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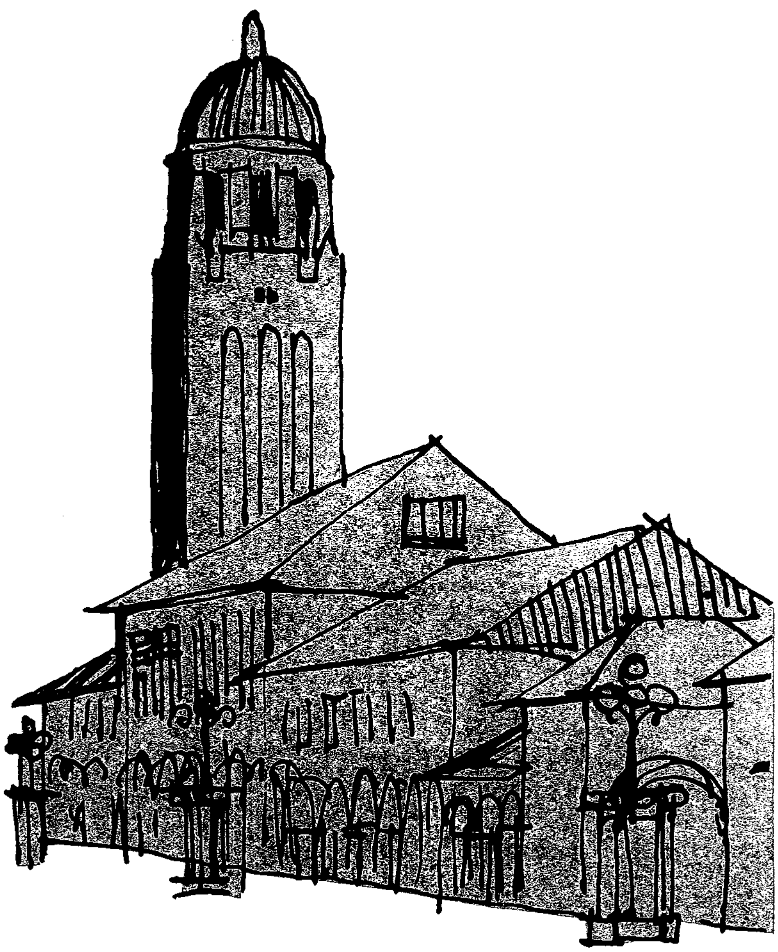
The John A. Blume Earthquake Engineering Center
Department of Civil Engineering
Stanford University

RISK AND PUBLIC POLICY



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July 1979

The John A. Blume Earthquake Engineering Center was established to promote research and education in earthquake engineering. Through its activities our understanding of earthquakes and their effects on mankind's facilities and structures is improving. The Center conducts research, provides instruction, publishes reports and articles, conducts seminars and conferences, and provides financial support for students. The Center is named for Dr. John A. Blume, a well-known consulting engineer and Stanford alumnus.

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Seismic risks are considered for which public authorities have all or part of the decisionmaking power to define collective interests and mitigate or control the level of exposure. The objective is to deal consistently with risks in a given philosophical framework in order to compare them and to allocate public funds for risk mitigation in an equitable and efficient way. The problem of "risk" is formulated and defined. Risk is measured with respect to the problem of consequential rare events, the density of risk, the choice of random variables in analysis and evaluation, and the perception and acceptance of seismic risk. Economic issues associated with risk in public policy such as the social rate of discount, economic life under uncertainty, and capital immobilization for the mitigation of risks are discussed. An investigation of priorities and life saving methods are reviewed. The problem of warnings and alerts is studied from the standpoint of warnings as a crisis situation, warnings and socio-economic structure, and the liability question.

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Marie-Elisabeth Paté

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TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

RISK AND PUBLIC POLICY

1 STATEMENT OF THE PROBLEM

1.1 RESTRICTION OF THE MEANING OF THE WORD "RISK"

The word "risk" in the public sector has been used in various senses. Basically, it describes the consequences of exposure to an uncertain event ("hazard") or to a set of events. The possible outcomes may range from the economic consequences of an investment to the result of enforcement of a law or the effects of natural hazards.

The word "risk" has also been used to mean a probabilistic description of the source of the hazard itself rather than its consequences. In the following pages, it will not be used in that sense but with the initial meaning of:

> "characterization in probabilistic terms of the exposure to a specific hazard, of human beings and property."

In particular, as far as seismic risk is concerned, it means here "probabilistic description of the losses--lives and property damage--from the seismic activity of an area" rather than a characterization of the seismicity itself.

The risks considered in this report are those for which the public authorities have all or part of the decision power to define collective interests and mitigate or control the level of exposure. Since seismic risks involve human lives as well as property, the public is highly sensitive to government decisions. Similar risks are inherent to the health sector and the transportation sector for traffic safety problems. Risks of this type are also found in the sector of housing and urban development as far as reaction to natural catastrophes is concerned.

The objective is to deal consistently with risks in a given philosophical framework in order to compare them and allocate public funds for risk mitigation in an equitable and efficient way.

Eventually, a decision has to be made as to when the global budget requires a shift from investing in protection to investing for other purposes such as increasing the productive capacity.

1.2 COMPARISON OF RISKS IN THE PUBLIC SECTOR. PRIORITIES

The seismic risk, which results from the conjunction of the seismic activity of an area with its human occupancy, can be alleviated by various public and private measures. However, this is not an isolated problem. Choices have to be made at several levels:

- which aspects of the seismic risk have to be mitigated in priority: the risk from the existence of dams in seismic areas, from the resistance of old buildings, from the existence of secondary geotechnical hazards such as liquefaction, the risk incurred by children in schools.

- which priority in the public budget should be given to seismic protection as opposed to the health sector or other investments toward the goal of saving lives.

- when should the protection against all hazards threatening lives give way to different goals such as education, defense or increase of the industrial capacity.

The question of risk mitigation is restricted here to the evaluation of projects that cannot be adopted from a "financial return" point of view but can be justified by a decrease, at a net cost, in the expected number of casualties. The problem is then how to allocate the funds for risk mitigation in an "optimal way," itself to be defined, and to decide on an acceptable limit point in that allocation when the goal of saving lives no longer appears to have priority.

The criterion of optimality used in the present study is a very simple one: save the maximal number of lives (in expected value) for a given investment. This has a certain number of implications developed below; it means in particular that, for the purpose of risk mitigation, saving human lives is the first public goal, and that all human lives have the same priority from the public planner point of view. But this does not mean that property damage is neglected, since the avoided damage is subtracted from the costs.

Among the risks involving government actions, the ones that are considered here are also the ones that are delegable with or without compensation as defined by Howard (1976). This means that the probability of death per year is smaller than 10^{-3}. The individual makes safety decisions for himself that are consistent with a certain level of "willingness to pay" in order to decrease the risks with which he lives every day and he expects the state to follow the same rule. The priorities would be changed for a high probability of death, in which case the mitigation of risks would no longer be comparable on the criterion of maximization mentioned above.

Another restriction of risk comparison and policy ranking is the degree of "voluntariness" with which the individuals expose themselves to the hazards involved. From voluntary to involuntary, the risks range on a continuous scale: risks from automobile transportation are certainly more voluntary than those inherent to air transportation, since the passenger has the choice to fly but no control over the aircraft. The "voluntariness" could therefore be ranked on a single scale, in order to perform a general risk comparison. The various levels could be defined by the individual's willingness to be exposed to a given hazard, his control over the occurrence of the hazardous event, and his control over the effects of the event. In this chapter the risks considered are the "quasi involuntary ones," for which the individual has a minimal level of choice and the government some range of action.

From a perception and liability point of view, the risks involving public decisions can again be divided in two categories: some are created or at least authorized by the government for a benefit that is estimated to be greater to society than the risk itself. Such is the case of nuclear power plants. Other risks are generated by natural causes; the role of the state, in this case, is to protect individuals to the extent that they themselves do not have sufficient information. For example, they cannot estimate themselves the performance of public buildings for a specific earthquake. These two types of risks should be mitigated on the same basis if one follows the criterion of maximization of the number of lives saved (having deducted the social benefits of the first type of activity). But they are certainly not perceived in the same way; the state is not only liable but considered deeply responsible for the risks that it creates for future benefits. The political decision process is essentially based on that perception of liability (Slovic 1977), as well as on the perception of the uncertainty.

These two types of risk are similarly involuntary and should be considered, from the planner's point of view, on the same scale of ranking in order to establish an optimal order of priorities.

1.3 VARIOUS APPROACHES TO RISK

Following from the work of Slovic (1977) and the work of Starr (1966), risk can be considered from four points of view:

- the real risk, which is by definition unknown; it is the actual loss observed after the event has occurred
- the statistical risk, determined by current available data on the past losses, as typically measured for insurance purposes
- the predicted risk, as determined analytically from probabilistic models involving the evolution in time of the various components
- the perceived risk, as seen intuitively by individuals

It is important to consider which aspects of risk prevail and should prevail in the choice of a public policy. The real risk obviously is not available for the design of the policy. Its approach through each of the three other aspects implies different decisions for various reasons.

(1) The statistical risk, measured as the average loss for a given period of time in the past, can be a sound approach to the real risk in the case of a stable system. If both the occurrence of the hazardous event and the target of its consequences remain constant, the statistical observation is the best information to the potential current loss. This is the case for lightning strikes, where both the occurrence and the targets remain relatively stable, but is not the case for some illnesses, which may propagate in waves of epidemics through a constantly growing population.

It is certainly not the case for the seismic risk in California. Whereas the occurrence of earthquakes is supposed to be stable in time, the target population and property in the seismic areas is constantly transforming, both in quantity and quality. Furthermore, the duration of historical observation of the urban system is too short to allow significant comparisons. Past historical information of the loss would therefore lead to an underestimation of the risk and would not be a sufficient basis for the design of a public policy.

(2) The predicted risk, as determined through systems analysis, can take multiple forms. There are three major components in such an analysis:

- the occurrence of the events over time
- the description of the evolution in size and quality of the target

- the characterization of the performance of the target in the occurrence of the source event .

In the seismic case, this implies that the seismicity is analyzed on the basis of historical data, and possibly updated through Bayesian techniques, that the growth of the urban areas concerned is measured and forecasted, that the performance of the buildings is assessed through the results of past observation and through simulation and mathematical techniques for new types of structures.

The conjunction of these different analytic tools allow the characterization of a random variable "loss in a given region and in a given period of time," which takes into account the different evolutions and can be constantly updated. It is thus the one that allows the evaluation of future costs and benefits of different public policy options, taking into account the uncertainty of the various elements in the most complete way, through past observation and experts' opinions.

(3) The perceived risk is, most of the time, the one that determines how codes and laws are generated, funds allocated and emergency measures conceived. But such a perception is subject to a double distortion in time and space:

- the imperfection of human memories is such that the event is soon forgotten. Measures are taken shortly after earthquakes, and soon economic constraints lower their priority among public investments.

- the misperception of a geographically remote event may distort the public's evaluation of both the probability of the event and its consequences. The occurrence of an earthquake in a Latin American country may appear in California as an image of what could happen in the U.S., even though the building methods are very different and the levels of risk incomparable.

The fluctuations of a public policy based on the perceived risk are therefore greatly dependent on the ratio between the duration of the human memory and the return period of the critical phenomena. The common result is a period of overperception followed by a period of underperception. This cycle is likely to make the resulting policy quite inefficient at the time of the next earthquake.

Public policy will always be largely determined by the public's perception of a phenomenon. But if, as Slovic concludes, the human mind has difficulty dealing with uncertainty, a more efficient solution than following the fluctuations of human memory is to correct it through education programs. A better public information would not only correct the effects of "saturation" and short memory but would also make more efficient all other public measures of seismic risk mitigation.

1.4 SEISMIC RISK IN THE PUBLIC SECTOR

The first part of this report is concerned with two topics: the problem of measuring risk, and the definition of the efficiency of public investments.

This efficiency, based on the maximization of a utility, can be related either to the analytical risk--in this case the utility of the public planner is maximized--or on the perceived risk, with its fluctuations--in this case the changing utility of the public is maximized. The public planner's point of view is adopted here, assuming that he has all the information available and that his utility is linear: he wants to maximize the total number of lives saved.

The seismic risk in this study is considered a quasi-involuntary one, although individuals choose to live in seismic areas. The seismic risks and the investments made to mitigate it will thus be compared to those made in sectors considered similar: the health sector--where individuals have some very limited control on their resistance-- and the transportation sector--where individuals often have only the choice of the means of transportation.

On the national level, the problem of sharing the loss leads to the question of liability. The liability of the state is engaged in its assistance to the population after an earthquake, which is one way of spreading the financial loss. Another way of spreading the loss is to make insurance compulsory, which represents a shift towards giving greater responsibility to the inhabitants of earthquake regions.

This raises the question of origin and uses of the funds involved in the decisions made by the public planner. The question is addressed further as a complement of the cost-benefit analysis. Indeed, all these costs and benefits are computed globally as pertaining to the whole society. But justice and equity considerations require an assessment of the source of payments used mainly for benefits to the inhabitants of seismic regions.

1.5 RISK ANALYSIS

The question of risk analysis is part of the broader problem of decision analysis. In this case, the actual decision process is a complex one, with several attributes, and involves bargaining processes between various interest groups. These groups are the citizens themselves, the elected citizens in charge of the decision at several levels (local, regional and national), the business world, which makes decisions regarding private investments, the press, which has a large influence on the perception of events, the engineers responsible for the resistance of the structures that they design, and the seismologists and geologists who gather information on seismicity.

The goal of risk analysis is to clarify the initial state of risk and the consequences of the different policy options. It is not in the scope of this study to examine the interactions between the various groups mentioned above, nor to determine the risk attitude and time preference that result from that interaction. Any quantification of the risk function will reflect an implicit utility and risk attitude. The choice of a neutral risk attitude, therefore of a linear utility, corresponds to the criterion of optimization--"maximization of the total number of lives saved"--and is justified further by equity considerations.

Similarly, the time preference included in the choice of a social rate of discount reflects both the state of the capital market and the present choices of intergeneration allocation. This social rate of discount applies to all the components of the results, including the lives. The marginal cost per life saved should be identical among the different sectors compared at a given time. This "acceptable marginal investment to save an anonymous life" determines the "acceptable risk" as revealed by private choices. The willingness of individuals to pay to save an extra life reflects, given the probability of death, the trade-offs between expected costs and expected benefits that seem acceptable in a given society at a given time.

Contrary to the decision analysis procedure, where the decision makers would be identified and their preferences assessed, in this risk analysis method hypotheses are made and justified on a philosophical basis about what the risk attitude and the risk preference should be in the scope of a given optimization criterion, with the understanding that the actual process might be different. It is a first important step toward eliminating the problems of perception and giving a measure of costs and benefits on a simple objective function. It gives, among other things, a measure of what would be the expected gain from correcting the distortions of the public perception through better education and information. Analysis and value judgment will thus be kept separate; the result of the analysis will be the basis of the decision and the value judgment will be applied to it at that time.

2 DEFINITION AND MEASURE OF RISK

2.1 THE PROBLEM OF RARE EVENTS WITH LARGE CONSEQUENCES

Rare events with large consequences have always been perceived as a special class of problems as far as public planning is concerned.

The uncertainties are multiple:

- in time, the average return period is known only through a short historical record and, in the case of large earthquakes in California, the uncertainties in the return period are of the order of the human lifespan with a variance roughly half of the mean.

- in the consequences themselves, the variations can be important between day and night. They will vary also with the performance of dams and the incidence of fires that may start after the rupture of life lines.

The public attitude before such events is contradictory. It reflects the general attitude of disbelief and "saturation" towards an event that seems potentially too large to be faced and too remote in the past to be remembered. On the contrary, the state tendency is to be overconservative for liability reasons, on one hand, and in order to decrease its potential intervention after an earthquake, on the other hand.

The result of such uncertainty is that, rather than taking into account the frequency of occurrence of the events, the temptation is great to figure out the maximal possible loss and base a public policy on such figures. This seems to be the case for the Uniform Building Code. The original maps that are used to develop its requirements show the maximal possible intensities in the present state of knowledge. They do not take into account the frequencies of occurrence.

The inconvenience of the method are obvious: it puts on the same level regions of very different seismicity and imposes the same constraints on their economies. Therefore in some of these regions the marginal return of such safety investments is expected to be very low and inconsistent with the general optimization criterion if it requires that the maximal number of lives be saved.

2.2 THE EXPECTED VALUE OF THE LOSS. DENSITY OF RISK

The choice of "maximal thinkable loss" as a basis for public policy relates to a decision rule to minimize that maximal loss, a most conservative one.

Such a loss can be in the domain of the extremely uncertain and would certainly put on the seismic risk a weight of too large an importance with respect to the other sectors involved in saving lives.

The expected value of the loss in a given period of time, as a measure of the risk and as a basis for public policy, is justified for the following reasons:

- it reflects each outcome and its probability
- it gives a priori the same priority to each potential victim in state planning, which seems legitimate in an egalitarian society and reflects the principles of justice and quity.

Such a linear utility function does not imply that the public reaction a posteriori is linear. It is true that fifty times the life of one bicyclist killed in a street accident makes less of an impression than fifty lives in a bus accident, and perhaps more than fifty additional lives in an earthquake that has already killed ten thousand persons.

But it means that the public planner should be willing to maximize the total number of lives that he expects to save rather than minimizing the public reaction, which is generally reflected in the press as a complex combination of pain, curiosity and astonishment.

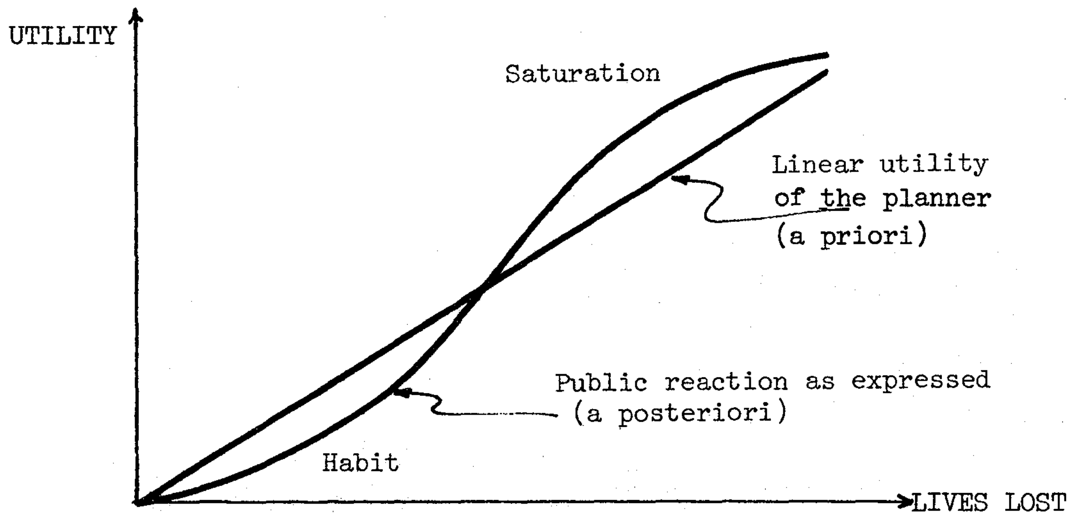

Fig. 1. PUBLIC REACTION vs A PLANNING CRITERION

The consequences of using such a measure of risk for the allocation of public funds in life saving are multiple:

- the quantity optimized is the total number of lives saved on the whole of the public sector
- the marginal investment to save a life is identical for each sector in an optimal situation

It sets each event, such as an earthquake, in a much broader perspective than its strict category, therefore decreasing the variance of the whole of their effects.

Density of risk:

Assuming that the potential loss associated with each event (earthquake for example) varies over time for each individual (according to the type of structure in which he stands), the expected value of the loss is a function of time. Let $\underline{L}(T)$ be the vector of the losses during the time period T, its two components being the loss of lives and the dollar damage (property damage and economic loss). $\underline{L}(T)$ is a random vector. Let R(T) be the measure of the risk during the same period of time, the risk is thus a vector equal to the expected value of $\underline{L}$.

$$R(T) = EV(\underline{L}(T)) \tag{1}$$

Such a measure reflects the state of knowledge of the global exposure of an individual during the time period T.

By differentiation with respect to time, one can introduce the variations of that exposure over time, and the notion of instantaneous risk, corresponding to the density function over time of the expected loss.

The total risk over a time period T can then be computed as an integration over time of the risk density function, thus taking into account the variations of exposure.

Let $\ell(t)$ be the density over time of the expected value of the loss of lives.

Let d(t) be the density over time of the expected value of the dollar loss.

Let r(t) be the vector "density of risk" over time.

$$r(t) = \begin{bmatrix} \ell(t) \\ \\ d(t) \end{bmatrix} \tag{2}$$

The global risk over the time period T is given by the integration:

$$R(T) = \int_0^T r(t)dt \tag{3}$$

or by components:

$$R(T) = \begin{bmatrix} \int_0^T \ell(t)dt \\ \\ \int_0^T d(t)dt \end{bmatrix} \tag{4}$$

The density of risk r(t) corresponds to the variation over time of the expected loss; in the case of earthquake risk it is used to take into account the movements of the populations between different types of structures, thus introducing the contribution of each of them to the global expected loss on the basis of occupancy. In the area of air traffic it would represent, for a given aircraft, the variation of the risk during the different phases of the flight. The instantaneous risk thus allows the analysis of the time dependent components of the system. It may explain the risk aversion created by the existence of peaks in the risk function. It emphasizes the role of the successive causes in the global risk as a function of their duration as sources of hazards.

The measure of the risk is thus the result of a double integration, over the set of possible outcomes with their probability of occurrence (seismic events and buildings performance), and over time (variation of the occupancy of the various structures).

A convenient form of that expression of the risk due to earthquakes is given by a discretization of the time period T into small intervals t_i during which the occupancy of each structure is assumed to be constant.

Let (s,t_i) be the loss of lives in an event s during the time interval t_i.

Let $d(s,t_i)$ be the loss of dollars in an event s during the time interval t_i.

Let $p(s,t_i)$ be the probability of each event s during the time interval t_i.

The total risk over the time period T is given by:

$$R(T) = \begin{bmatrix} \sum_{\{t_i\}} \sum_{\{s\}} \ell(s,t_i)p(s,t_i) \\ \\ \sum_{\{t_i\}} \sum_{\{s\}} d(s,t_i)p(s,t_i) \end{bmatrix} \quad \text{with } \{t_i\} = [0,T] \qquad (5)$$

2.3 CHOICE OF THE RANDOM VARIABLES

The evaluation of the expected value of the loss requires a double choice of random variables: the ones that are considered the basis of the analysis and reflect the level of observation, and the ones that are considered critical in the evaluation of the risk for the purpose of ranking policy alternatives.

The choice of the level of observation, as mentioned above, must be the one of a stable phenomenon. That is why in the case of natural catastrophes, the occurrences of the source event (e.g., earthquakes) and the consequences of the event on a unit of the target (buildings performance) can be chosen as the observed phenomena rather than the loss itself, which varies with the target.

As for the choice of critical variables, the question is to know which variables should be introduced along with their probability distribution function and which ones can be replaced by their expected value without reversing the order of the priorities expressed by the result.

In general, the seismicity itself is a critical variable--choosing the average intensity would lead to a nil expected value of the loss in California--and the performance of the buildings and its uncertainty depends on the specific region studied.

2.4 PERCEPTION AND ACCEPTANCE OF THE SEISMIC RISK

The perceived risk has been historically the basis for the anti-seismic public policy in the U.S. Human reaction, building codes and emergency preparedness, have followed a cycle linked to the relative length of human memory and the return period of large earthquakes. Immediately after an earthquake--e.g., Long Beach in 1933--measures are taken; as the danger fades in memory, the mitigation of the seismic risk is given less attention. Then, when the elapsed time gets closer to the return period, as intuition hardly accepts that the seismic process could be of Poissonian nature, the public opinion calls for new public policy measures.

The improvement of the mass media, making people more constantly aware of the danger of earthquakes, since they are reported from other countries, seems to attenuate the effects of such cycles. But there are constant fluctuations in the voters' pressure for public seismic safety measures. Those fluctuations make all protection systems less efficient since the whole of a community is built over a long period of time.

Public information thus seems a necessity, in order to improve the public perception about both the hazard itself and its consequences.

Assuming good public information, the question remains of an acceptable level of seismic risk. In order to assess an acceptable level of risk, one solution certainly is to observe the currently accepted one and the compensation, if any, that is required for its acceptance.

Following the criterion of maximization of the total number of lives saved, the ranking of the policies will be made on the marginal cost per life saved. The question is to know how this marginal cost compares to the individual's willingness to pay for saving his own life by decreasing the various risks to which he is exposed. Howard (1977) shows that this willingness to pay depends on the probability of death beyond a threshold of chances ($\sim 10^{-3}$) for which the individual requires compensation.* One can assume that for the type of involuntary risks considered here, the probabilities of death are under that threshhold, at least at the time of planning, thus that the individual's willingness to pay in order to save his life by decreasing the risk is independent of that probability. It could be different if the decision were to be made in a crisis situation--for example, at the time of an earthquake prediction. Then emergency measures can be justified at a much higher cost per life saved.

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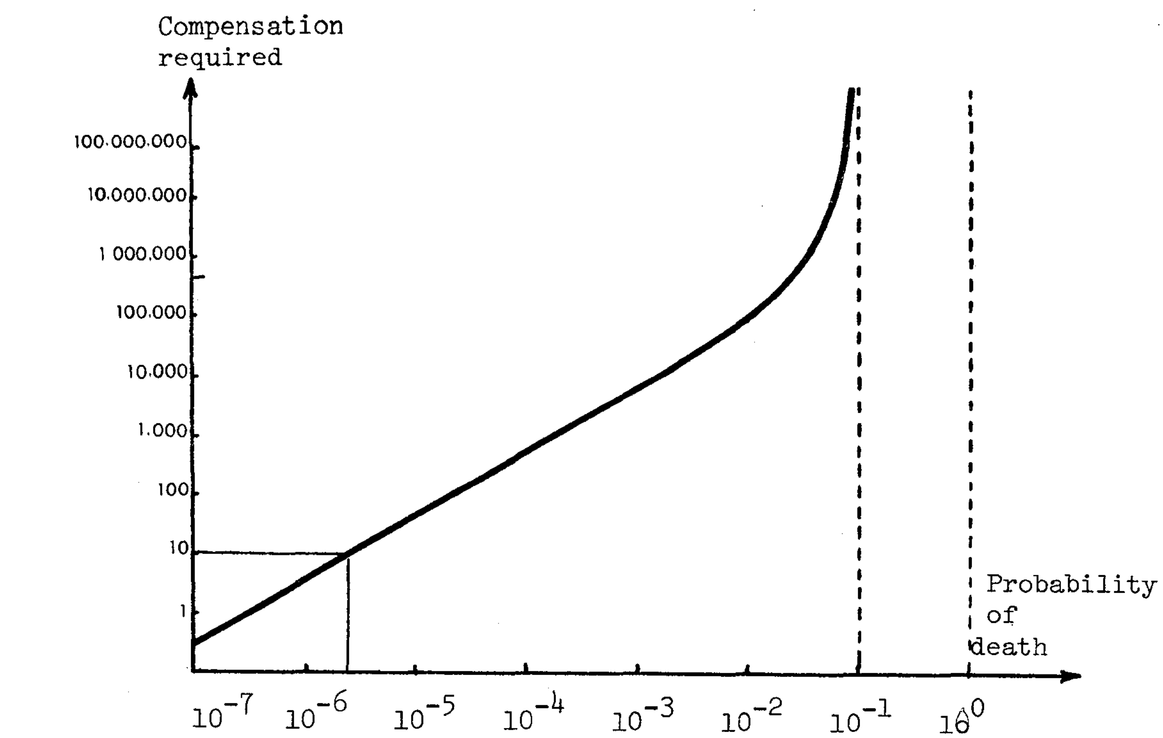
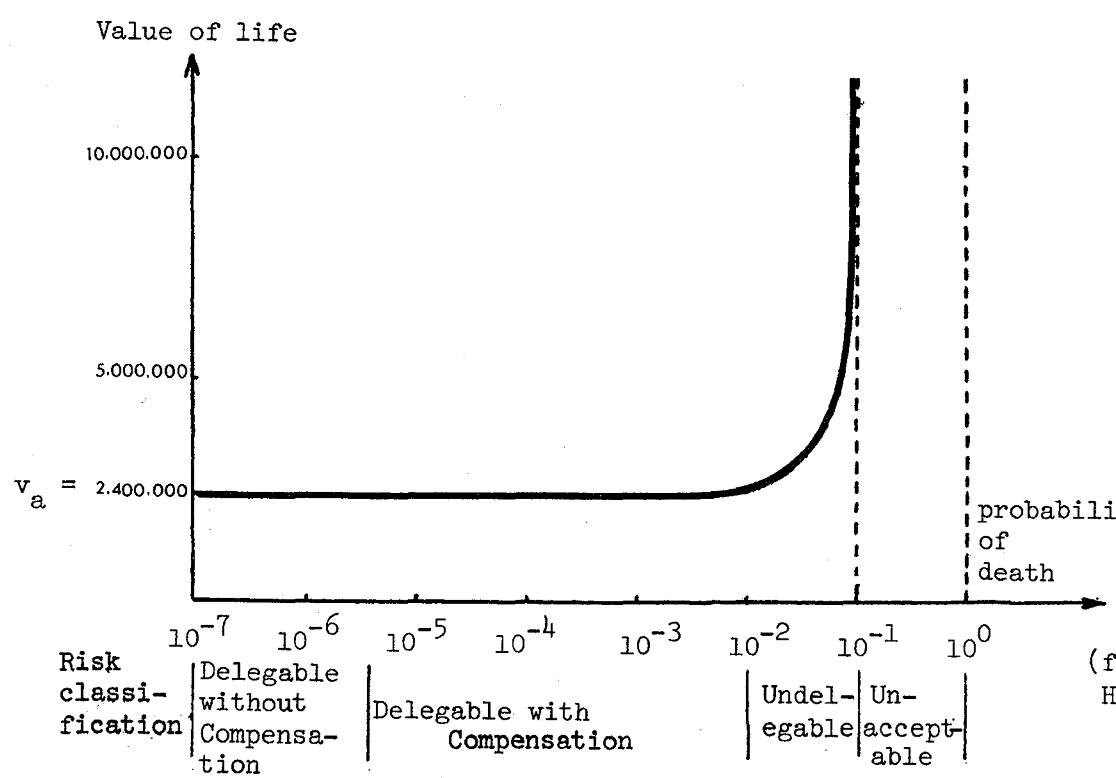
* See Fig. 2 and 3 .



(from Howard 1977)

Fig. 2 . Willingness to Pay for Reduction of Death Probability

Fig. 3 . Derived Value of Life Assuming Linear Utility



(from Howard 1977)

In any case the level of seismic risk that eventually will be reached is a function of the constraints that society will put on its efforts of risk mitigation, and of the limits within which the planner tries to optimize his efforts.

The constraints can be formulated in many different ways, with different implications for the ranking of policies:

- a maximal probability of death
- a maximal investment per expected life saved
- a maximal social investment to protect society against a given source of hazard

(1) The maximal probability of death acceptable without compensation seems to be the present approach to nuclear safety, for instance. The factor of 10^{-7} has been proposed as a ceiling of acceptability for the individual's risk.

(2) The maximal investment per expected life saved is what derives from the minimization of the total number of casualties. It assures that in the range of probabilities that makes the decision "delegable without compensation" an investment is not made in one sector that could save many more lives in another one. It is the approach that seems to prevail in the assessment of safety regulations in the U.S.

(3) A maximal social investment for the public protection from a given hazard is often what derives from the actual political process where funds are allocated by a vote from an assembly.

The policy implications of these three types of constraints follow different objectives: the last one gives preference to the sectors in which the state has a direct liability. In the limits of a specific investment, if the planner wants to maximize the total number of lives saved, he will rank the policy alternatives on their marginal cost to save a life. But the process will be isolated from the results obtained in other sectors.

The link between the first two types of constraints is easy to establish in the range of death probabilities where the risk is delegable without compensation: the planner will accept a project provided that the net cost per life saved is inferior to the maximum that the individual is willing to pay in his private choice for a corresponding reduction of the risk. And given that secondary constraint, he will rank the alternatives on the marginal cost per life saved in order to minimize the total number of deaths.

By considering, for each possible risk mitigation measure, the net marginal cost to save a life, the planner can thus make sure that he acts consistently with a desire to maximize the total number of lives saved, whatever the other constraints imposed from the public or the legislator on the final level of security reached. The three constraints considered here are a maximal probability of death for each individual, a fixed global investment for a given hazard, or a global investment in protection measures for all hazards. From an optimization point of view, it follows that the marginal investment to save a life should be equal in all sectors. It is such an attempt that has led the American government to put a maximal value on the expected cost to save one life ($200,000, for example, in the domain of traffic safety). This study shows the equivalent implications in the domain of seismic risk mitigation.

3 SOME ECONOMIC ISSUES ASSOCIATED WITH RISK IN PUBLIC POLICY

3.1 SOCIAL RATE OF DISCOUNT

The next question, after that of measuring the risk at a given point of time, is that of time preference, which reflects the willingness of the government to trade a certain amount of capital spent at time t_0 for a safety acquired later. First it should be noted that the problem no longer involves the question of risk attitude as far as the uncertainty of the benefits is concerned. The choice of a neutral attitude is assumed. Then the problem is equivalent here to the one of two certain payments at different times.

Two major elements enter in the question of discount: time prefeeence for capital and time preference for lives. The first aspect is the relation between the rate of discount of capital in the private sector, as reflected by the market, and the rate of discount to be adopted for the evaluation of public projects. The second aspect is the rate of preference between two projects saving lives at different times.

a) Social rate of discount of capital

The choice of an appropriate rate of discount of capital is still a very debated question among economists. At the microeconomic level, it determines the acceptance or the rejection of a project: a rate of discount of 5% might make acceptable a project that would be rejected at a rate of 10%. At the macroeconomic level, the question is to make sure that the capital formation in the public sector is as satisfactory to the nation as it would be through the private sector.

If one eliminates the question of economic risk, which is introduced in this study for each period in the utilities to be discounted, there are basically two points of view for the choice of a social rate of discount. The first one is that it should reflect the social opportunity cost of capital, or intertemporal marginal cost of transformation (MRT). This would guarantee that a public undertaking does not displace capital that would have a higher return in the private sector. This raises the question of how to measure such opportunity cost, which depends on how the marginal dollar in public funds will be raised and whether it affects the investment or the consumption. The argument has been made nevertheless that a crude comparison between the results of the private sector and the public sector may not take into account the "spillover" effects on the market of a public investment. The second point of view is to base the social rate of discount on the marginal rate of substitution (MRS), which reflects society's willingness to forego resources today for resources tomorrow, leaving utilities unchanged. The two approaches would give the same result if there were no market imperfections, no taxes and no externalities.

The argument has been made that in any case the current market situation is inappropriate to represent the interests of future generations. The social rate of discount could be then chosen lower than the present opportunity cost of capital, if it is not certain that the market mechanisms will be able to provide later what the current investment proposes to allocate to future generations. The question remains to know what will be the preferences of future generations and what will be the efficiency of the technology at that time to provide the same welfare or utility.

The rate that has been proposed and adopted in the U.S. by the administration is 10% and essentially reflects the desire to adjust the profitability of the public sector to the performance of the private sector. Alternatively, one could consider the opportunity cost of capital in the public sector: the rate of return on risk-free government bonds (7%). In general, the rates that have been proposed, between 7.5 and 10%, reflect weightings of the opportunity cost of capital and the time preference rates. None of these rates is meant to reflect the inflation, and all costs are expressed in t_0 dollars.

b) The discounting of the number of lives

The extension of discounting to other attributes of the problem, in that case the number of lives saved, has to be done by comparison with alternatives. Assuming no discounting of the number of lives saved would mean that society is indifferent between spending N dollars now in order to save one life now, and N dollars now to save one life T years later. At time T, provided that the N dollars have been invested, they will be worth $N(1 + r)^T$ dollars. Such an amount would clearly provide more technology to that generation than N dollars did at time t_0, which violates the principles of equity considered here as basic. It would also lead to a systematic delay of life saving to the expense of the present generation.

Assuming that the goal is to provide the same amount of technology to each generation, society will be indifferent between spending the same present value to save a life at each future time. This implies that in the analysis all factors are equally discounted. It is therefore necessary to discount lives as well as dollars. By doing so, one only takes into account the alternative investments of capital in the intermediate period and assumes that all generations are allocated the same amount of technology for the purpose of life saving.

3.2 ECONOMIC LIFE UNDER UNCERTAINTY

a) Economic life and seismic activity

The uncertainty about the occurrence of a natural catastrophe such as an earthquake is likely to affect the economic life of a region at several stages:

- before an earthquake, without earthquake prediction
- after an earthquake that has not been predicted
- in case of an earthquake prediction, before and after the prediction

Before an earthquake, the level of consumption of goods and services and their market prices reflect the likelihood of the occurrence of a catastrophe. The land and property market, the construction sector are affected by the prior probability of occurrence of the various magnitudes of earthquakes.

After an earthquake, the choice of that level of consumption varies according to the sector, then comes back to an equilibrium similar to the previous one, which reflects the preferences attached to a known seismicity. At the same time, the production in the earthquake area slows down or is interrupted, affecting in turn, at the national scale, the sectors that are linked to the production of the earthquake area either by demand or supply.

An earthquake prediction is an information that would temporarily reduce the uncertainty over the seismicity of the area. It could affect the economic life in three ways: (1) the level of consumption, therefore the market price, would reflect the preferences attached to the "posterior probabilities" of seismic occurrence as given by the prediction system and understood by the public, (2) the level of production would decrease from the preventive measures of evacuation taken by individuals and businesses before the earthquake, (3) the loss of production after an earthquake would be decreased by the preventive measures previously taken.

The effects of earthquake engineering on the economic life of a seismic area are the direct effects of building codes on the construction sector and the sectors linked to it. On the other hand, earthquake engineering reduces the uncertainty, not of the seismic occurrence itself, but of its effects on society; it therefore affects the property market and reduces the production disruption after an earthquake.

b) Economic activity and economic well-being

In order to analyze the economic life under such an uncertainty, and its possible disruption, the two aspects of production and welfare have to be considered separately. At any particular time the economic life of a country can be described in two fundamentally different ways:

(1) the level of economic activity in the region or the nation, thus giving results on different aspects of the problem according to

the choice of the geographic boundaries of the system (total national loss or regional impact).

(2) the economic well-being of the producers and the consumers, based on the stocks of goods and services and the utilities attached to them (whereas the economic activity relates to the variation of these stocks).

The common way to measure the economic activity of a nation or a region is to measure its gross product. The gross product can be evaluated either at the stage of the outputs of each sector, or at the stage of the final demand, which can be relatively easily measured through its main components: private consumption, private investment, government purchases, and net exports.

$$GNP = C + I + G + E \tag{6}$$

The variation of each of those elements--output and final demand from each sector--can be analyzed through an input-output model as developed by Leontief (1966), thus taking into account the interrelations between the different sectors of the economy.

But the GNP is only a measure of the output of the economy: it does not isolate the corresponding primary inputs. Added value represents the net result of the economic activity of a region, and the loss of added value will be taken as a measure of the national and regional economic loss in the rest of the present study. The uncertainty inherent to the economic activity of the region is reflected by the random variations of output, final demand and added value, due to the variations of primary inputs (labor, capital and imports) caused by earthquakes.

In order to analyze the well being of the nation, one has to assess what is the utility to the nation of the available goods and services, for the consumers and for the producers.

The demand curve represents the consumers' willingness to pay for various levels of consumption. The consumers' surplus represents the difference between what the consumers would be willing to pay for those goods and what they actually pay. In the same way, the supply curves represent the producers' willingness to sell at different prices. The producers' surplus represents the difference between what the producers receive and the minimum for which they would be ready to sell.

A measure of the overall well being of the citizens can be given by the Net Social Surplus (NSS), sum of the consumers' surplus and the producers' surplus. Fig. 4 shows the Net Social Surplus in two cases that will be important later: the case of a fixed supply (e.g., land) and the case of a variable supply (e.g., manufactured goods).

$$NSS = CS + PS \tag{7}$$

The variation of the welfare function with the level of uncertainty reflects the variation of these surpluses when an additional information is given, which allows the citizens to make choices adapted to their risk attitude.

Under uncertainty, the consumer chooses a level of consumption and the producer chooses a level of production that maximizes economic

Case of a fixed supply (e.g.,land) Case of a variable supply(e.g.,food)

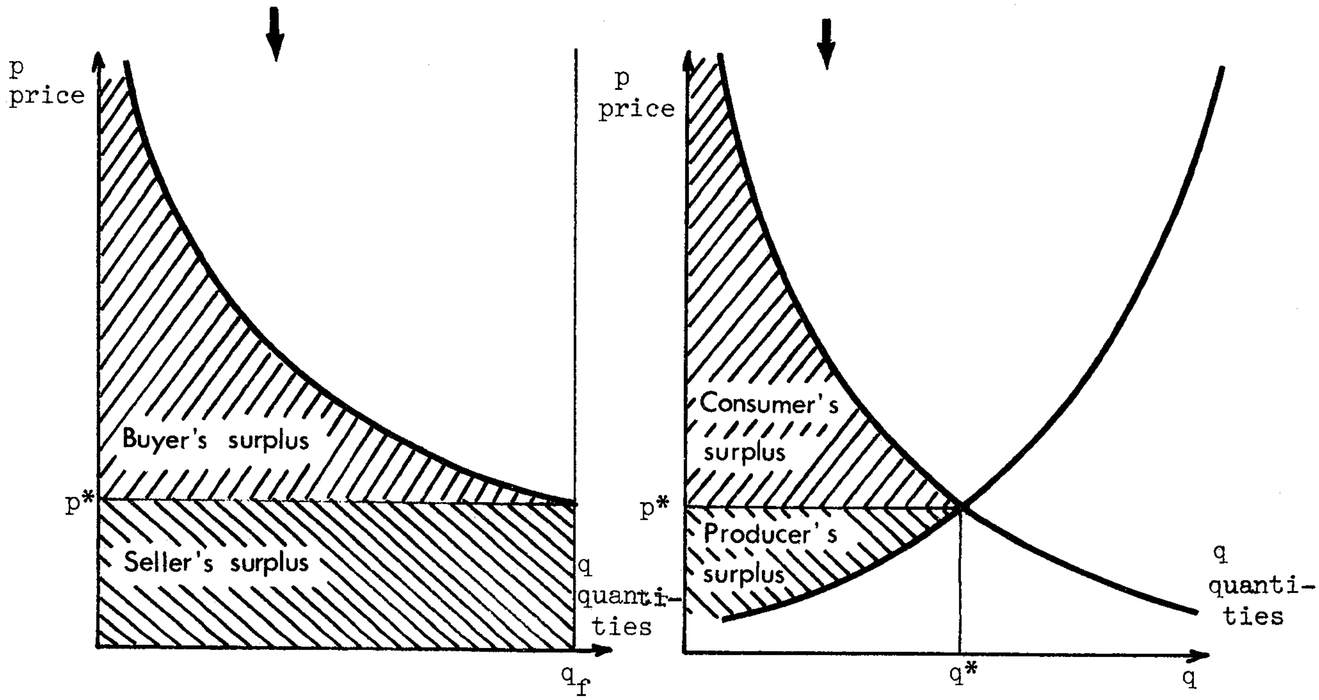


FIG. 4. NET SOCIAL SURPLUS

utility as a function of the probability of large earthquakes. The reinforcement of the structures through earthquake engineering, by decreasing the consequences of such a large earthquake, increases the economic utility of certain levels of consumption or production (e.g., in the construction sector). Earthquake prediction modifies for the next period of time the probability of a large earthquake, thus the level of consumption or production that maximizes the economic utility of consumers and producers.

Fig. 5 shows the variations of the utility of the citizens (consumers and producers) as a function of the probability of occurrence of a large earthquake at each period of time. The conditional

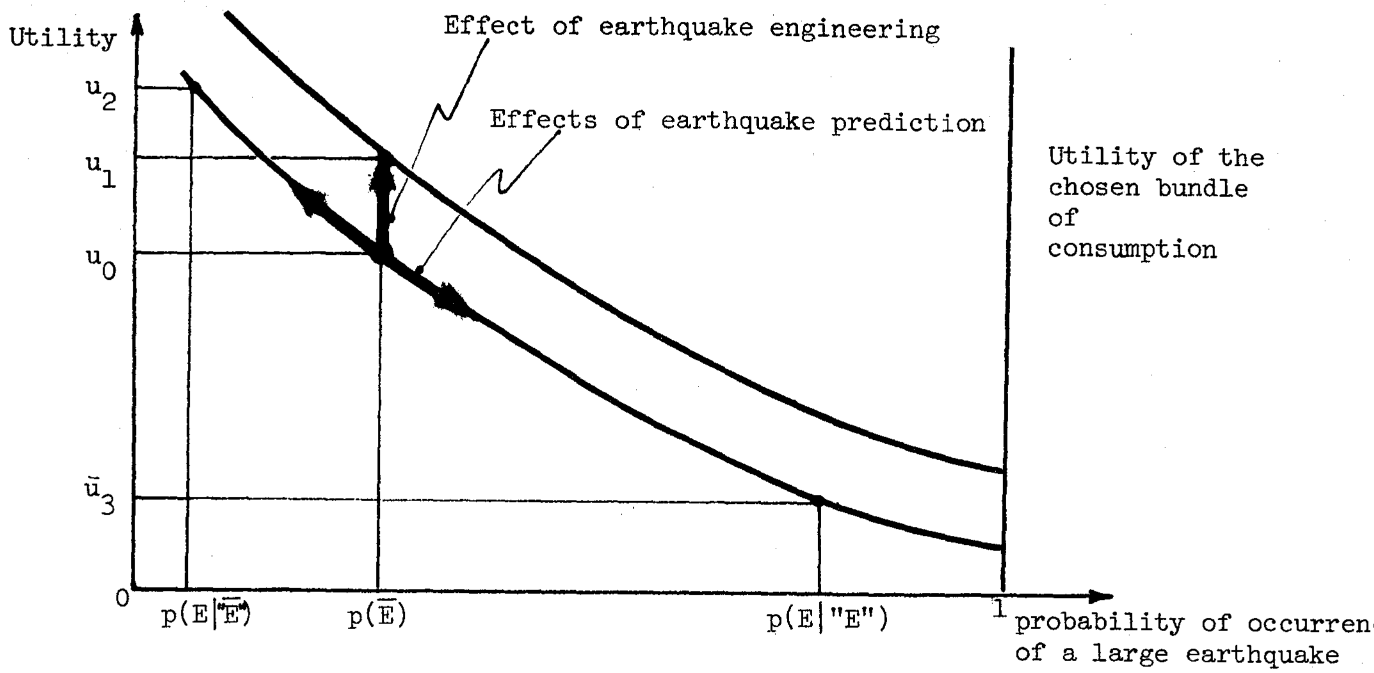


FIG. 5. WELFARE FUNCTION AND PROBABILITY OF A LARGE EARTHQUAKE

probabilities p(E|"E") and p(E|"Ē") represent the posterior probabilities of a large earthquake for the citizens, after the system of prediction has announced an earthquake for the following period of time, and when it has predicted no earthquake. This is the analysis that is developed further in Chapter 5 of the study by Paté, (1978). It shows what would be the influence of an earthquake prediction system on the economy in a welfare economics approach.

c) Risk and economic uncertainty

The economic component of risk, in the earthquake question, can thus be expressed in two different ways:

- the welfare risk attached to the expected decreased in the welfare function with the occurrence or the prediction of a large earthquake.

for a false alert, it seems logical that the individuals' preferences will be to leave in any case. The other issue in which the state's role clearly determines the criteria of choices of the individuals is the post-disaster policy. The amount of low-interest loans and grants that will be immediately allocated to the victims determines greatly the desirability of earthquake insurance, for instance, and even possibly the level of engineering that may appear desirable from the beginning.

3.3 CAPITAL IMMOBILIZATION FOR RISK MITIGATION. ORIGIN OF FUNDS

When the risk distribution is not uniform among the citizens and when a public policy is implemented to reduce that risk, the question of redistribution becomes an important aspect of the economic impact of any of the options. In the case of the seismic risk, one can examine for each of the alternatives the net effects of the capital investment and the redistribution effects.

In the alternatives involving earthquake engineering, the individuals subject to the seismic risk hear the cost of reinforcement of the buildings that they own. The state itslef bears the cost for public buildings and the costs of the disaster relief programs. These costs increase with the losses. Therefore, the higher the requirements of the building codes, the more the seismic risk is born by the inhabitants of the seismic regions.

One way to spread the risk after the event is to require insurance. This does not reduce the global risk on the whole of the nation, but

• the risk of loss of production, which is the expected loss of added value attached to the occurrence or the prediction of a large earthquake.

From a qualitative point of view, both were examined by Paté, (1978), in order to point out the effects of each policy on the economic component of the risk.

From a quantitative point of view, only loss of added value will be evaluated because it is of a nature comparable to the property damage: eventually, the production will have to compensate for that damage. Therefore it seems more appropriate in a first approach to add these quantities. The evaluation of the variations of the welfare function can be done through the evaluation of surpluses and assumed the knowledge of the various elasticities of supply and demand with respect to the probability p of a large earthquake. The data have not yet been gathered on that subject but the positivity of the variation of the welfare function will be established under the current assumption of concavity of the utility curves.

d) State's incentives and individuals' decisions under uncertainty

The behavior of individuals under the uncertainty of the occurrence of a large earthquake, in particular after a prediction, will depend greatly on the incentives that the state gives them. If the state accepts no liability for the prediction and provides the public with all the information available, the individuals will reveal preferences and take measures that will probably correspond more to their true belief and interest. On the contrary, if the state can be sued acts as a redistribution agent after the disaster, diminishing the global risk for the highly seismic areas, increasing it indirectly for the others.

As for earthquake prediction systems, the state makes the initial investment, which means a different set of incentives. The whole of the nation accepts a priori to bear part of the seismic risk and the incentive is less strong in the seismic areas for a higher level of seismic design. But the present tendency to make earthquake insurance unavailable after a prediction is an attempt to reduce the part of the risk that the less seismic areas have to bear.

For each of the chosen alternatives, a balance has to be found between two extreme cases:

- the case of a totally "free" system in which the individual is not submitted to the requirements of the building codes and, assuming the best public information, chooses the level of design and the level of insurance that maximizes his utility.

- the case of a totally state controlled system, where the whole of the nation would bear the financial risk given building codes backed up by the public funds. Then the utility of the public planner would be maximized.

The extent to which the risk should be spread depends then very much on the whole philosophy of the socio-economic system involved. It depends on the freedom that people have to decide on the protection measures they will take, on the role that the state gives itself as a coordinator or as an imperative planner and on the willingness of the rest of the nation to accept part of the risk in return for other benefits (such as their own insurance). Again, it may not seem desirable to isolate one of the risks but rather to establish a global risk policy that would insure a certain coherence in the government's risk attitude and provide the public with incentives to maximize individual utilities.

4 PRIORITIES AND LIFE SAVING. ORDINAL METHOD

4.1 PROJECT EVALUATION WITH AN INITIAL CHOICE OF A VALUE OF LIFE.

The evaluation of a public project involving the reduction of risks and life saving, raises the question of quantification of a variable that has no market value: the increase or decrease of human mortality.

Linnerooth (1975) reviews four approaches to the evaluation of life saving. Starting from each of the obtained results, one can quantify directly the costs and benefits in dollars of each of the alternatives.

- The human-capital approach values a life according to the potential of the individual for future productivity.

- The implicit value observable in societal acceptance of public and private risk has had recent attention but little application.

- The judicial value is the one observed through the purchase of life insurance or the court award in various trials.

- The willingness of individuals to pay in order to lower or eliminate a risk is the most significant measure of what an individual may require from a public policy. It varies with the level of risk in the highest range of probabilities.

Each of these approaches raises questions of feasibility, equity, consistency between the different risks and global efficiency on the whole of the public sectors.

Each of these approaches puts a different value on the individuals. The human capital approach would tend to put lower values on the human life than the willingness to pay or the observation of private decisions ($200,000 or $300,000 vs. 2 to 3 million dollars). The judicial approach gives very variable results according to specific cases. The willingness to pay should be aggregated among the different categories of the population. The result should reflect a general risk attitude, a dàta that makes sense only for a large population with symmetric distribution of risk attitude. It has, for a specific individual, the advantage of reflecting the value that the individual himself puts on his own life and it is logical that such value be adopted for public decisions as well.

The observability of these values is another problem; not only do they vary among individuals but according to the nature of the risk and the individuals' perception of that risk over time.

Because of these variations, it may seem desirable not to include the "value of life" in the evaluation of the whole project, but rather to separate completely the analysis from the value judgment. The procedure is thus to give two separate results:

- the balance (costs vs. benefits) of the directly marketable quantities in dollars or other monetary terms

- the reduction of the risk in terms of human lives saved.

From these two results the value of life that is implicit in the acceptance of the policy can be derived, compared with the different criteria adopted for the acceptance of similar projects, and the preferences expressed independently of the analysis.

This applies only to the case where the costs do not cover the expected benefits, thus where the acceptance of the project is based on the lives saved at a net cost. In the opposite case, the financial considerations are sufficient to justify the decision.

4.2 THE MARGINAL INVESTMENT TO SAVE A LIFE

The result of the reduction of the risk from a given public policy point of view can be classified into the following components:

C_i — the cost of the i^{th} proposed alternative, or the present value of a stream of costs on a given period of time

ΔD_i — the amount of dollars saved, in the earthquake case by avoiding damage and economic loss. In any case, the financial benefit.

ΔL_i — the total number of lives saved

If the avoided damage ΔD_i is higher than the costs C_i the project can be adopted on the basis of the financial component alone. If it is not so, the net cost to be balanced with life saving is $C_i - \Delta D_i$.

The net cost per life saved is thus:

$$CPL_i = \frac{C_i - \Delta D_i}{\Delta L_i} \qquad (8)$$

The marginal cost per life saved can be compared between all sectors. All systems of preferences can be applied, starting from that result.

It does not make any distinction between the individuals to whom the policy is applied, thus respecting the principle of anonymity in the value judgment. The final decision will depend on the criterion of choice. If the goal is to save the maximum number of lives, at each time this marginal cost should be identical in each sector; otherwise it would mean that for the same investment more lives could have been saved in marginal terms in the sectors where the public effort stopped at a lower allocation for life saving.

Using such a ratio as one of the decision elements means basing the decision on a collective willingness to pay for a specific project given its financial benefits and the alternatives for life saving if that turns out to be the main goal.

4.3 EQUITY AND OPTIMALITY

The use of such a ratio in the ranking of the alternatives is thus going to be determined by the objectives and preferences of the planner.

(1) If the public planner is dealing with a project for which all lives in his mind have same weight (which, according to all equity principles, should always be the case), the cost per life saved will be the direct criterion of ranking. It will insure that the maximum number of lives will be saved on the whole of the protection investments of the public sector.

(2) If the public planner thinks that he is dealing with a category of the population that he wants to give priority, he can use such a CPL ratio to determine the ratios of weights that he is willing to put

on the different human groups. This can be justified to balance, for instance, the capacity of reaction in case of disaster of the different categories of the population (e.g., children vs. adults vs. old people).

Whatever the preferences and constraints, the ratio cost per life saved is a good tool for the ranking of the various alternatives, since it clarifies the weights (if any) put on the different groups and insures the consistency of public decisions for risk mitigation.

4.4 LINEAR UTILITY AS A BASIS FOR PUBLIC PLANNING

Using the expected value of the cost per life saved as a basis for ranking the public policy alternatives implies that in its "a priori" planning the state is "risk indifferent." This implies, as developed in Section 2.2, that the state is not concerned about minimizing the public reaction (with its distortion of "saturation" for example), but with maximizing the expected number of lives saved for a given global investment. Risk indifference therefore means that the state gives the same priority to the tenth expected victim as the thousandth one. <u>But it has no implication for the value of that willingness to pay</u>, which can be quite higher at the beginning of the curve than the public reaction would require for daily events.

The problem is that there exists no common measure of the utility in a group, except in certain cases of a large population with a symmetrical distribution of "coefficients of risk attitude," which determine the curvature of the utility curves as described in Fig. 6.

The decision is thus the result of a bargaining process between the various groups involved, and equity considerations determine the result only to the extent that the democratic procedure is applied at the decision stage.

The state risk indifference may have scale limits: if the consequences of an event may reach the scale of the nation itself, the state can no longer afford to be risk indifferent (this is, for example, the case of a nuclear threat). The strategic and tactical choices will then reflect its risk aversion.

It will thus be assumed that even in the case of a large earthquake in the U.S., the maximal loss will remain several orders of magnitude below the size of the country in the property damage as well as in the economic consequences and in the number of casualties.

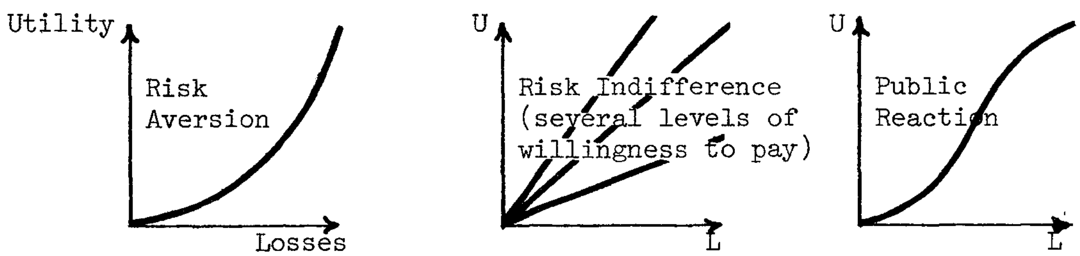


FIG. 6. UTILITIES AND RISK ATTITUDES

4.5 ALLOCATION OF FUNDS ON A DECREASING MARGINAL RETURN BASIS

The goal of the problem has thus been defined as follows:

- maximize the expected number of lives saved, through the choice of a public policy for a given period of time

- subject to the constraint of a total allocated budget C_{max}.

This means that, in the considered limits, the property damage is itself minimized. The difference C - ΔD, if positive, is allocated to life saving and could be reallocated to the reduction of other risks if that is more efficient. This implies also as mentioned before, that the state is risk indifferent and that all lives have the same priority in planning.

The optimal allocation of public funds in decreasing a two-component risk (lives and dollars) can be performed in the following way:

(1) for each alternative the ratio CPL is computed. $CPL = \frac{C_i - \Delta D_i}{\Delta L_i}$

(2) then the alternatives are ranked in such a way that the ratio CPL is constantly increasing, thus that marginal return of each policy is decreasing. Therefore the most efficient measures are adopted first.

The marginal return of the last adopted policy is thus the lowest one. The global return of a sequence of policy measures can be plotted on a concave curve of the following type:

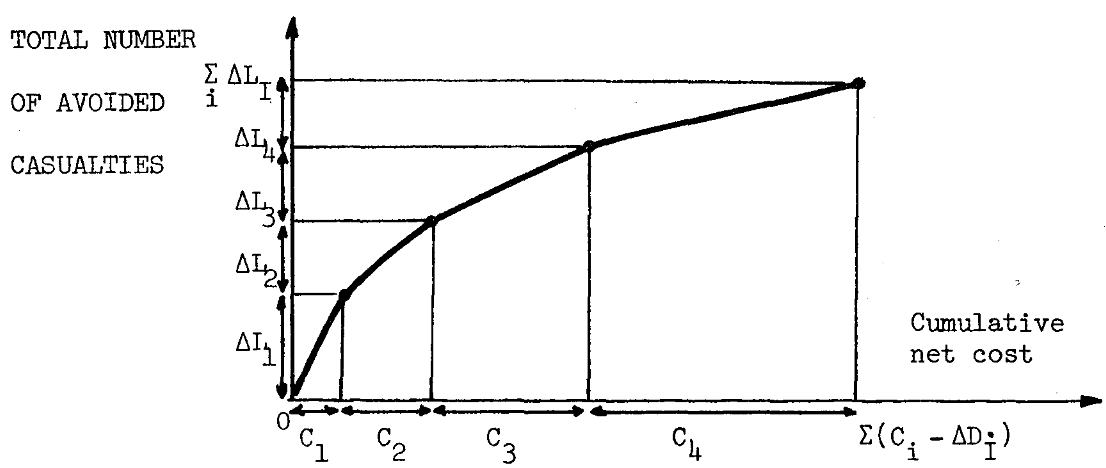


FIG.7.RANKING OF INDEPENDENT ALTERNATIVES FOR THE MITIGATION OF ONE GIVEN RISK

By doing so, one maximizes the total number of lives saved for a given total net cost. If it were not the case, it would mean that at some point, there would exist another ranking such that the corresponding cumulative curve would be above the one obtained here. Thus, for one of the previous segments (assuming the linearity of the return of each policy), there would have been a dominant alternative that would have shown a higher ratio $\frac{\Delta L}{C - \Delta D}$. This means that one of the alternatives with a lower cost per life saved (inverse of the slope of the corresponding segment) would have been neglected, which is contrary to the procedure.

The intersectorial comparison is clear on such a cumulative curve.

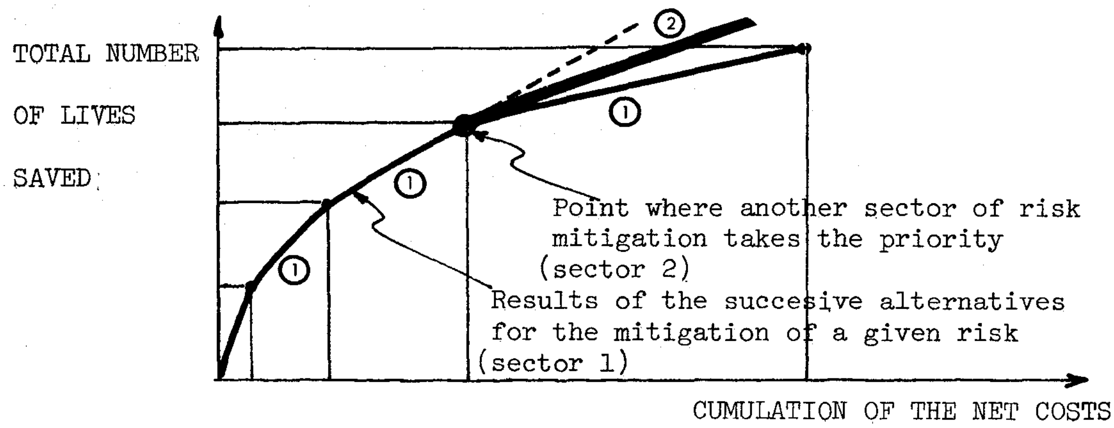


FIG. 8 . INTERSECTORIAL COMPARISON OF THE RETURNS OF RISK MITIGATION INVESTMENTS

If at a given point in the mitigation of one of the risks (sector 1), an additional investment leads to a decrease in the number of casualties that could be higher if the same investment were made in sector 2, then the order of priorities should change. The mitigation of the risk in sector 1 should give way to investments in sector 2.

Such a move would insure that for the whole of the risk mitigation sectors the total number of lives saved for a global investment is maximal.

The interpretation of such curves in the field of seismic risk, is that after a certain level of design in the most critical buildings, it would be more efficient for the purpose of life saving in general to shift towards medical programs, for instance. The alternatives ranked on the inital cumulative evaluation of the total number of lives saved correspond to the reinforcement of various types of buildings, per category of use and structures. One of the questions addressed later is where on that curve is situated the result of earthquake prediction under different hypotheses.

4.6 THE ULTIMATE CONSTRAINT IN THE ALLOCATION PROCESS

The major question that remains (assuming that consistency has been observed through the whole allocation process) is to know the final constraint: when should the state stop investing in protection measures and shift towards the production sector?

The constraint can be formulated in different ways as developed in Section 2.4. Society's willingness to pay for the marginal cost of saving a life, all other benefits having been taken into account, will be the last point of reference. Nevertheless, it is not a decision variable but reflects the current choices and preferences politically, economically and philosophically. The other constraints can be directly related to that one.

The maximal risk of death per unit of time for a given benefit can be considered in the light of a cost-benefit approach. If lowering the risk below the maximal level of say 10^{-7} implies a NET cost per life saved above the acceptance of the other sectors, the project is clearly not acceptable.

The notion of net cost--financial costs minus financial benefits--is fundamental, since other benefits may make the project desirable even if extremely costly safety measures have to be taken. This is what may happen in fields such as the operation of nuclear power plants. It is assumed that all the other attributes of the benefit function can be expressed in dollar terms (environmental aspects, political aspects, for example), and that the life problem is the only one that is tested from the results of the analysis.

The equivalence of the three sorts of constraints generally imposed on public decisions in the area of risk mitigation is established in Fig. 9 . The equivalence between the total net cost and the maximum probability of exposure per year is established through the marginal cost per life saved. The reduction of the probability of death down to PMAX (maximal annual probability of death, decreasing when each new policy is adopted), corresponds to a marginal number of lives saved. The adoption of this last policy determines a marginal cost per life saved (MCPL) and the corresponding total net cost of safety policies (CMAX).

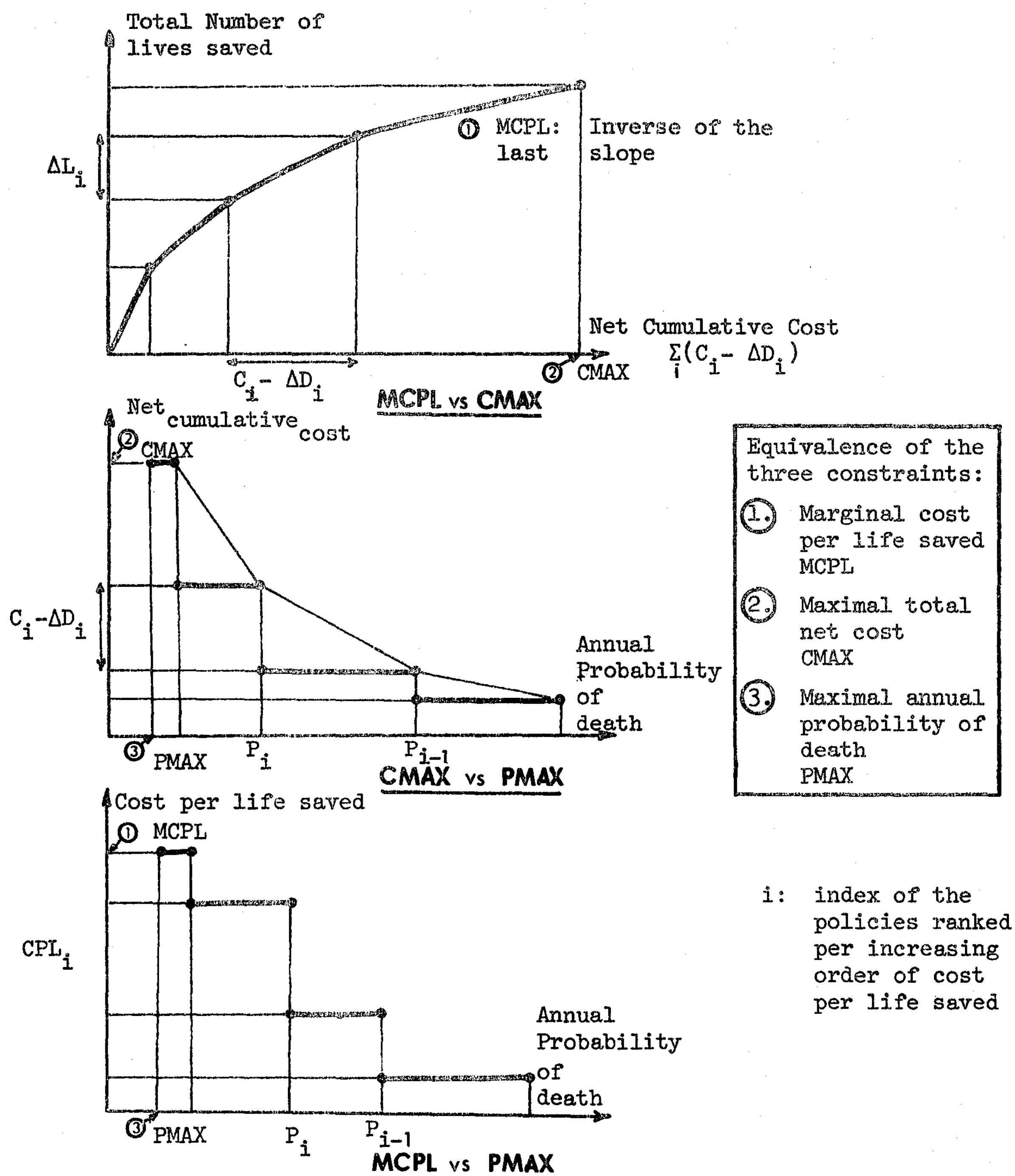


Fig. 9. Public Policy for Life Saving: The Ultimate Constraint

5 THE PROBLEM OF WARNINGS AND ALERTS

5.1 WARNINGS AS A CRISIS SITUATION

One of the major issues in the question of earthquake prediction and its potential efficiency is the public reaction to a situation of warning or alert. Such reactions have been observed in case of other natural catastrophes but it is felt that earthquakes in that respect are of a different nature. The perception of precursor signals and individual evaluation of their meaning will be much more difficult than the perception of a coming flood, for example. In fact, it is a different type of "crisis" that populations will have to face, whether American or from another continent.

There are basically two types of crisis.* A first type is that of a confused situation, in which the issues are unclear, the situation ill-defined, the possibilities of action very large but the consequences difficult to evaluate. In that sort of crisis, there is a dominant state of anxiety that leads to drastic moves with potentially serious effects. A typical example of such a crisis is the situation of August, 1914 in Europe. It could be the case of an earthquake prediction situation, in particular, if the information did not help clarify the situation. The second type of crisis is one where the uncertainties are much more limited, the course of action as well as the consequences much more clear. This situation is better than the first one in all respects. The anxiety and irrationality are much less dominant. The classical example is London in 1942.

* I wish to thank Prof. R. C. North (Department of Political Science, Stanford University) for an interesting conversation on this topic.

The point here is that in such a case a major role of the authorities would be to try to convert a situation of the first type--which would add to the danger itself--into a situation of the second type, where the level of information is better, the level of anxiety is lower and the behavior much more rational.

The first idea is thus that whatever the level of uncertainty chosen by the authorities to issue a warning, the full information should be given. This would give the citizens the best decision power and would increase the benefits of the prediction.

5.2 WARNING AND SOCIO-ECONOMIC STRUCTURE

Two factors will be decisive in the reaction to a warning situation:

- the level of development and internal communications insider the country
- the structure of the relation between the state (and state-related organizations such as the army and the police) and the citizens.

The level of development and communications will be critical in the first stage for the diffusion and the comprehension of the information. A barrier in the communication, which could rise particularly in developed countries between the state and the citizens, is the one of legal liability, which might lead the authorities to keep the information instead of bradcasting it. This problem will have to be faced, preferably before the earthquake prediction system is operational, which might very well happen before the society is ready to receive such information.

The second point is the extent to which the government is entitled to influence the citizens' actions when the threat is not clearly perceived. The Chinese experience shows that in totalitarian regimes, becasue of a different conception of private rights, there is no liability problem. The state and the army are able to take radical moves without major disruption of the socio-economic life. In a democratic society, where individuals have much more decision power, a much higher level of consensus and organization has to be found before the earthquake prediction system becomes viable.

5.3 GENERALITY OF THE LIABILITY QUESTION

The liability question will basically revolve around the expression of the uncertainty attached to any prediction or warning. A probabilistic statement will have to be issued, comparable to that made in forecasting the weather. But it can take a different form in the people's minds since they will have to rely entirely on the judgment of others--in that case the geologists and the seismologists. The expression of the statement is no longer "a hurricane will reach our coast with a chance of 99%, based on past experience with currently observable phenomena" but "as far as geologists can tell, and given the observation of a certain number of signals, there is a 50% chance that a large earthquake will occur in the next two years."

The liability question is thus the significance of a probabilistic statement before the law. The whole issue will be the procedure by which the conclusion will be reached and the consensus of the professional group involved. The legal procedure refers to peers' judgment, and the consensus on a probabilistic statement will be still more difficult to reach than on the qualitative meaning of a signal.

In any case, if one believes that the public is capable of taking rational decisions in such a crisis situation, it is necessary to make sure that such a probabilistic statement be understood. This requires both an effort of education and an effort of information in order to prevent the liability questions from making the issue still more confused than it is likely to be, at least initially.

REFERENCES

Arrow, K. J., 1971: "Essays in the theory of risk bearing", Markham Publishing Company, Chicago.

Arrow, K. J., 1977: "The Rate of Discount on Public Investments with Imperfect Capital Markets," Apologetic notes towards a paper, Harvard University, Cambridge, Massachusetts.

Acton, J. P., 1973: "Evaluating public programs to save lives: the case of heart attacks", Report R-950-RC, Rand Corporation, Santa Monica, California.

Benjamin, J. R. and C. A. Cornell, 1970: "Probability, statistics and decision for civil engineers", McGraw-Hill, New York.

City and County of San Francisco, 1974: "Earthquake Response Plan", Emergency Operations Plan, Part I, San Francisco, California.

Cochrane, H. C., 1974: "Predicting the Economic Impact of Earthquakes", in "Social Science Perspectives on the Coming San Francisco Earthquake. Economic Impact, Prediction and Reconstruction", by Cochrane, Haas, Bowden and Kates. Working Paper No. 25, Institute of Behavioral Science. University of Colorado, Boulder, Colorado.

Cook, W. H., B. R. Judd and C. N. Smart, 1973: "Value in Nuclear Power Plant Safety Evaluation: A Pilot Model for Assessing the Health Consequences and Related Societal Costs of Exposing a Sample Population to High Levels of Radiation", (The Scoial Cost Model), Prepared for the Atomic Energy Commission by the Stanford Research Institute, Menlo Park, California.

Fischhoff, B., P. Slovic and S. Lichtenstein, 1976: "How Safe is Safe Enough? A Psychometric Study of Attitudes Towards Technological Risks and Benefits", Decision Research Report #76-1, Decision Research, A Branch of Perceptronics, University of Oregon, Eugene, Oregon.

Grandori, G. and D. Benedetti, 1973: "On the choice of an acceptable risk. A New Approach", Proceedings of the Fifth World Conference on Earthquake Engineering, Vol. 2, pp 2541-2549, Rome, Italy.

Haas, J. E. and D. S. Mileti, 1976: "Socioeconomic impact of earthquake prediction on Government, Business and Community". Institute of Behavioral Science. University of Colorado.

Howard, R. A., 1966: "Decision Analysis: Applied Decision Theory", in "Readings in Decision Analysis", Decision Analysis Group, Stanford Research Institute, Menlo Park, California.

Howard, R. A., J. E. Matheson and D. W. North, 1972: "The Decision to Seed Hurricanes", Science, Vol. 176 pp 1191-1202.

Howard, R. A., 1977: "Life and death decision analysis", unpublished manuscript, Stanford University, Stanford, California.

Keeney, R. and H. Raiffa, 1976: "Decision with multiple objectives", J. Wiley and Sons, England.

Kunreuther, H., 1971: "Risk Taking and Disaster Insurance", Proceedings of the Conference on Earthquake Risk, Carmel, California.

Leontief, W. W., 1966: "Input-Output Economic", Oxford University Press, New York, New York.

Lind, Robert C., 1968: "Benefit-Cost Analysis: a criterion for social investment" - Water Resources Management and Public Policy; ed. by Thomas H. Campbell and Robert O. Sylvester (Seattle: University of Washington Press), pp. 44-64.

Linnerooth, Joanne, 1975: "The Evaluation of LIfe Saving: A Survey", IIASA PR-75-21, International Institute for Applied Systems Analysis, Laxenburg, Austria.

Mishan, E. J., 1976: "Cost-Benefit Analysis", Praeger Publishers, New York, New York.

Mukerjee, T., 1971: "Adjusting to Earthquakes: Costs and Benefits", Proceedings of the Conference on Earthquake Risk. Carmel, California.

Mukerjee, T., 1971: "Economic Analysis of Natural Hazards: A Preliminary Study of Adjustments to Earthquakes and their Costs". University of Toronto, Canada.

Owen, P. A., 1978: "Decisions that affect outcomes in the distant future". Doctoral thesis, Department of Engineering Economic Systems, Stanford University, Stanford, California.

Panel on the Public Policy Implications of Earthquake Prediction, 1975: "Earthquake Prediction and Public Policy". National Academy of Sciences, Washington, D.C.

Paté, M-E., 1978: "Public Policy in Earthquake Effects Mitigation: Earthquake Engineering and Earthquake Prediction", Doctoral thesis, Department of Engineering-Economic Systems, Stanford University, Stanford, California.

Raisbeck, G., 1971: "Problems in the Establishment of Practical Safety Goals in Transportation", Proceedings of the Conference on Earthquake Risk, Carmel, California.

Rowen, H. S., 1976: "Choice of a social rate of discount", Class NOtes of the Course of Public Management, Graduate School of Business, Stanford University, Stanford, California.

Sen, A., 1977: "Approaches to the Choice of Discount Rates for Social Cost-Benefit Analysis", paper presented at the Conference on "Energy Planning and the Social Rate of Discount" Resource fot the Future, Washington, D.C.

Shishko, R., 1976: "Choosing the Discount Rate for Defense Decision Making", Rand Corporation, R-1953-RC.

Slovic, P., B. Fischhoff and S. Lichtenstein, 1976: "Cognitive Process and Societal Risk Taking", in "Cognition and Social Behavior", J. S. Carroll and J. W. Payne (Editors), Lawrence Erlbaum Assoc. Potomac, Maryland.

Slovic, P., 1977: "Judgment, Choice and Societal Risk Taking".

Starr, C., 1969: "Social Benefit versus Technological Risk", Science, Vol. 165, pp. 1232-1283.

Starr, C., 1971: "Social Benefits vs Risk", Proceedings of the Conference on Earthquake Risk, Carmel, California.

Starr, C., R. Rudman and C. Whipple, 1976: "Philosophical Basis for Risk Analysis", Annual Review of Energy.

Stiglitz, J., 1974: "Economics of uncertainty", Department of Economics, Stanford University, Stanford, California.

Tani, S. N. and D. W. Boyd, 1976: "Measuring the Economic Cost of an Oil Embargo". Report prepared for the Strategic Petroleum Reserve Office. Federal Energy Administration, Stanford Research Institute, Menlo Park, California.

United States Atomic Energy Commission, 1974: "Reactor Safety Study--An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants" - WASH 1400 - Washington, D.C.

United States Congress, Joint Economic Committee, 1971: "The Analysis and Evaluation of Public Expenditures: The PPB System", A Compendium of Papers submitted to the Subcommittee on Economy in Government of the Joint Economic Committee, Vol. 1, Joint Committee Print, 91st Congress, 1st Session.