which one can retrieve it from memory. The importance of past experience in influencing consumer decisions to purchase insurance against low probability events (Kunreuther, et al. 1978) reflects this characteristic of human behavior. In a similar spirit, March and Olsen (1976) suggest that random events and their timing play a critical role in many organizational decisions because of the ambiguity of many situations and the limited attention that can be given to any particular problem by the interested parties unless it is perceived as being critical. They provide empirical evidence to support their theory using empirical studies of organizations in Denmark, Norway, and the United States.

With respect to legislative decisionmaking, Walker (1977) suggests the importance of graphically and easily understood evidence of trouble as an important factor in setting the discretionary agenda of the U.S. Congress or a government agency. He also suggests that the political appeal of dealing with a specific problem is increased if it has an impact on large numbers of people. To support these points, Walker presents empirical evidence on the passage of safety legislation in the U.S. Numerous examples of this process are also provided by Lawless (1977) through a series of case histories of problems involving the impact of technology on society. He points out that frequently:

> new information of an "alarming" nature is announced and is given rapid and widespread visibility by means of modern mass communications media. Almost overnight the case can become a subject of discussion and concern to much of the populace, and generate strong pressures to evaluate and remedy the problem as rapidly as possible. (p.16)

In the case of decisions such as the siting of facilities, random events such as an LNG explosion or an oil spill may be sufficiently graphic and affect enough people to cause a reversal of earlier decisions, inject other alternatives into the process and change the relative strength of parties interested in the decision outcome. The mass media may play critical role in focusing on these specific events and in many cases exaggerating their importance.

Model Formulation

The concepts discussed above have motivated the following descriptive model of the societal decisionmaking process. A scenario consists of a sequence of decisions $\{D_1, \ldots, D_n\}$, which have to be made by different interested parties. In focusing on any particular problem, it is necessary to specify what the n different decisions are that comprise a particular scenario. For example, Ahern (1980a) and Linnerooth (1980) have constructed a detailed flow diagram of the different decision points with respect to the siting of the LNG terminal in California. Here the process begins with the Western LNG Terminal Company filing an application with the Federal Power Commission (FPC) for terminal facilities. It continues through a set of interactions between federal, state and local governmental agencies, as consumer groups and the Western LNG Terminal. In the case of the nuclear power plant licensing decision Jackson and Kunreuther (1980) have constructed a scenario which emphasizes the decentralized nature of decisions by separate divisions of the Nuclear Regulatory Commission. The performance of a plant under a series of predetermined accident scenarios is a basis for the final decision as to whether or not to approve a power plant.

These two examples suggest that, although one can look at a particular decision in isolation, it will be integrated with other actions by being dependent on earlier decisions (e.g., the LNG siting decision) or by being integrated at a later stage with other decisions which are made independently of it (e.g., the licensing of nuclear power plants).

Consider a particular decision, D_j, (e.g., the safety of an LNG terminal) which is part of a overall scenario. Figure 1 depicts the relevant aspects of the process. At any time period, t, there are a set of *exogenous factors* which limit the set of alternatives for consideration. For example, a disaster may trigger specific legislation which provides restrictions on where an LNG terminal can be located. The *input phase* of the process involves the relationship between the set of alternatives and the relevant stakeholders and attributes or measurable impacts (e.g., number of lives lost from an LNG explosion) which are considered important by at least one of the interested parties. There is a clear interaction between stakeholders and attributes: as one changes the composition of stakeholders then the relative importance of attributes also changes. For example, if public interest groups have a voice in the site selection process then the safety factor may be treated as much more relevant than if these parties did not have an input into the final decision. Similarly if certain attributes are specifically introduced into the picture by one of the interested parties, then this may cause other groups to play a more active role in the process. For example, if the

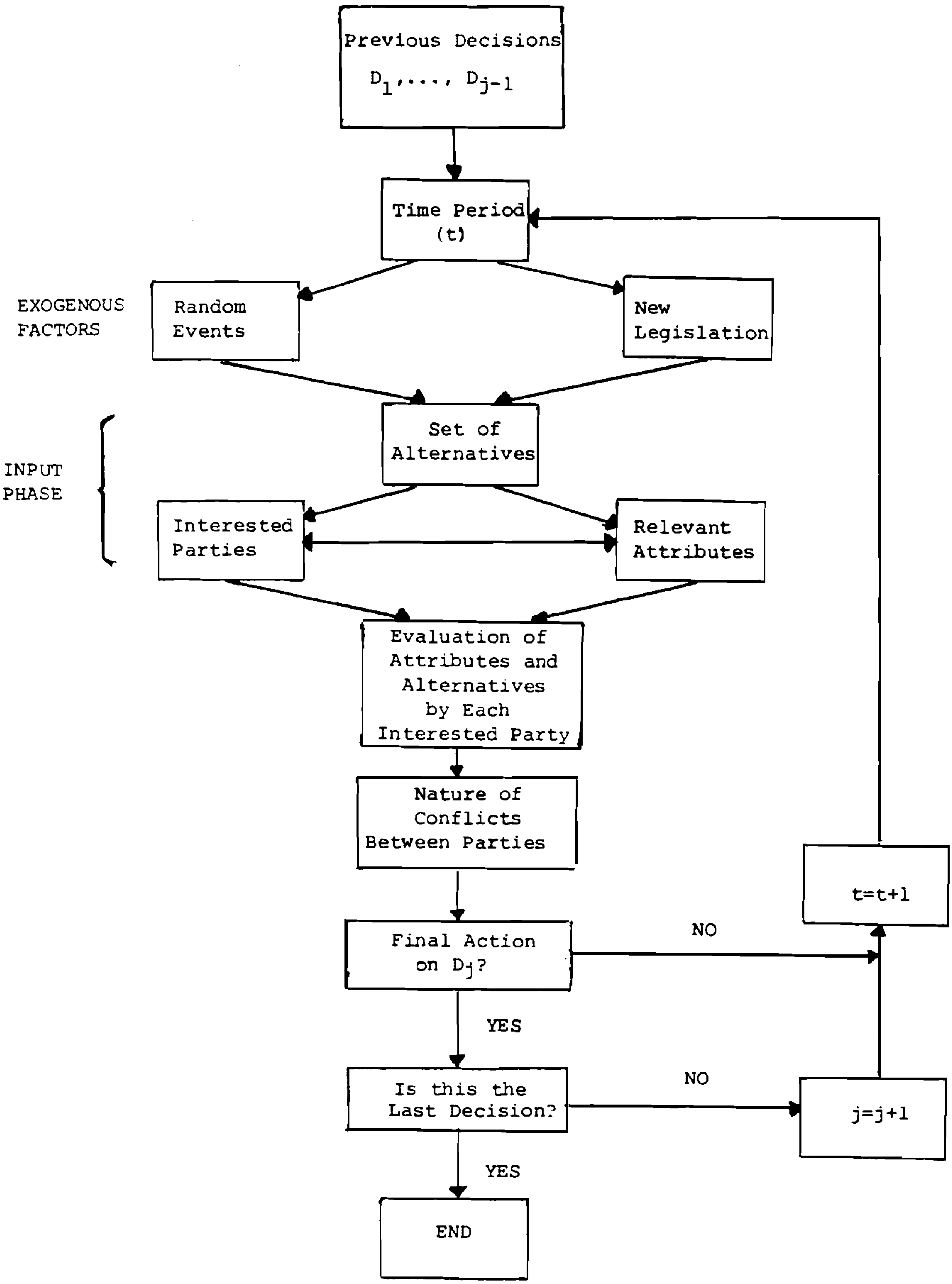

Figure 1. Descriptive Model of Choice.

federal government suggests the critical importance of safety factors as part of the siting decision, then concerned citizens may unite to prevent their community from being chosen as a site.

Each interested party is likely to have a different set of attributes that they consider to be important to the particular problem. Furthermore, there is no guarantee that two interested parties who focus on the same attribute will measure it in the same manner. For example, public interest groups concerned with the safety of potential sites may have a different estimate of the number of lives lost from a severe accident then the gas companies or the consortium proposing the project. Over time the nature and importance of these attributes may also change due to exogenous factors and a new set of alternatives.

When it comes to the *analysis phase*, stakeholders are likely to evaluate different alternatives by looking for satisfactory options rather than trying to find an optimal solution (Cyert and March 1963). For each decision D_j there may be some level of a particular attribute that is deemed satisfactory, but whose value may differ between interested parties. For example, public interest groups may view the acceptable level of risk for a large accident to be somewhat lower than the gas company proposing the project. As a result these two interested parties may have differing views on the acceptability of alternative sites. When such conflicts occur, they may cause long delays in reaching a final decision because there are no clear responsibilities between different agencies. Eventually they may be resolved through some form of consensus by the interested parties, by court rulings or by governmental bodies with specific legislative powers to settle the controversy. For some problems no resolution may take place and the status quo is maintained.

Looking at Figure 1, a critical question is the nature of stakeholder conflicts. If there is a call for more information, this is treated in the figure as being equivalent to postponing action until the next period. In period t+1, a set of random events may occur that substantially change the situation. The breach of a gas tank or the discovery of an earthquake fault may reveal certain features of facilities or sites which may make them unacceptable. These random events may change the relative importance of different stakeholders and attributes. In addition, the events and the public's reaction to them may trigger new legislation which deem certain previously satisfactory alternatives unacceptable and force a re-evaluation of earlier decisions $\{D_1, ..., D_{j-1}\}$.

To summarize, there are a set of decisions which have to be made over time as part of a scenario for a particular problem. There are laws and regulations which guide the acceptability of specific alternatives and there are different stakeholders involved in the process. Because of the uncertainty of information regarding probability and potential impacts of catastrophic events, interested parties with different goals and objectives and with limited computational capacities may have different estimates of the risks associated with specific actions (e.g., the safety of an LNG terminal at a particular location). Furthermore, random events in period t can have a major impact on the decisionmaking process by triggering new legislation which change the set of alternatives, relevant stakeholders and attributes for consideration. Conflicts between relevant stakeholders can lead to lengthy delays with respect to taking final action.

III. THE LNG SITING DECISION IN THE UNITED STATES

The above descriptive model, outlined in Figure 1, will be illustrated by analyzing the decision process associated with siting an LNG terminal in the US. I will first describe the nature of the problem, delineate the relevant stakeholders and attributes perceived to be important and then discuss the role of exogenous factors in the decision process.

Nature of the Problem

Liquefied natural gas (LNG) is a potential source of energy which requires a fairly complicated technological process that has the potential, albeit with very low probability, of creating severe losses. To import LNG the gas has to be converted to liquid form at about 1/600 the volume. It is shipped in specially constructed tankers and received at a terminal where it undergoes regasification and is then distributed. The entire system (i.e., the liquefication facility, the LNG tanker and the receiving terminal and regasification facility) can cost more than $1 billion to construct (Office of Technology Assessment 1977). The siting problem of interest consists of two principal decisions: whether proposed facilities for regasifying and shipping LNG is in the national interest (D_1), and if so, whether the proposed site is considered safe enough (D_2).

Interested Parties and Relevant Attributes

According to the descriptive model, there will be a set of interested parties associated with each of these decisions. Some of these stakeholders will be specified by law (e.g., government agencies), others will play a role because of specific concerns with the hazard (e.g., public interest groups) and others because of their economic interest in the project (e.g., gas companies). In the case of D_1, there are two principal stakeholders, each of whom considers different attributes as important to their decision process. The *gas company* or the consortium proposing the project conducts the site selection process by considering such attributes as accessibility by large tankers, availability of the market, i.e., proximity of an existing pipeline network, cost of land acquisition, availability of skilled labor supply, and in some cases, land use characteristics and environmental factors (OTA 1977). The other interested party is the *Department of Energy*, which has to determine whether an individual LNG import project is in the public interest and should be allowed.[1] If the project involves foreign imports, then the responsibility resides with the Economic Regulatory Agency (ERA); if the terminal involves interstate commerce then the Federal Energy Regulatory Commission (FERC) is involved.

According to the National Gas Act of 1973 which governs all imported natural gas cases, the Department of Energy (DOE) cannot approve any project which is not consistent with the public interest. Among the principal attributes that DOE is supposed to consider in making this judgment are factors such as the security of supply, the proposed LNG price in relation to the price of alternative supplies, impact of the price schedule on conservation of energy, and whether the proposed site meets safety and environmental requirements as stated in any national guidelines (DOE/ERA 1977).

The current decision process is an attempt to reduce conflicts between the parties: the gas company or consortium proposes a site which they consider to be safe and in the national interest. Relevant agencies of the Department of Energy then evaluate this site and issue an opinion as to whether or not it satisfies their criteria for the national interest.[2] If it does, then the question of safety of the site (D_2) is analyzed. Otherwise, revisions in the proposed site have to be made by the gas company or consortium.

Even if a site is considered to be in the national interest it does not mean that it will necessarily satisfy the safety guidelines of other federal agencies as well as local interests. Other relevant stakeholders or parties now enter the scene, each of whom has a set of attributes for consideration. *The Office of Pipe-*

line Safety (OPSO) is concerned that the facilities comply with the safety code of the National Fire Protection Association as well as the uniform building code with respect to maximum earthquake specifications. Another interested party is the *Coast Guard* who has jurisdiction over the entire portion of the LNG system that connects the tanker to the distribution system. Recently the Coast Guard has issued a set of regulations which apply to terminal siting, so that this agency is now an interested party.

At the local level, groups such as the *City Council* play a key role in determining whether or not a particular site satisfies their safety standards. In California there are two other agencies: the California Coastal Commission (CCC) and the California Public Utilities Commission (CPUC), both of whom have legislative responsibilities for determining whether a particular site is acceptable on the basis of local standards. In addition, there are frequently *public interest groups* who are concerned with the environmental safety impact of specific proposed sites.

Prior to 1977 there first had to be approval at the city or community level (e.g., by the Los Angeles City Council), and then at the state level through the CPUC. Both groups had to hold hearings to determine whether all interests were being served. Since 1977 the process at the state level has been centralized through the passage of the LNG Terminal Siting Act of 1977 whereby the California Public Utilities Commission was given sole authority to issue a siting permit.

The concept of acceptable risk has played a key role in the analysis of the relative safety of particular projects, but as we shall see below it has also created obstacles for final approval. The following procedure is employed: a detailed risk analysis of a proposed site specifies the chances of death per year (p) from LNG-related accidents to an individual at risk. If p is below some threshold level, p^*, then the project is considered safe; if $p > p^*$ then it is not. The value of p* currently used by the FERC is 10^{-7} (i.e., 1 in 10 million) (OTA 1977).[3]

Role of Exogenous Events

What is most interesting about the historical record regarding these siting decisions, is the tremendous uncertainties associated with the final choice. Each interested party focuses on limited information and uses the data in different ways. Due to the difficulty of resolving stakeholder conflicts, a particular event can cause a reversal or reinvestigation of a particular decision if the case has not been finalized. Consider the four following examples:

1. In 1973 an LNG tank in Staten Island, New York, exploded and the roof collapsed burying 40 workers. There was no LNG in the tank but it had seeped through the insulation and caused a huge fire. A result of this explosion was the increased concern with the dangers of LNG by Staten Island residents. The neighborhood organization called BLAST, which was formed a year before the accident, attracted considerable attention and interest because of the media coverage of the tank explosion. In the context of the presented model (see Figure 1) a new interested party played a key role because of a random event. What may have been a foregone decision regarding the location of an LNG tank in Staten Island became problematical (Davis 1979).

2. The worst LNG accident occurred in 1944 when the storage tank operated by the East Ohio Gas Company in Cleveland ruptured, spilling LNG on adjacent streets and sewers. The liquid evaporated, the gas ignited and exploded, resulting in 128 deaths, 300 injuries and approximately $7 million in property damage. An investigation of this accident indicated that the tank failed because it was constructed of 3.5% nickel

steel, which becomes brittle when it comes in contact with the extreme cold of LNG. All plants are now built with 9% nickel steel, aluminum or concrete and the storage tanks are surrounded by dikes capable of containing the contents of the tank if a rupture occurs. This example illustrates the impact of a particular incident on new regulations, which otherwise may not have been passed.

3. In December of 1976, the Los Angeles City Council voted to allow work to begin on an LNG terminal in San Pedro Bay. The following day an explosion ripped the oil tanker Sansinena in Los Angeles harbor leaving 9 dead and 50 injured. A week later the City Council commissioned a study as to the relative safety of the proposed site. They later approved the terminal. This explosion, although it had nothing to do with liquefied natural gas, alerted many Californians to the potential dangers of LNG.

4. Until the publication of the worst case scenario in 1976 on the possible consequences of a $300 million terminal in Oxnard in California, there was almost unanimous agreement by all stakeholders that Oxnard would be an ideal site for an LNG terminal. At the time even the Sierra Club was in favor of this location. (They changed their feelings about Oxnard in 1977.) A worst case scenario indicated that a spill of 125,000 cubic meters of LNG from all five tanks on a tanker would cause a vapor cloud which would affect 50,000 people. Residents could look on a map to determine whether the cloud covered one's own house (Ahern 1980a). No estimate of a probability was attached to this scenario. The graphic depiction of these consequences generated a public reaction by a small group organized by concerned citizens of Ventura County. The California legislature was influenced by this public reaction. One

legislative staff member stressed that it was not possible to allow a site that would lead to a large number of deaths in a catastrophe.[4] Hence, new siting regulations were passed stating that no more than an average of 10 people per square mile could be within one mile of the terminal and no more than 60 within four miles of the terminal. The President's National Energy Plan incorporated similar population guidelines which effectively ruled out any high density areas as candidates for an LNG terminal.

In the case of California, Point Conception replaced Oxnard as the leading candidate for locating an LNG terminal. The introduction of Point Conception into the picture changed the responsibility for approving the site at the federal level. The ERA handles all cases where there is no interstate commerce while the FERC handles cases where there may be shipments of gas from other states. Oxnard involved shipments of gas from Indonesia only, so it came under the jurisdiction of the ERA. In the case of Point Conception, gas would be shipped from Alaska as well as from Indonesia, so the FERC now maintains primary responsibility (DOE/ERA 1977, p.38). The FERC conditionally approved Point Conception subject to state and local acceptance.

This example illustrates how the context in which information is presented (i.e., a worst case scenario) may provoke strong reactions by interested parties and eventually lead to legislative changes.

The picture painted in the four scenarios above highlights the critical role that institutional arrangements (e.g., the relationship between different interested parties) and legal considerations (e.g., specific regulations) play with respect to public policy decisions. What is also significant, is the importance of specific events in triggering new coalitions and frequently new legislation.

Where there are conflicts of interest between different parties, the balance of power normally lies with the stakeholder who is in the position to make the final decision. In the case of California, the key question was whether the California Energy Commission (CEC) or the California Public Utilities Commission (CPUC) would have final siting authority regarding the safety issue (i.e., D_2). Once CPUC was chosen over the more conservation-minded CEC as the agency with sole state permit authority, then the final decision regarding a site was probably different than it would have been had CEC played this role. Here again, the dynamics of the process had a critical bearing on the final decision.

IV. SUGGESTIONS FOR IMPROVING THE DECISION PROCESS: PRESCRIPTIVE ANALYSIS

This section, explores the role of prescriptive analysis given the descriptive model of choice specified above and the empirical data on LNG siting decision in the United States. I will focus on three techniques: decision analysis, assumptional analysis, interactive computer models, and policy analysis.

Role of Decision Analysis

An appropriate starting point is to determine how decision analysis may aid in this process. Keeney (1980) has shown how this approach can apply to structuring the siting decision but has focused primarily on a single decisionmaker rather than more than one interested party with conflicting objectives and different information bases. Many of the general concepts proposed by Keeney are relevant for the problem treated here. It is particularly important to specify the set of decisions $\{D_1,..., D_n\}$ that have to be made, how they relate to each other, the role each stakeholder is likely to play with respect to each of the n decision points, and the relevant attributes that each of them are likely to utilize. It would be useful for each stakeholder to rank the relative importance of certain attributes as part of their final decision process.[5]

This is a time consuming process, but an important first step toward understanding what the critical differences are likely to be between interested parties in their evaluation of specific decisions. At the end of this process there is likely to be a recognition that to go any further with formal analysis, such as estimating utilities and probabilities of events occurring, would be tedious and not likely to yield benefits concommitant with the costs of undertaking this task. Furthermore, the different interested parties may feel that such a process would not be descriptive of their own behavior.

An alternative approach does present itself. Rather than trying to analyze each of the n subdecisions independently, it may be possible to focus on the final objective and examine the factors which influence the choice process. For example, in Section III the final objective was determining "an appropriate site, if any, in California for locating an LNG terminal." It should then be possible to construct a strategy/stakeholder matrix, such as the one represented in Figure 2 which in this case lists three possible sites and four types of stakeholders.

Stakeholder / Strategy	Department of Energy	State Agencies	Citizen Group	Local Agencies
Locate Site at Oxnard				
Locate Site at Point Conception				
Locate Site at Port of Los Angeles				

Figure 2. Stakeholder-Strategy Matrix for LNG Siting Decisions.

Coupled with this matrix one can also construct for each interested party a strategy/attribute matrix, which lists all possible considerations in judging the relative attractiveness of different sites. An example of this matrix is presented in Figure 3. The challenge, of course, is to fill in the cells of these two

Attribute / Strategy	Economic Factors	Environmental Factors	Safety Factors	Energy Policy
Locate Site at Oxnard				
Locate Site at Point Conception				
Locate Site at Port of Los Angeles				

Figure 3. Attribute-Strategy Matrix for LNG Siting Decisions.

matrices which represent the perception of different sites by respective stakeholders (Figure 2) and how each site scores on each of the different attributes (Figure 3). The final matrix to complete the circle, is a stakeholder/attribute matrix such as the one shown in Figure 4.

Attribute / Stakeholder	Economic Factors	Environmental Factors	Safety Factors	Energy Policy
Department of Energy (DOE)				
State Agencies				
Citizen Group				
Local Agencies				

Figure 4. Stakeholder-Attribute Matrix for LNG Siting Decisions.

At this point it is difficult to know how to proceed using formal techniques such as decision analysis. Different stakeholders are likely to rank sites differently (Figure 2), will assign different costs and benefits to the attributes at each site (Figure 3) and will weigh the relative importance of each attribute differently (Figure 4). On the other hand, these matrices force the parties to recognize the tradeoffs in making a decision and hence reduce the relative importance of random events. These discrepancies may produce stakeholder conflicts which should be treated explicitly.

Use of Assumptional Analysis

One way to help understand and possibly reconcile differences between parties is to perform some type of assumptional analysis, such as the one developed by Mitroff, Emshoff, and Kilmann (1979). The authors have proposed a dialectical approach to strategic planning by forcing individuals to state the most important assumptions guiding their analysis and then to defend their position. Majone (1979) has suggested that the knowledge base on which to make decisions for these types of problems is so inadequate that such a process will enable one to explore avenues of disagreement and improve their understanding of the problem. In the above example, an attempt would be made to define the important attributes influencing each stakeholder's attitudes toward different sites, the weight given to each attribute and the impact that each of the different sites will have on each attribute.

If there are conflicts among stakeholders through this type of analysis, it may be necessary to evaluate the impact of choosing one site in period t should certain events occur in period t+1 and future periods. Mitroff, et al., discuss this process by asking what the impact will be if one chooses site 1, 2 or 3 based on certain assumptions which turn out to be false. They classify three types of errors of a policy assumption: (1) the real cost; (2) the visible cost; and (3) the reversibility cost. In terms of our example, there will be certain costs associated with any LNG siting decision should an event occur in future periods (e.g., an explosion) which changes the estimates of the costs and benefits of different states. By having conflicting opinions represented and examining the implications of a range of alternatives under different assumptions the rationality and legitimacy of decisions should be improved.

Role of Interactive Computer Models

If it is impossible to bring the different interested parties together, then other techniques may have to be used which involve indirect confrontation. One of the most promising approaches in theory, but one that has not been successfully applied in policy situations, is the development of interactive computer models for scenario generation. This type of decision support system would enable each interested party to construct his/her own scenario as to potential consequences of adopting one strategy over another. Having already constructed different matrices such as the ones shown in Figures 2 through 4, each stakeholder would be in a position to articulate the potential consequences of say, locating an LNG terminal at Oxnard, Port of Los Angeles, or Point Conception. At this point it would be possible to develop not only "worst case scenarios," but also less extreme situations, including the possibility that no accident occurs.[6]

There undoubtedly will be differences between the way interested parties view the situation, but the advantage of the interactive computer models is that these differences can then be openly discussed. In developing these scenarios, one can separate out the uncertainties, such as the probability of a particular situation occurring, from the more concrete data such as the losses which would take place conditional upon a particular event. One can then analyze separately very uncertain data (such as probability information) without linking them closely to a stream of events. Fairley's (1977) excellent discussion on difficulties associated with estimating low probabilities and their resulting consequences could then serve as a basis for a detailed exploration of this issue through sensitivity analyses. For example, suppose one estimated the annual probability of a severe accident to be between P_1 and P_2 with losses ranging from L_1 to L_2. One could then develop scenarios which examine the relative merits of different alternatives as one changed these estimates. If specific sites were preferred over a wide range of values for probabilities and losses then this would simplify the choice process. If the rankings changed as P_i and L_j were varied, then this would suggest that these estimates be refined.

The resolution of conflicts between interested parties may be extremely difficult even if one uses an assumptional analysis approach or constructs scenarios using an interactive modeling system. In fact, the descriptive model described in Section II suggests that interested parties may not want to get together to solve a particular problem unless they are forced to by existing legislation. Reconciliation of stakeholder conflicts is a time consuming and threatening process since it involves detailed analysis on the part of each of the groups and acceptance of responsibility for one's actions. From a political standpoint, this may not always be the wisest thing to do. Hence, the above prescriptive suggestions can only be viewed as a starting point for developing a dialogue. The final solution is likely to hinge on explicit legislation as to who "should" bear the costs of adopting certain measures. In the next subsection we briefly consider a set of policy options which may help reconcile these conflicts.

Use of Policy Analysis

There are three general classes of policy options which should be considered: (1) use of market mechanisms; (2) development of incentive systems; and (3) regulatory mechanisms.[7] In determining which one or combination of these three measures could be utilized, it is necessary to determine who is responsible for damages should an accident occur.

I will illustrate how these options can be utilized in facilitating the LNG siting decision; similar analysis can be undertaken for other policy decisions which affect a number of interested parties. In the case of LNG there are many different facilities which can cause an accident (e.g., ships, tanks, etc.) so it may be difficult to attribute fault to any one party. Furthermore, the ships, the LNG itself, and the terminals are owned by different subsidiaries or companies. The local, national and international jurisdictions make legal problems even more difficult (Davis 1979).

If LNG accidents are viewed primarily as a private responsibility by the gas consortium or supplier, then some form of insurance is the logical ***market mechanism*** to utilize. A General Accounting Office (GAO) report of July 1978 concluded that injured parties could not be fully compensated for a serious accident under present liability arrangements. For this reason, market mechanisms with insurance firms providing adequate protection are not likely to cover all damages and there may be a reluctance on the part of gas companies or consortiums to invest in LNG projects unless the government provides some insurance against catastrophic losses.

With respect to *incentive systems*, it may be possible to provide special compensation to homeowners and individuals who reside in areas where LNG facilities are constructed. If land values drop then some type of lump sum payment might be desirable. Lower energy rates can also compensate residents for the increased risk of having an LNG terminal in their "back yard." Terminal owners who saw a need for a liability fund could finance it by a tax on LNG sales. These types of subsidies and taxes would shift some of the economic burden from those bearing the physical risk to residents and businesses who are benefiting from the facilities. If the government feels that the LNG terminals yield substantial public benefits, then they may want to cover catastrophic losses through special funds such as those earmarked by the Price Anderson Act for nuclear accidents. Note that each of the above incentive systems implies a set of value judgments as to whom should benefit and whom should bear the costs of constructing LNG facilities.

Finally, it may be deemed desirable to have special regulations to protect the public from certain risks. Legislation, with respect to location of LNG terminals, have recently reflected this concern by requiring certain conditions on population density around an LNG terminal as well as specifying certain construction standards on tanks and dikes around the terminal. As pointed out above, many of these regulations were passed because of some specific accident or crisis that pointed out the need for these provisions.

By adopting any of these policy recommendations one is implicitly (if not explicitly) answering questions as to the weight that should be assigned to each of the relevant stakeholders in any evaluation process. Furthermore, the adoption of any policy provides guidelines as to how society views the tradeoff between efficiency and distributional considerations.

V. CONCLUSIONS

At the heart of the problem for societal decisionmaking on low probability events is the increasing recognition that there is great uncertainty on the data necessary to undertake any analysis: the probability of a loss occurring, consequences of disasters of different magnitudes, and how well certain protective measures will mitigate these losses. It is thus not surprising that there are large differences in stakeholder estimates on these figures.

As I have tried to emphasize in this paper, this situation causes a set of dynamics that are only partially predictable because of the occurrence of random events. On the other hand, there are ways of directly addressing the problem by having policy makers indicate what aspects should be viewed as private and public responsibilities, who should benefit and lose by any set of decisions, and what actions in the form of market mechanisms, incentives or regulations should be taken to produce a particular effect. The results may differ from what one expects, however, because one is dealing with a situation fraught with uncertainty on most dimensions. The challenge in dealing with societal decision making for low probability events is to be resilient in the face of uncertainty. Any other strategy is likely to prove catastrophic.

NOTES

1. Prior to 1977 this responsibility resided with the Federal Power Commission (FPC).
2. An example of one of these reports, with its full documentation, is DOE/ERA (1977).
3. Keeney, et al. (1979) utilize this figure in support of the acceptability of a proposed LaSalle terminal. They claim in this case that it is less than 2% of 10^{-7}, so that the societal risk due to operation of the terminal is much less the OTA's criterion for social acceptance which appears to have originally been proposed by Starr (1969).
4. This comment was made to John Lathrop in an interview in Sacramento, California, in July 1980, regarding the siting process of an LNG terminal.
5. See Keeney and Raiffa (1976) for a more detailed discussion as to techniques for ranking these attributes.
6. This approach differs from decision analysis by focusing on individual scenarios rather than a probability distribution over outcomes. For a more detailed discussion of decision support systems see Keen and Scott Morton (1978).
7. A more detailed discussion of the tradeoffs between the advantages and disadvantages of these methods appears in Stokey and Zeckhauser (1978).

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