

AN OVERVIEW OF THE PROBLEMS OF PUBLIC SAFETY

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## Introduction

The design of technological systems always involves an overt choice among alternative synthesized solutions and operating conditions, so as to optimize eventual performance. The criteria for such an optimization are usually well defined for most components, "black boxes," or subsystems in already specified large systems. One of the most common criterion is, of course, direct monetary cost. Technological analyses for disclosing the relationship between expected performance and monetary costs are a traditional part of all engineering planning and design. The inclusion in large system studies of all societal costs" (indirect as well as direct) is much less customary, and obviously makes the analysis more difficult and less certain quantitatively.

Of obvious interest is the social "cost" associated with the public safety consequences of design decisions. For example, if analysis of a new development predicts an increased annual income of "x percent, but also predicts an associated accident risk of "y" fatalities annually, then how are these to be compared in their effect on the "quality-of-life" Because the penalties or risks to the public arising from a new development can always be reduced by applying constraints, there will usually be a functional relationship (or tradeoff) between utility and risk, the "x" and "y" of our example.

We have many historical illustrations of such tradeoff relationships empirically determined. For example, automobile and airplane safety have been continuously weighed by society against economic costs and operating performance. In these, and other cases, the real tradeoff process is actually one of dynamic adjustment, with the time behavior of many portions of our social systems out-of-phase due to the many separate "time-constants" involved. The ready availability of historical accident and health data, for a variety of public activities, provides an enticing quantitative steppingstone to an evaluation of this particular type of social cost. The corresponding social benefits arising from some of these

activities can be roughly determined. On the assumption that such historical situations have achieved a socially acceptable and reasonably optimum trade-off of values, any generalizations developed might then be used for predictive purposes. This approach could give a rough answer to the slyly simple question "how safe is safe enough?"

The pertinence of this question to all of us, and particularly to governmental regulatory agencies, is obvious. Hopefully, a functional answer might provide a basis for establishing performance "design objectives" appropriate for technology entering into social use.

#### Voluntary and Involuntary Activities

Societal activities fall into two general categories, those in which the individual participates on a voluntary basis, and those in which the participation is "involuntary" i.e., imposed by the society in which the individual lives. The process of empirical optimization of benefits Ind. costs is fundamentally similar in both cases -namely a reversible exploration of available options - but the time required for empirical adjustments (the time-constant of the system) and the criteria for optimization are quite different in the two situations.

In the case of "voluntary" activities, the individual uses his own value system to evaluate his own experiences. Although his eventual tradeoff may not be consciously or analytically determined, or based upon, objective knowledge, it nevertheless is likely to represent, for that individual, a crude optimization appropriate to his value system. For example, an urban dweller may move to the suburbs because of lower crime rate and better schools, at the expense of increased highway travel time and accident probabilities. If, subsequently, the traffic density increases, he may decide the penalties are too great and move back to the city. Such an individual optimization process can be comparatively rapid (because of the rapid feedback of experience to the individual) so that the statistical pattern of a large social group may be an important

"real-time" indicator of societal trade-offs and values.

"Involuntary" activities differ in that the criteria and options are determined not by the individuals affected but by a controlling body. Such control may be in the hands of a government agency, political entity, a leadership group, an assembly of authorities or opinion-makers, or a combination of such bodies. Because of the complexity of large societies, only the control group is likely to be fully aware of all the criteria and options involved in their decision process.

Further, the time required for the feedback of the empirical experience resulting from the controlling decisions is apt to be very long. The feedback of cumulative individual experiences into societal communication channels (usually political or economic) is a slow process, as is also the process of altering the direction of the control group. We have many examples of such "involuntary" activities, with perhaps war being the most extreme case of the operational separation of the decision-making group from those most affected.

In examining the historical benefit-risk relationships for "involuntary" activities, it is important to recognize the perturbing role of public psychological acceptance of risk arising from the influence of authorities or traditional dogma. Because in this situation the decision making is separated from the affected individual, society has generally clothed many of its controlling groups in an almost impenetrable mantle of authoritative wisdom. The public generally assumes that the decision-making process is based on a rational social benefit-risk analysis. While it often is, we have all seen disclosed after-the-fact examples of irrationality. It is therefore important to omit such "witch-doctor" situations from the selection of examples of optimized "involuntary" activities because, in fact, they are not as yet optimized, but only in the initial stages of option exploration.

### Quantitative Correlations

With this description of the problem, and the associated caveats, we are in a position to discuss the quantitative correlations. For the sake of simplicity in this initial study, I have taken as a measure of the physical risk to the individual the fatalities (deaths) associated with each activity, although it might be useful to include all injuries (which run 100 to 1000 times as many as deaths), the difficulty in obtaining data and the unequal significance of varying disabilities made it an inconvenient complexity. So the risk measure used here is the statistical probability of fatalities per hour of exposure of the individual to the activity considered.

The choice of the hours exposure unit was deemed to be more related to the individuals intuitive process in choosing an activity than an "annual" unit, and using the "annual unit" did not appear to change the substance of the results. Another possible alternate, the risk per activity, involved the comparison of too many unlike units of measure. Thus, in comparing the various transportation modes one could use risk per hour, per mile, or per trip. As this study was directed toward exploring a methodology for determining social acceptance of risk - rather than the safest mode for a particular trip - the simplest common unit of risk per exposure hour was chosen. A future study might explore this issue further.

The social benefit derived from each activity was converted into a dollar equivalent, as a measure of integrated value to the individual. This is perhaps the most uncertain aspect of the correlations because it reduced the "quality-of-life" benefits of an activity to an overly simplistic measure. Nevertheless, the correlations seemed useful, and no better measure was available. In the case of the voluntary activities the amount of money spent on the activity by the average involved individual was assumed proportional to its benefit to him. In the case of the "involuntary" activities, the contribution of the activity to the individual's annual income (or the equivalent) was assumed proportional

to its benefit. This assumption of roughly constant relationship between benefits and monies for each class of activities, is clearly an approximation. However, as we are dealing in orders of magnitude, the distortions likely to be introduced by this approximation are relatively small.

In the case of transportation modes, the benefits were equated to the sum of the monetary cost to the passenger and the value of the time saved by that particular mode as compared to a slower competitive mode. Thus, airplanes were compared to autos, and autos were compared to public transportation or walking. Public transportation "benefits" were equated to their COSL. In all cases, the benefits were taken on an annual dollar basis because it seemed to be more appropriate to the individual intuitive process. For example, most luxury sports require an investment and upkeep only partially dependent on usage. The associated risks, of course, exist only during the hours of exposure. Probably the best example of the analysis of an involuntary activity is the benefit and risk associated with the use of electricity. In this case the fatalities included those arising from electrocution, electrically caused fires, the operation of power plants, and the mining of the required fossil fuel. The benefits were estimated from a United Nations study of the relationship between energy consumption and national income, and the traction associated with electric power was used.

As compared to the use of electricity in industry, the more subtle contributions of electric power to our quality of life are, of course, omitted. For instance the availability of refrigeration has certainly improved our national health and the quality of dining. The electric light has certainly provided great flexibility in living. The contributions of TV may be more uncertain, but the public response indicates that it is a positive element in our living patterns. Perhaps, however, the income measure used here is sufficient for the present purpose.

Information on 'voluntary' risk acceptance by individuals as a function of income benefits is not easily available, although we know that such a relationship must exist. Of particular interest therefore is the special case of miners exposed to high occupational risks. Fig. 1 is a plot of the accident rate and severity rate of mining injuries vs. the hourly wage. The acceptance of individual risk is an exponential function of the wage, and can be roughly approximated by a cube relationship in this range. If this relationship has validity, it may mean that three parameters in the "quality-of-life" (perhaps health, essentials, and recreation) are partly influenced by any increase in available personal resources, and thus the increased risk acceptance is proportionally motivated. The degree that this relationship is "voluntary" for the miners is not obvious, but it is interesting nevertheless.

The results for those societal activities studied, both voluntary and involuntary, are assembled in Fig. 2. Also shown in Fig. 2 is the cube relationship between risk and benefit characteristic of Fig. 1. For comparison purposes also shown is the average risk of death from accident and disease. As the average accident fatalities are only about one tenth that of disease, their inclusion is not significant.

#### Risk Comparisons

Several major features of the benefit-risk relations are apparent, the most obvious being the separation by several orders of magnitude between the "voluntary" and "involuntary" acceptance of risks. As one would expect, we are loathe to let others do unto us what we happily do to ourselves.

The disease death rate appears to play a yardstick role in determining the acceptability of risk on a voluntary basis. Most sporting activities are surprisingly close to the disease level almost as though the individual's subconscious computer adjusted his sporting courage to meet but not exceed the statistical mortality due to involuntary exposure. Perhaps this defines the demarcation between boldness and foolhardiness.

# MINING ACCIDENT RATES VS. INCENTIVE

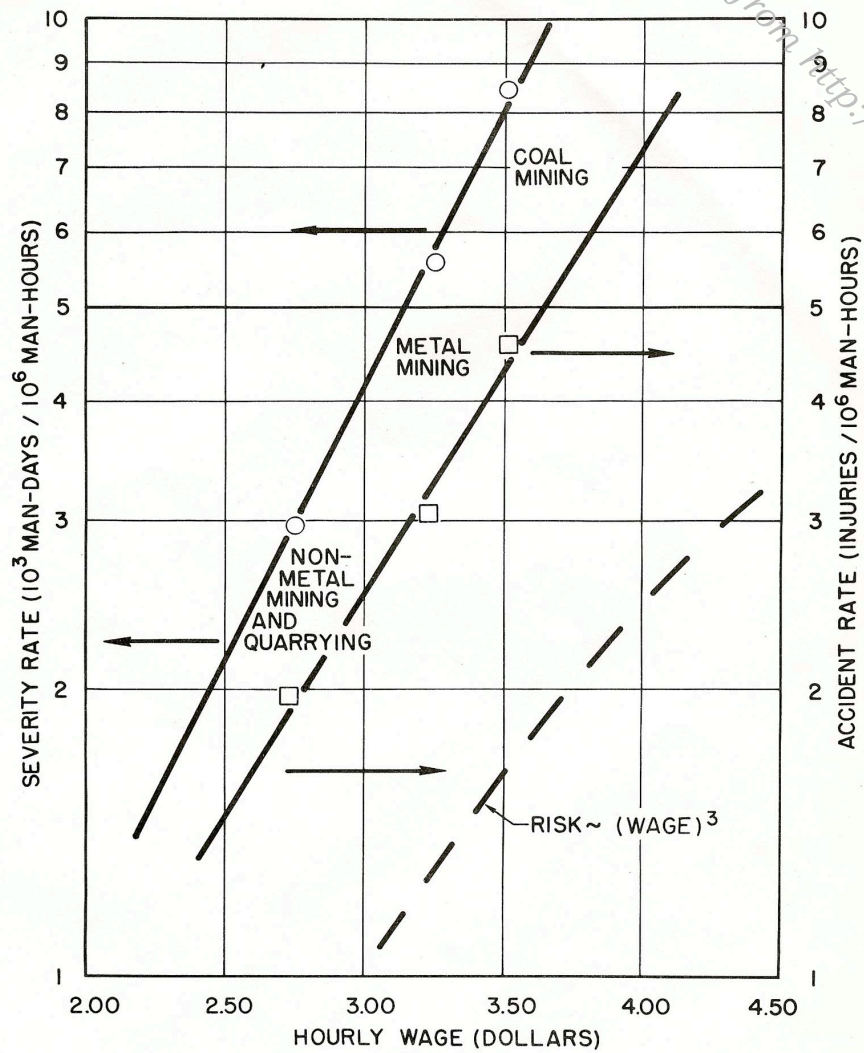


FIGURE 1



# RISK VS. BENEFIT VOLUNTARY AND INVOLUNTARY EXPOSURE

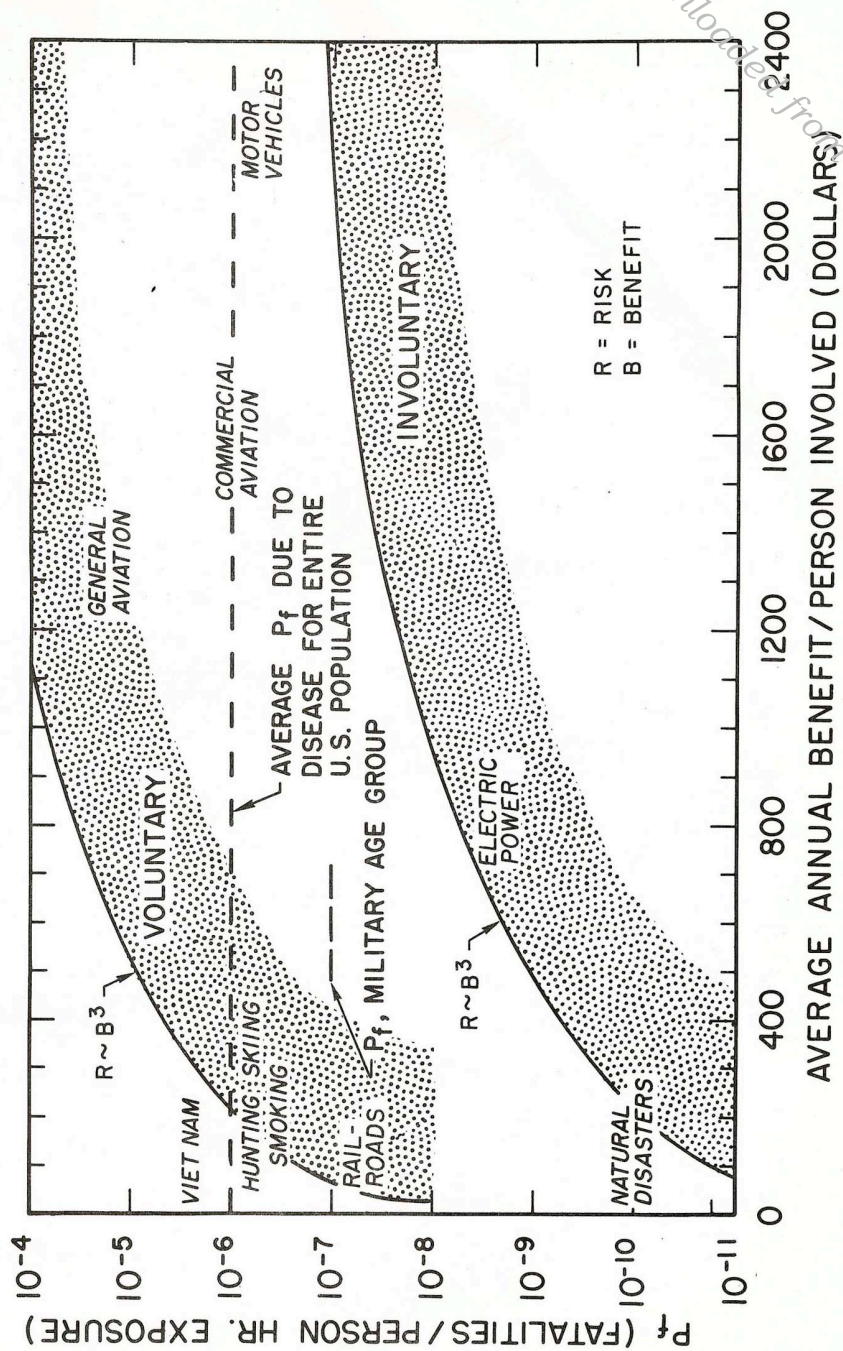


FIGURE 2

The Vietnam war statistic was shown because it raises an interesting point. Its risk is only slightly above the average disease risk. Assuming that some long-range societal benefit was anticipated from this war, the related risk as seen by society as a whole is not substantially different from the average nonmilitary disease risk. However, to the exposed military age group (20-30) the Vietnam risk is about ten times the normal mortality (accident plus disease) rate for that age. Hence a difference in perspective between the population as a whole and those directly exposed. This raises the question as to whether the disease risk pertinent to the average age of the involved group might not make a more meaningful comparison than the national average. This would complicate these simple comparisons, but it may be more significant as a yardstick.

The risk positions of general aviation, commercial aviation, and motor vehicles deserve special comment. Motor vehicles originated as a "voluntary" sport, and have had a half-century to become an essential utility. General aviation is still highly voluntary. Commercial aviation is partly voluntary and partly essential, and additionally is subject to government administration as a transportation utility.

The motor vehicle has now reached a mature benefit-risk balance, as shown in Fig. 3. It is interesting that its present risk level is only slightly below the basic disease level. In view of the high percentage of the population involved, this probably represents a true societal judgment on the acceptability of risk in relation to benefit. It also appears from Fig. 3 that future reductions in the risk level will be slow in coming, even if the historical trend of improvement can be maintained.

Commercial aviation has barely approached a risk level comparable to that set by disease. The trend is similar to that of motor vehicles, as shown in Fig. 4. However, the percent of the population participating is now only a twentieth that of motor vehicles. Increased public participation will undoubtedly increase

# RISK AND PARTICIPATION TRENDS FOR MOTOR VEHICLES

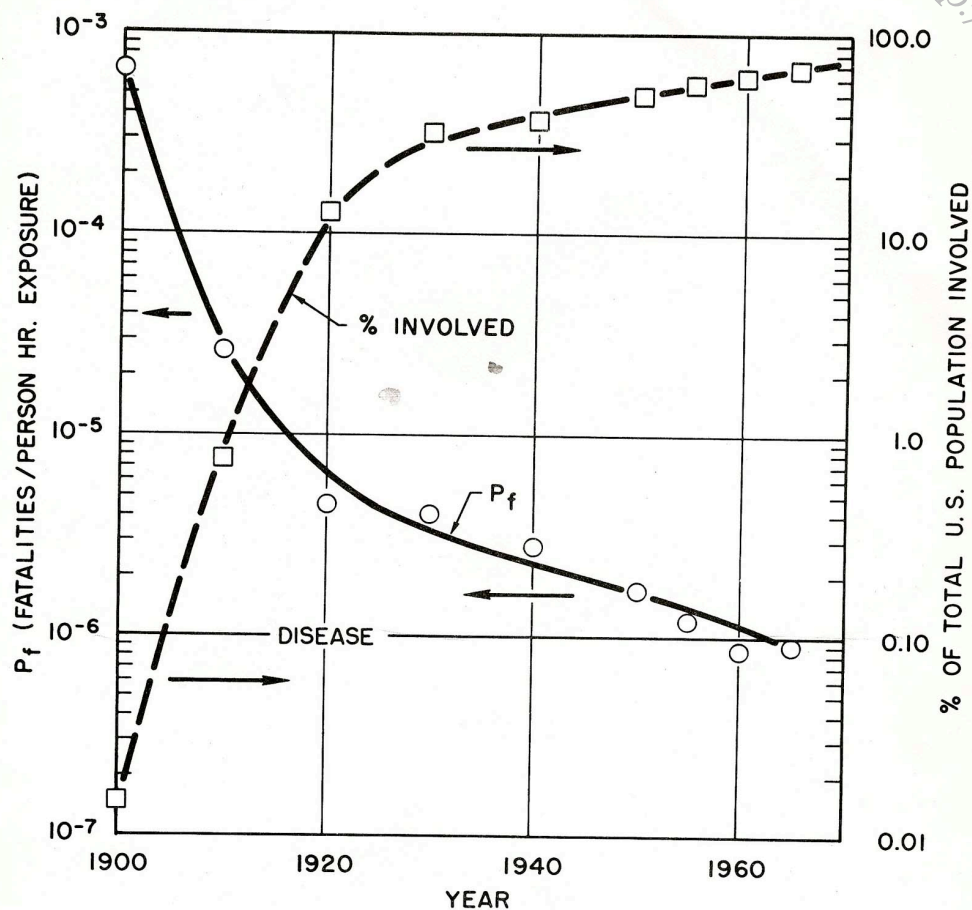


FIGURE 3

# RISK AND PARTICIPATION TRENDS FOR CERTIFIED AIR CARRIERS

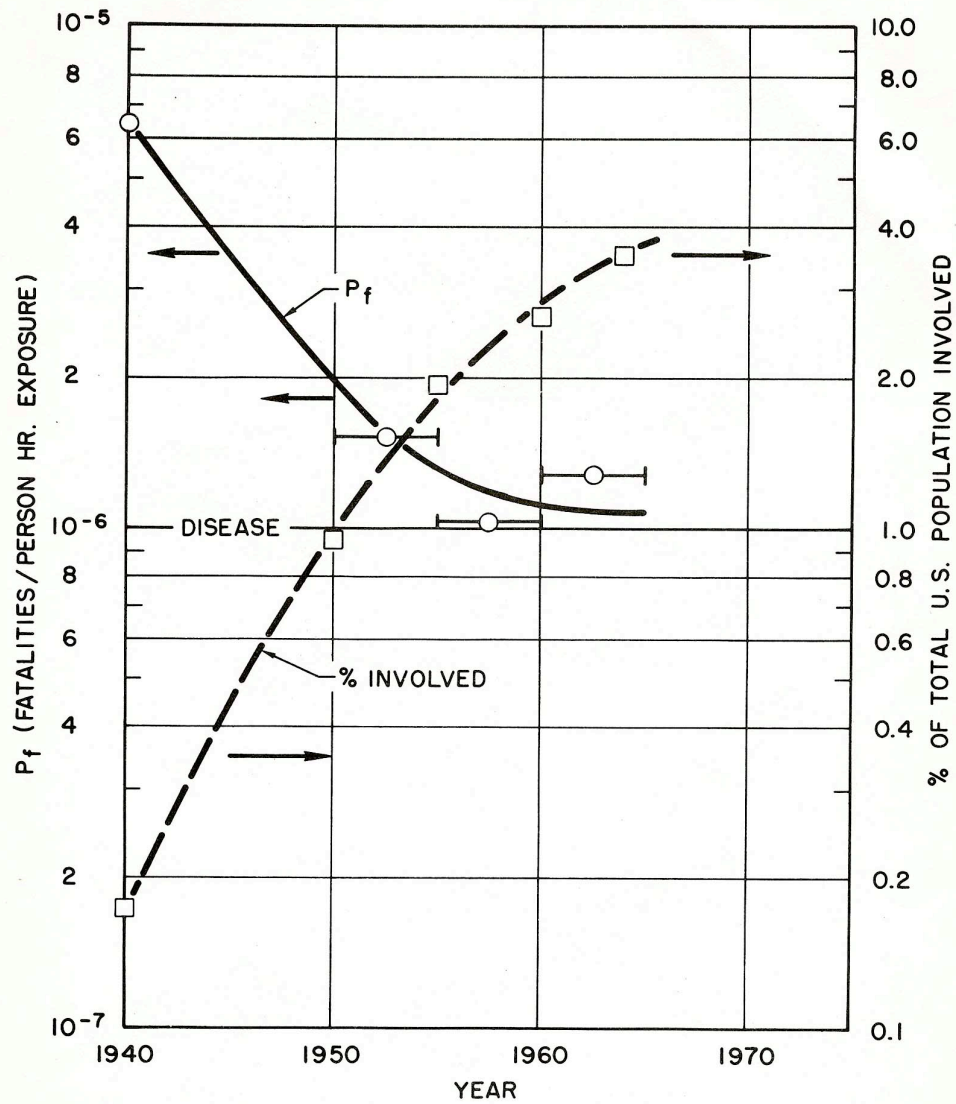


FIGURE 4

the pressure to reduce the risk, because for the general population the benefits are much less than those associated with motor vehicles. Commercial aviation has not yet reached a mature optimum of benefit-risk tradeoff.

General aviation has similar trends, as shown in Fig. 5. Here the risk levels are so high (20 times disease risks) that this activity must properly be considered in the category of an adventuresome sport. However, the rate of decrease of risk is so rapid, that eventually general aviation may approach commercial aviation in performance. The percent of the population involved is so small that the present average risk levels can be considered as acceptable only to a limited group.

The similarity of the trends in Figs. 3, 4, and 5 may be the basis for another hypothesis as follows. The acceptable risk is inversely related to the number of people participating in an activity

The product of the risk and percent of population involved in each of the activities in Figs. 3, 4, and 5 have been plotted in Fig. 6. This represents the historical trend of total fatalities per hour of exposure of the population involved. The leveling off of motor vehicle risk at about 100 fatalities per hour of exposure of the participating population may be significant. Because most of the U.S. population is involved, this rate of fatalities may have sufficient public visibility to set a level of social acceptability. It is interesting, and disconcerting, that the aviation trend of fatalities, both commercial and general, is uniformly upwards.

#### Public Awareness

As a final attempt to quantitatively probe our societal attitudes, the relationship of this risk data with a crude measure of public awareness of the social benefits was attempted. This is shown in Fig. 7. The "benefit awareness" was arbitrarily defined as the product of the relative level of advertising, the square of

# RISK AND PARTICIPATION TRENDS FOR GENERAL AVIATION

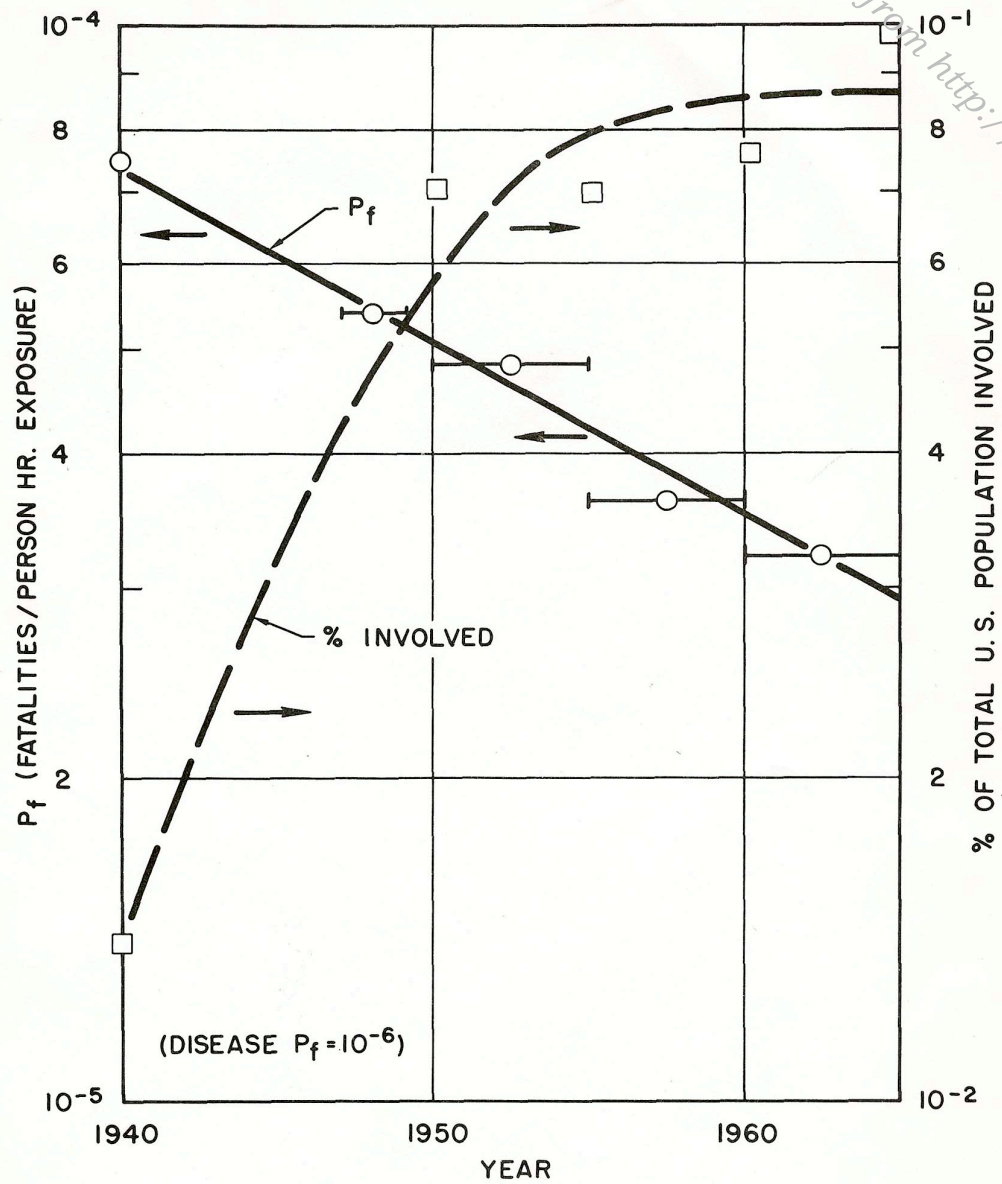
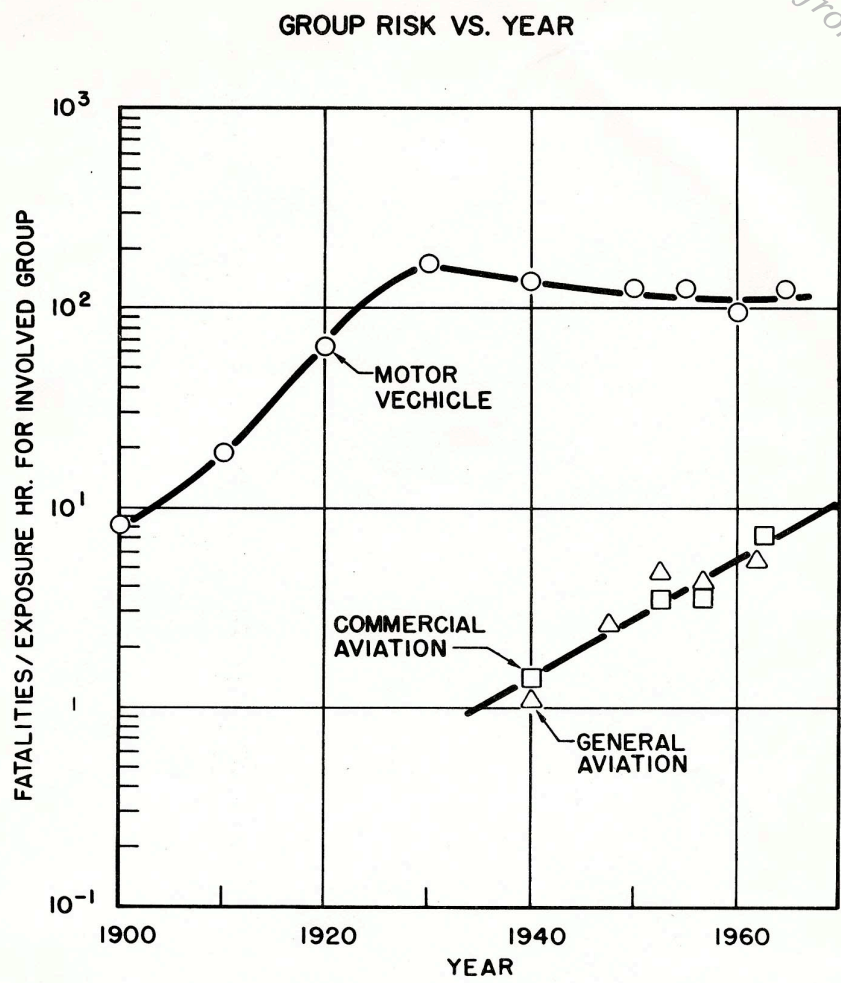


FIGURE 5





**FIGURE 6**

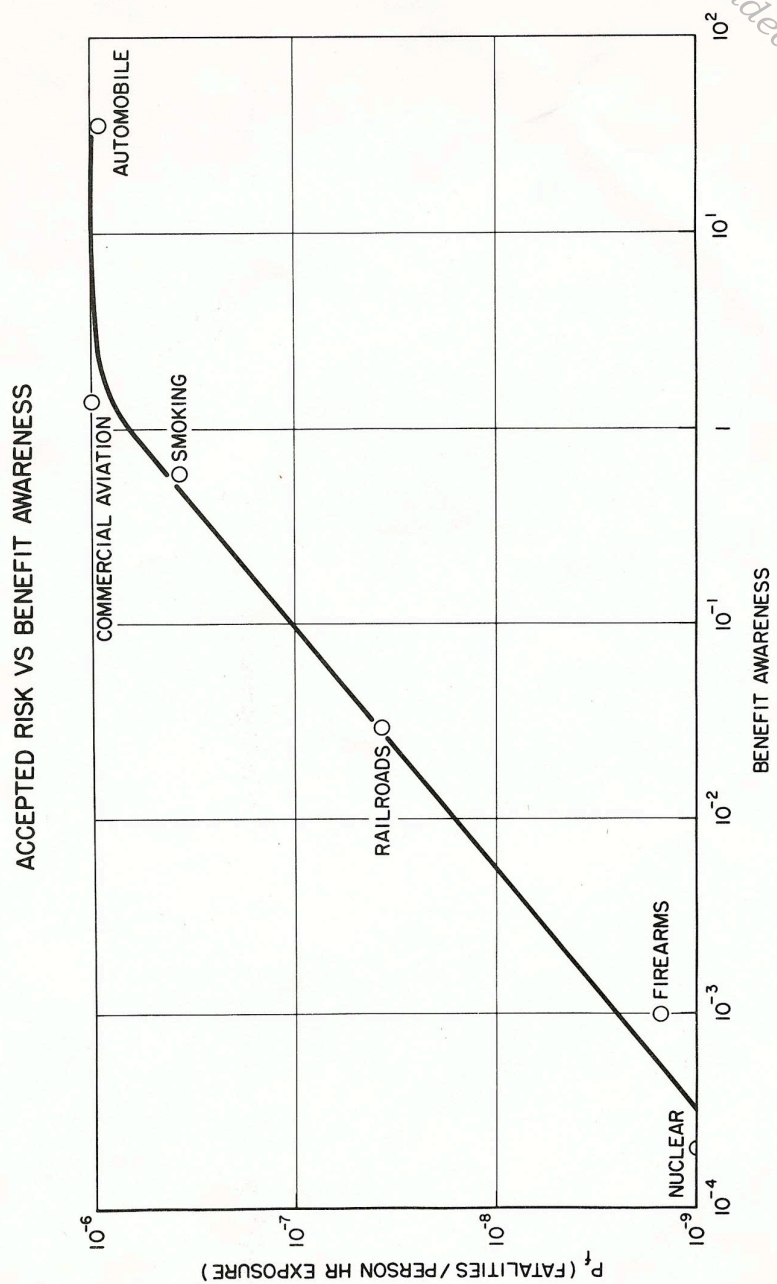


FIGURE 7



the percent of population involved in the activity, and the relative utility (or importance) of the activity to the individual. Perhaps these assumptions are too crude, but Fig. 7 does support the reasonable position that advertising the virtues of an activity increases the public acceptance of a greater level of risk. This, of course, could subtly produce a fictitious benefit-risk ratio as may be the case for smoking.

#### Atomic Power Safety Example

Recognizing the uncertainty inherent in the quantitative approach discussed in this presentation, the trends and magnitudes may nevertheless be of sufficient validity to warrant their use in determining national "design objectives" for technological activities. How then would this be done?

Let us consider as an example the introduction of nuclear power plants as a principal source of electric power. This is an especially good example because the technology has been primarily government nurtured, guided and regulated with industry undertaking the engineering development and diffusion into public use. The government specifically maintains responsibility for public safety. Further, the engineering of nuclear plants permits continuous reduction of accident probabilities with an associated substantial increase in cost. Thus the trade-off of utility and potential risk can be made quantitatively.

Another feature of the nuclear power plant is that the historical empirical approach to achieving an optimum benefit-risk tradeoff is not pragmatically feasible. All such plants are now so safe, that it may be 30 years or longer before meaningful risk experience will be accumulated. By that time, many plants of varied design will be in existence, and the empirical accident data may not be applicable to those being built. So a very real need exists now to establish "design objectives" on a predictive performance basis.

Let us first arbitrarily assume that nuclear power plants should be twice as safe as coal burning plants, so as not to increase public risk. Fig. 2 indicates that the total electric power risk is about  $2 \times 10^9$  fatalities per person per hour of exposure. Fossil fuel plants contribute about 1/5 of this, so we target nuclear plants at 1/10 of this risk. Assuming continuous operation, the nuclear plant would have to achieve a fatality level of not more than 2 deaths per million population per year ( $2 \times 10^{-9} \times 10^{-1} \times 10^6 \times 10^4 \text{ hrs/yr} = 2$ ). In a modern society a million people may require a million kilowatts of power, and this is about the size of most new power stations. So, we now have a target risk limit of 2 deaths per year per  $10^6$  kw power station.

Technical studies of the consequences of hypothetical extreme (and unlikely) nuclear power plant catastrophes, which would disperse radioactivity into populated areas, have indicated that about 10 lethal cancers per million population might result. On this basis, each such power plant might statistically have one such accident every 5 years and meet the risk limit set. However, such a catastrophe would completely destroy a major portion of the nuclear section of the plant, and either require complete dismantling or years of costly reconstruction. Because power companies expect plants to last about 30 years, the economic consequences of a catastrophe every 5 years would be completely unacceptable. In fact, the operating companies would not accept one such failure, on a statistical basis, during the normal plant lifetime.

It is likely that, in order to meet the economic performance requirements of the power companies, a catastrophe rate less than once in about 100 plant-years would be needed. This would be a public risk of 10 deaths per 100 plant-years, or one tenth death per year per million population. So the economic investment criteria of the nuclear plant user, the power company would probably set a risk level two hundred times less than the present socially accepted risk associated with electric power, or forty times safer than present coal burning plants

An obvious design question is whether a nuclear power plant can be engineered with a predicted performance of less than one catastrophic failure in 100 plant-years of operation. I believe the answer to that question is yes, but that is a subject for a different occasion. The principal point is that the issue of public safety can be focused on a tangible, quantitative, engineering design objective.

This example reveals a public safety consideration which may apply to many other activities. As in this case, the economic requirement for the protection of major capital investments may be a more demanding safety constraint than social acceptability.

### Conclusion

The application of this approach to other areas of public responsibility is self-evident. It does provide a useful methodology for answering the question "how safe is safe enough?" Further, although this study is only exploratory, it does reveal several interesting points.

First, the indications are that the public is willing to accept "voluntary" risks roughly 1000 times greater than "involuntary" exposures. Second, the statistical risk set by disease appears to be a psychological yardstick for establishing the level of acceptability of other risks. Third, the acceptability of risk appears to be crudely proportional to the cube of the benefits (real or imagined). Fourth, the social acceptance of risk is directly influenced by public awareness of the benefits of an activity, as determined by advertising, usefulness, and the number of people participating. Fifth, in the application of these criteria to atomic power plant safety, it developed that an engineering design objective determined by the economic criteria resulted in a design target risk level about 200 times less than the present socially accepted risk for electric power.

Perhaps of greatest interest is that this methodology for revealing existing social preferences and values may be a means of providing the social benefit vs. cost insight so necessary for judicious national decisions in new technological developments.