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# Social Benefit versus Technological Risk

## What is our society willing to pay for safety?

Chauncey Starr

The evaluation of technical approaches to solving societal problems customarily involves consideration of the relationship between potential technical performance and the required investment of societal resources. Although such performance-versus-cost relationships are clearly useful for choosing between alternative solutions, they do not by themselves determine how much technology a society can justifiably purchase. This latter determination requires, additionally, knowledge of the relationship between social benefit and justified social cost. The two relationships may then be used jointly to determine the optimum investment of societal resources in a technological approach to a social need.

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 such studies of *all* societal costs (indirect as well as direct) is less customary, and obviously makes the analysis more difficult and less definitive. Analyses of social value as a function of technical performance are not only uncommon but are rarely quantitative. Yet we know that implicit in every nonarbitrary national decision on the use of technology is a trade-off of societal benefits and societal costs.

In this article I offer an approach for establishing a quantitative measure of benefit relative to cost for an important element in our spectrum of social values—specifically, for accidental deaths arising from technological developments in public use. The analysis is based on two assumptions. The first is that historical national accident records are adequate for revealing consistent patterns of fatalities in the public use of technology. (That this may not always be so is evidenced by the paucity of data relating to the effects of environmental pollution.) The second assumption is that such historically revealed social preferences and costs are sufficiently enduring to permit their use for predictive purposes.

In the absence of economic or sociological theory which might give better results, this empirical approach provides some interesting insights into accepted social values relative to personal risk. Because this methodology is based on historical data, it does not serve to distinguish what is "best" for society from what is "traditionally acceptable."

### Maximum Benefit at Minimum Cost

The broad societal benefits of advances in technology exceed the associated costs sufficiently to make technological growth inexorable. Shef's socioeconomic study (*1*) has indicated that technological growth has been generally exponential in this century, doubling every 20 years in nations having advanced technology. Such technological growth has apparently stimulated a parallel growth in socioeconomic benefits and a slower associated growth in social costs.

The conventional socioeconomic benefits—health, education, income—are presumably indicative of an improvement in the "quality of life." The cost of this socioeconomic progress shows up in all the negative indicators of our society—urban and environmental problems, technological unemployment, poor physical and mental health, and so on. If we understood quantitatively the causal relationships between specific technological developments and societal values, both positive and negative, we might deliberately guide and regulate technological developments so as to achieve maximum social benefit at minimum social cost. Unfortunately, we have not as yet developed such a predictive system analysis. As a result, our society historically has arrived at acceptable balances of technological benefit and social cost empirically—by trial, error, and subsequent corrective steps.

In advanced societies today, this historical empirical approach creates an increasingly critical situation, for two basic reasons. The first is the well-known difficulty in changing a technical subsystem of our society once it has been woven into the economic, political, and cultural structures. For example, many of our environmental-pollution problems have known engineering

The author is dean of the School of Engineering and Applied Science, University of California, Los Angeles. This article is adapted from a paper presented at the Symposium on Human Ecology held at Airlie House, Warrenton, Virginia, in November 1968.

solutions, but the problems of economic readjustment, political jurisdiction, and social behavior loom very large. It will take many decades to put into effect the technical solutions we know today. To give a specific illustration, the pollution of our water resources could be completely avoided by means of engineering systems now available, but public interest in making the economic and political adjustments needed for applying these techniques is very limited. It has been facetiously suggested that, as a means of motivating the public, every community and industry should be required to place its water intake downstream from its outfall.

In order to minimize these difficulties, it would be desirable to try out new developments in the smallest social groups that would permit adequate assessment. This is a common practice in market-testing a new product or in field-testing a new drug. In both these cases, however, the experiment is completely under the control of a single company or agency, and the test information can be fed back to the controlling group in a time that is short relative to the anticipated commercial lifetime of the product. This makes it possible to achieve essentially optimum use of the product in an acceptably short time. Unfortunately, this is rarely the case with new technologies. Engineering developments involving new technology are likely to appear in many places simultaneously and to become deeply integrated into the systems of our society before their impact is evident or measurable.

This brings us to the second reason for the increasing severity of the problem of obtaining maximum benefits at minimum costs. It has often been stated that the time required from the conception of a technical idea to its first application in society has been drastically shortened by modern engineering organization and management. In fact, the history of technology does not support this conclusion. The bulk of the evidence indicates that the time from conception to first application (or demonstration) has been roughly unchanged by modern management, and depends chiefly on the complexity of the development.

However, what *has* been reduced substantially in the past century is the time from first use to widespread integration into our social system. The techniques for *societal diffusion* of a new technology and its subsequent exploitation are now highly developed. Our ability to organize resources of money, men, and materials to focus on new technological programs has reduced the diffusion-exploitation time by roughly an order of magnitude in the past century.

Thus, we now face a general situation in which widespread use of a new technological development may occur before its social impact can be properly assessed, and before any empirical adjustment of the benefit-versus-cost relation is obviously indicated.

It has been clear for some time that predictive technological assessments are a pressing societal need. However, even if such assessments become available, obtaining maximum social benefit at minimum cost also requires the establishment of a relative value system for the basic parameters in our objective of improved "quality of life." The empirical approach implicitly involved an intuitive societal balancing of such values. A predictive analytical approach will require an explicit scale of relative social values.

For example, if technological assessment of a new development predicts an increased per capita annual income of $x$ percent but also predicts an associated accident probability of $y$ fatalities annually per million population, 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 be reduced by applying constraints, there will usually be a functional relationship (or trade-off) between utility and risk, the $x$ and $y$ of our example.

There are many historical illustrations of such trade-off relationships that were 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 trade-off process is actually one of dynamic adjustment, with the behavior of many portions of our social systems out of phase, due to the many separate "time constants" involved. Readily available historical data on accidents and health, for a variety of public activities, provide an enticing stepping-stone to quantitative evaluation of this particular type of social cost. The social benefits arising from some of these activities can be roughly determined. On the assumption that in such historical situations a socially acceptable and essentially optimum trade-off of values has been achieved, we could say that any generalizations developed might then be used for predictive purposes. This approach could give a rough answer to the seemingly 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" for the safety of the public.

### 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," imposed by the society in which the individual lives. The process of empirical optimization of benefits and costs is fundamentally similar in the two cases—namely, a reversible exploration of available options—but the time required for empirical adjustments (the time constants 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 experiences. Although his eventual trade-off 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 a lower crime rate and better schools, at the cost of more time spent traveling on highways and a higher probability of accidents. If, subsequently, the traffic density increases, he may decide that the penalties are too great and move back to the city. Such an individual optimization process can be comparatively rapid (because the feedback of experience to the individual is rapid), so the statistical pattern for 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, a 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 con-

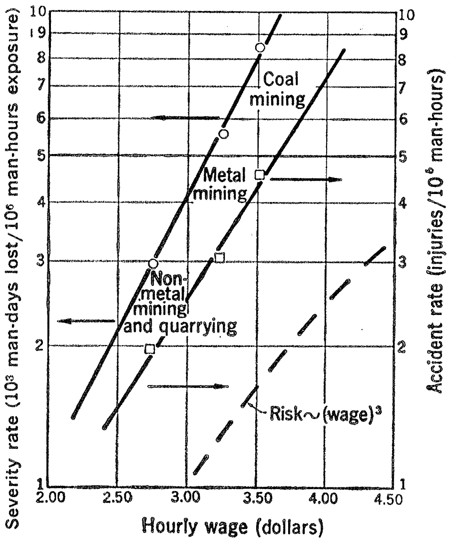



Fig. 1. Mining accident rates plotted relative to incentive.

trol group is likely to be fully aware of all the criteria and options involved in their decision process. Further, the time required for feedback of the experience that results from the controlling decisions is likely to be very long. The feedback of cumulative individual experiences into societal communication channels (usually political or economic) is a slow process, as is the process of altering the planning of the control group. We have many examples of such "involuntary" activities, war being perhaps the most extreme case of the operational separation of the decision-making group from those most affected. Thus, the real-time pattern of societal trade-offs on "involuntary" activities must be considered in terms of the particular dynamics of approach to an acceptable balance of social values and costs. The historical trends in such activities may therefore be more significant indicators of social acceptability than the existent trade-offs are.

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 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 authority and of imputed wisdom. The public generally assumes that the decision-making process is based on a rational analysis of social benefit and social risk. While it often is, we have all seen after-the-fact examples of irrationality. It is important to omit such "witch-doctor" situations in selecting examples of optimized "involuntary" activities, because in fact these situations typify only the initial stages of exploration of options.

## 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 are 100 to 1000 times as numerous as deaths), the difficulty in obtaining data and the unequal significance of varying disabilities would introduce inconvenient complexity for this study. So the risk measure used here is the statistical probability of fatalities per hour of exposure of the individual to the activity considered.

The hour-of-exposure unit was chosen because it was deemed more closely related to the individual's intuitive process in choosing an activity than a year of exposure would be, and gave substantially similar results. Another possible alternative, the risk per activity, involved a comparison of too many dissimilar units of measure; thus, in comparing the risk for various modes of transportation, 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 of transportation for a particular trip, the simplest common unit—that of risk per exposure hour—was chosen.

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, because 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 with the sum of the monetary cost to the passenger and the value of the time saved by that particular mode relative to a slower, competitive mode. Thus, airplanes were compared with automobiles, and automobiles were compared with public transportation or walking. Benefits of public transportation were equated with their cost. In all cases, the benefits were assessed on an annual dollar basis because this seemed to be most relevant to the individual's intuitive process. For example, most luxury sports require an

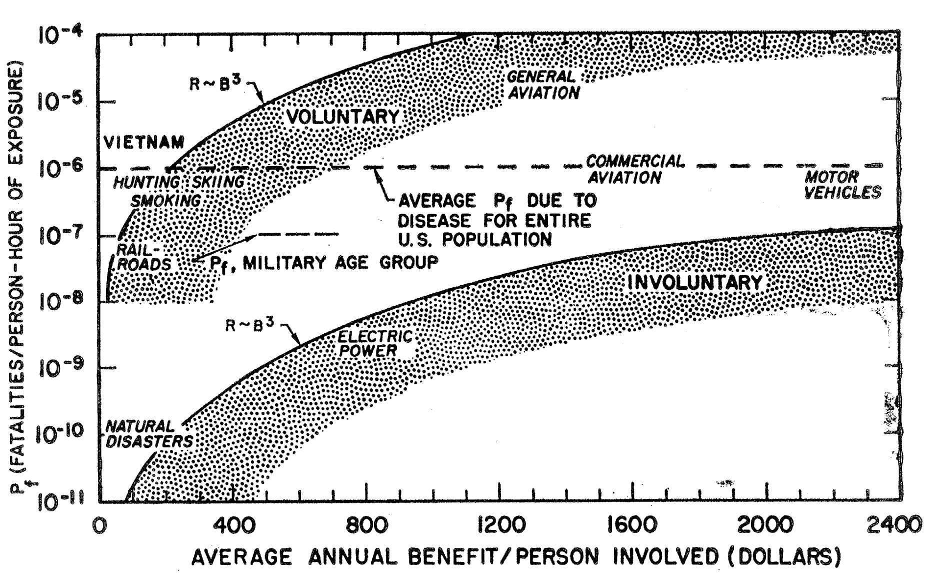



Fig. 2. Risk (*R*) plotted relative to benefit (*B*) for various kinds of voluntary and involuntary exposure.

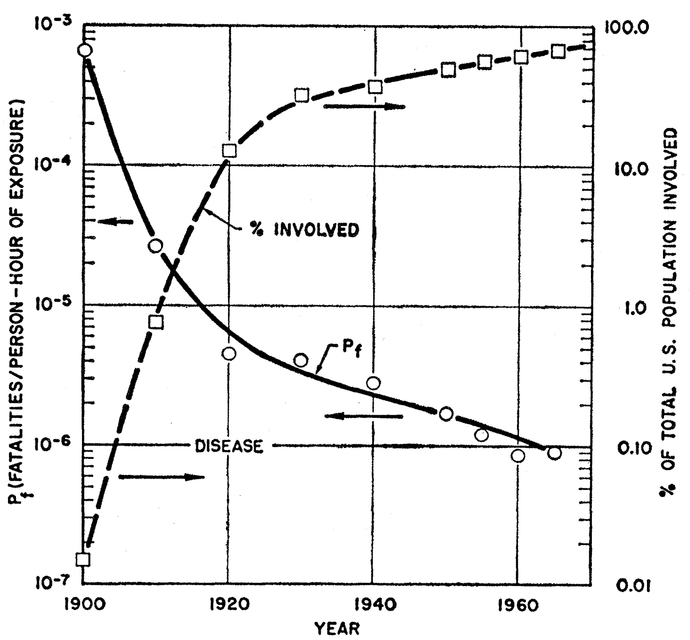
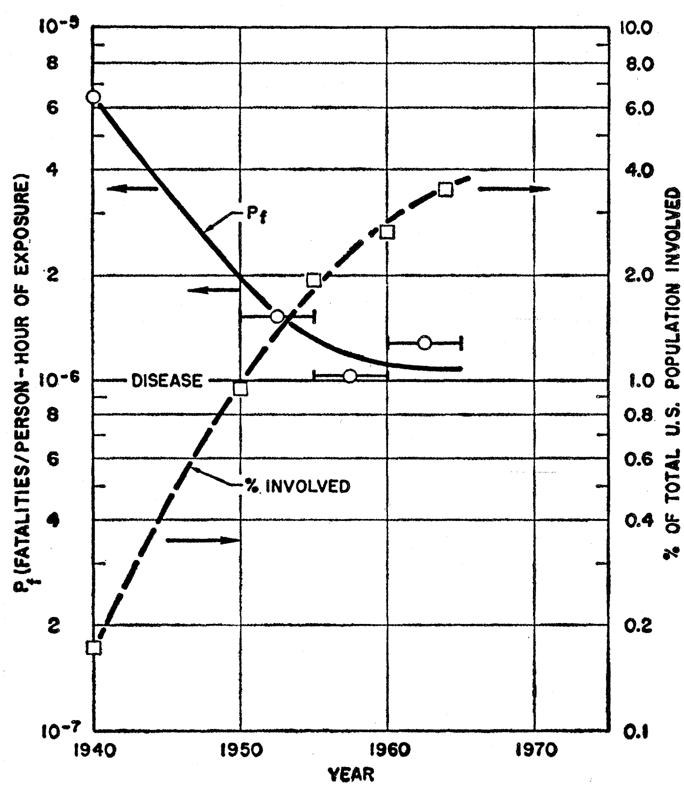



Fig. 3 (above). Risk and participation trends for motor vehicles.

Fig. 4 (right). Risk and participation trends for certified air carriers.




investment and upkeep only partially dependent upon usage. The associated risks, of course, exist only during the hours of exposure.

Probably the use of electricity provides the best example of the analysis of an "involuntary" activity. In this case the fatalities include 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; the energy fraction associated wtih electric power was used. The contributions of the home use of electric power to our "quality of life"—more subtle than the contributions of electricity in industry—are omitted. The availability of refrigeration has certainly improved our national health and the quality of dining. The electric light has certainly provided great flexibility in patterns of living, and television is a positive element. Perhaps, however, the gross-income measure used in the study is sufficient for present purposes.

Information on acceptance of "voluntary" risk 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. In Fig. 1, the accident rate and the severity rate of mining injuries are plotted against the hourly wage (*2, 3*). The acceptance of individual risk is an exponential function of the wage, and can be roughly approximated by a third-power relationship in this range. If this relationship has validity, it may mean that several "quality of life" parameters (perhaps health, living essentials, and recreation) are each partly influenced by any increase in available personal resources, and that thus the increased acceptance of risk is exponentially motivated. The extent to which this relationship is "voluntary" for the miners is not obvious, but the subject is interesting nevertheless.

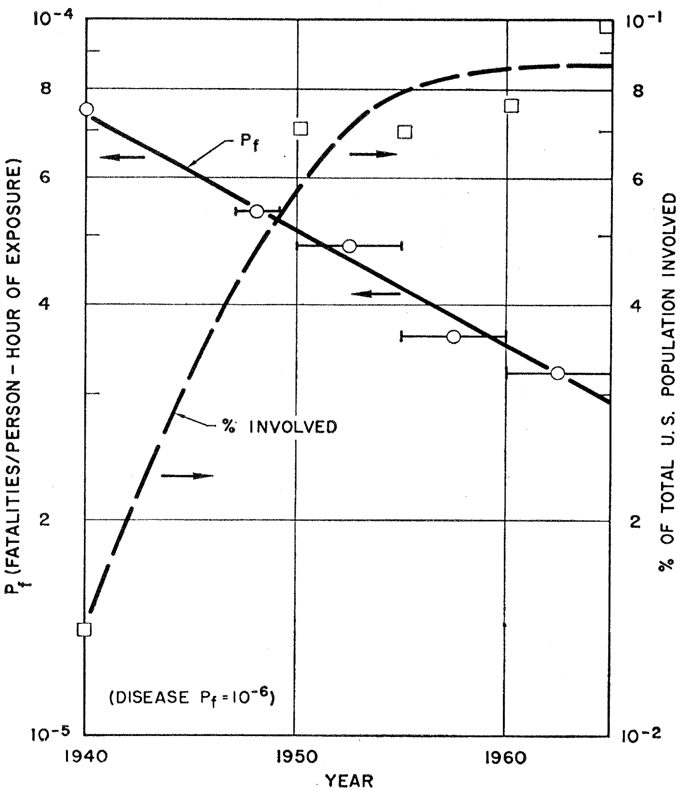
## Risk Comparisons

The results for the societal activities studied, both "voluntary" and "involuntary," are assembled in Fig. 2. (For details of the risk-benefit analysis, see the appendix.) Also shown in Fig. 2 is the third-power relationship between risk and benefit characteristic of Fig. 1. For comparison, the average risk of death from accident and from disease is shown. Because the average number of fatalities from accidents is only about one-tenth the number from disease, their inclusion is not significant.

Several major features of the benefit-risk relations are apparent, the most obvious being the difference by several orders of magnitude in society's willingness to accept "voluntary" and "involuntary" risk. As one would expect, we are loathe to let others do unto us what we happily do to ourselves.

The rate of death from disease appears to play, psychologically, a yardstick role in determining the acceptability of risk on a voluntary basis. The risk of death in most sporting activities is surprisingly close to the risk of death from disease—almost as though, in sports, the individual's subconscious computer adjusted his courage and made him take risks associated with a fatality level equaling but not exceeding the statistical mortality due to involuntary exposure to disease. Perhaps this defines the demarcation between boldness and foolhardiness.

In Fig. 2 the statistic for the Vietnam war is shown because it raises an interesting point. It is only slightly above the average for risk of death from disease. Assuming that some long-range societal benefit was anticipated from this war, we find that the related risk, as seen by society as a whole, is not substantially different from the average nonmilitary risk from disease. However, for individuals in the military-service age group (age 20 to 30), the risk of death in Vietnam is about ten times the normal mortality rate (death from accidents or disease). Hence the population as a whole and those directly exposed see this matter from different perspectives. The disease risk pertinent to the average age of the involved group probably would provide the basis



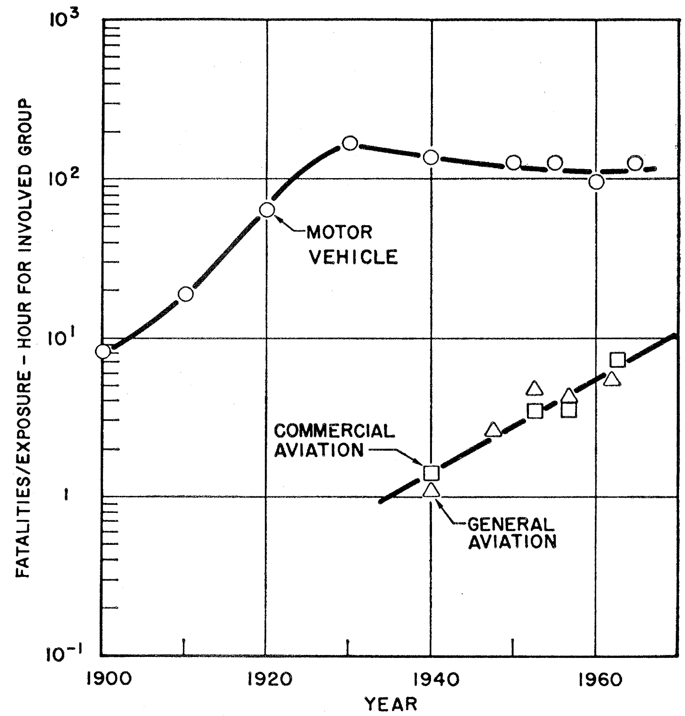




Fig. 5 (left). Risk and participation trends for general aviation. Fig. 6 (above). Group risk plotted relative to year.

for a more meaningful comparison than the risk pertinent to the national average age does. Use of the figure for the single group would complicate these simple comparisons, but that figure might be more significant as a yardstick.

The risks associated with general aviation, commercial aviation, and travel by motor vehicle deserve special comment. The latter originated as a "voluntary" sport, but in the past half-century the motor vehicle has become an essential utility. General aviation is still a highly voluntary activity. Commercial aviation is partly voluntary and partly essential and, additionally, is subject to government administration as a transportation utility.

Travel by motor vehicle has now reached a benefit-risk balance, as shown in Fig. 3. It is interesting to note that the present risk level is only slightly below the basic level of risk from disease. 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 (*4*).

Commercial aviation has barely approached a risk level comparable to that set by disease. The trend is similar to that for motor vehicles, as shown in Fig. 4. However, the percentage of the population participating is now only 1/20 that for motor vehicles. Increased public participation in commercial aviation will undoubtedly increase 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 the point of optimum benefit-risk trade-off (*5*).

For general aviation the trends are similar, as shown in Fig. 5. Here the risk levels are so high (20 times the risk from disease) that this activity must properly be considered to be in the category of adventuresome sport. However, the rate of risk is decreasing so rapidly that eventually the risk for general aviation may be little higher than that for commercial aviation. Since the percentage of the population involved is very small, it appears that the present average risk levels are acceptable to only a limited group (*6*).

The similarity of the trends in Figs. 3–5 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 the percentage of the population involved in each of the activities of Figs. 3–5 is plotted in Fig. 6. This graph represents the historical trend of total fatalities per hour of exposure of the population involved (*7*). The leveling off of

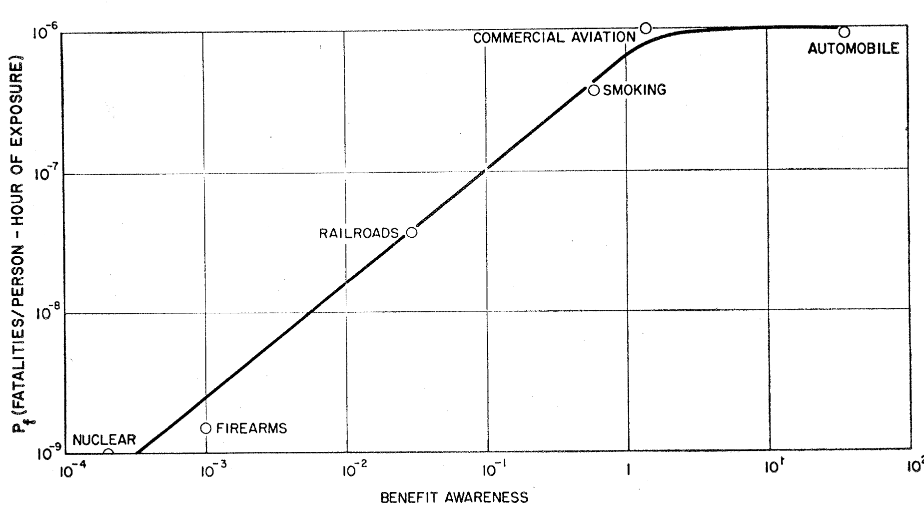



Fig. 7. Accepted risk plotted relative to benefit awareness (see text).

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, to note that the trend of fatalities in aviation, both commercial and general, is uniformly upward.

### Public Awareness

Finally, I attempted to relate these risk data to a crude measure of public awareness of the associated social benefits (see Fig. 7). The "benefit awareness" was arbitrarily defined as the product of the relative level of advertising, the square of the percentage of population involved in the activity, and the relative usefulness (or importance) of the activity to the individual (*8*). Perhaps these assumptions are too crude, but Fig. 7 does support the reasonable position that advertising the benefits of an activity increases 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 Plant Safety

I recognize the uncertainty inherent in the quantitative approach discussed here, but the trends and magnitudes may nevertheless be of sufficient validity to warrant their use in determining national "design objectives" for technological activities. How 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 nurtured, guided, and regulated by the government, with industry undertaking the engineering development and the diffusion into public use. The government specifically maintains responsibility for public safety. Further, the engineering of nuclear plants permits continuous reduction of the probability of accidents, at a substantial increase in cost. Thus, the trade-off of utility and potential risk can be made quantitative.

Moreover, in the case of the nuclear power plant the historical empirical approach to achieving an optimum benefit-risk trade-off 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 as safe as coal-burning plants, so as not to increase public risk. Figure 2 indicates that the total risk to society from electric power is about $2 \times 10^{-9}$ fatality per person per hour of exposure. Fossil fuel plants contribute about ⅕ of this risk, or about 4 deaths per million population per year. 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 4 deaths per year per million-kilowatt power station (*9*).

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 (*10*). On this basis, we calculate that such a power plant might statistically have one such accident every 3 years and still 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 few years would be completely unacceptable. In fact, the operating companies would not accept one such failure, on a statistical basis, during the normal lifetime of the plant.

It is likely that, in order to meet the economic performance requirements of the power companies, a catastrophe rate of less than 1 in about 100 plant-years would be needed. This would be a public risk of 10 deaths per 100 plant-years, or 0.1 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 1/200 the present socially accepted risk associated with electric power, or 1/40 the present risk associated with coal-burning plants.

An obvious design question is this: Can a nuclear power plant be engineered with a predicted performance of less than 1 catastrophic failure in 100 plant-years of operation? I believe the answer 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: The economic requirement for the protection of major capital investments may often 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 provides a useful methodology for answering the question "How safe is safe enough?" Further, although this study is only exploratory, it reveals several interesting points. (i) The indications are that the public is willing to accept "voluntary" risks roughly 1000 times greater than "involuntary" risks. (ii) The statistical risk of death from disease appears to be a psychological yardstick for establishing the level of acceptability of other risks. (iii) The acceptability of risk appears to be crudely proportional to the third power of the benefits (real or imagined). (iv) 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. (v) In a sample application of these criteria to atomic power plant safety, it appears that an engineering design objective determined by economic criteria would result in a design-target risk level very much lower than the present socially accepted risk for electric power plants.

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

### Appendix: Details of Risk-Benefit Analysis

*Motor-vehicle travel.* The calculation of motor-vehicle fatalities per exposure hour per year is based on the number of registered cars, an assumed 1½ persons per car, and an assumed 400 hours per year of average car use [data from *3* and *11*]. The figure for annual benefit for motor-vehicle travel is based on the sum of costs for gasoline, maintenance, insurance, and car payments and on the value of the time savings per person. It is assumed that use of an automobile allows a person to save 1 hour per working day and that a person's time is worth $5 per hour.

*Travel by air route carrier.* The estimate of passenger fatalities per passenger-hour of exposure for certified air route carriers is based on the annual number of passenger fatalities listed in the *FAA Statistical Handbook of Aviation* (see *12*) and the number of passenger-hours per year. The latter number is estimated from the average number of seats per plane, the seat load factor, the number of revenue miles flown per year, and the average plane speed (data from *3*). The benefit for travel by certified air route carrier is based on the average annual air fare per passenger-mile and on the value of the time saved as a result of air travel. The cost per passenger is estimated from the average rate per passenger-mile (data from *3*), the revenue miles flown per year (data from *12*), the annual number of passenger boardings for 1967 ($132 \times 10^6$, according to the United Air Lines News Bureau), and the assumption of 12 boardings per passenger.

*General aviation.* The number of fatalities per passenger-hour for general aviation is a function of the number of annual fatalities, the number of plane hours flown per year, and the average number of passengers per plane (estimated from the ratio of fatalities to fatal crashes) (data from *12*). It is assumed that in 1967 the cash outlay for initial expenditures and maintenance costs for general aviation was $\$1.5 \times 10^9$. The benefit is expressed in terms of annual cash outlay per person, and the estimate is based on the number of passenger-hours per year and the assumption that the average person flies 20 hours, or 4000 miles, annually. The value of the time saved is based on the assumption that a person's time is worth $10 per hour and that he saves 60 hours per year through traveling the 4000 miles by air instead of by automobile at 50 miles per hour.

*Railroad travel.* The estimate of railroad passenger fatalities per exposure hour per year is based on annual passenger fatalities and passenger-miles and an assumed average train speed of 50 miles per hour (data from *11*). The passenger benefit for railroads is based on figures for revenue and passenger-miles for commuters and noncommuters given in *The Yearbook of Railroad Facts* (Association of American Railroads, 1968). It is assumed that the average commuter travels 20 miles per workday by rail and that the average noncommuter travels 1000 miles per year by rail.

*Skiing.* The estimate for skiing fatalities per exposure hour is based on information obtained from the National Ski Patrol for the 1967–68 southern California ski season: 1 fatality, 17 days of skiing, 16,500 skiers per day, and 5 hours of skiing per skier per day. The estimate of benefit for skiing is based on the average number of days of skiing per year per person and the average cost of a typical ski trip [data from "The Skier Market in Northeast North America," *U.S. Dep. Commerce Publ.* (1965)]. In addition, it is assumed that a skier spends an average of $25 per year on equipment.

*Hunting.* The estimate of the risk in hunting is based on an assumed value of 10 hours' exposure per hunting day, the annual number of hunting fatalities, the number of hunters, and the average number of hunting days per year [data from *11* and from "National Survey of Fishing and Hunting," *U.S. Fish Wildlife Serv. Publ.* (1965)]. The average annual expenditure per hunter was $82.54 in 1965 (data from *3*).

*Smoking.* The estimate of the risk from smoking is based on the ratio for the mortality of smokers relative to nonsmokers, the rates of fatalities from heart disease and cancer for the general population, and the assumption that the risk is continuous [data from the *Summary of the Report of the Surgeon General's Advisory Committee on Smoking and Health* (Government Printing Office, Washington, D.C., 1964)]. The annual intangible benefit to the cigarette smoker is calculated from the American Cancer Society's estimate that 30 percent of the population smokes cigarettes, from the number of cigarettes smoked per year (see *3*), and from the assumed retail cost of $0.015 per cigarette.

*Vietnam.* The estimate of the risk associated with the Vietnam war is based on the assumption that 500,000 men are exposed there annually to the risk of death and that the fatality rate is 10,000 men per year. The benefit for Vietnam is calculated on the assumption that the entire U.S. population benefits intangibly from the annual Vietnam expenditure of $\$30 \times 10^9$.

*Electric power.* The estimate of the risk associated with the use of electric power is based on the number of deaths from electric current; the number of deaths from fires caused by electricity; the number of deaths that occur in coal mining, weighted by the percentage of total coal production used to produce electricity; and the number of deaths attributable to air pollution from fossil fuel stations [data from *3* and *11* and from *Nuclear Safety* **5**, 325 (1964)]. It is assumed that the entire U.S. population is exposed for 8760 hours per year to the risk associated with electric power. The estimate for the benefit is based on the assumption that there is a direct correlation between per capita gross national product and commercial energy consumption for the nations of the world [data from Briggs, *Technology and Economic Development* (Knopf, New York, 1963)]. It is further assumed that 35 percent of the energy consumed in the U.S. is used to produce electricity.

*Natural disasters.* The risk associated with natural disasters was computed for U.S. floods ($2.5 \times 10^{-10}$ fatality per person-hour of exposure), tornadoes in the Midwest ($2.46 \times 10^{-10}$ fatality), major U.S. storms ($0.8 \times 10^{-10}$ fatality), and California earthquakes ($1.9 \times 10^{-10}$ fatality) (data from *11*). The value for flood risk is based on the assumption that everyone in the U.S. is exposed to the danger 24 hours per day. No benefit figure was assigned in the case of natural disasters.

*Disease and accidents.* The average risk in the U.S. due to disease and accidents is computed from data given in *Vital Statistics of the U.S.* (Government Printing Office, Washington, D.C., 1967).

### References and Notes


1. A. L. Shef, "Socio-economic attributes of our technological society," paper presented before the IEEE (Institute of Electrical and Electronics Engineers) Wescon Conference, Los Angeles, August 1968.
2. *Minerals Yearbook* (Government Printing Office, Washington, D.C., 1966).
3. *U.S. Statistical Abstract* (Government Printing Office, Washington, D.C., 1967).
4. The procedure outlined in the appendix was used in calculating the risk associated with motor-vehicle travel. In order to calculate exposure hours for various years, it was assumed that the average annual driving time per car increased linearly from 50 hours in 1900 to 400 hours in 1960 and thereafter. The percentage of people involved is based on the U.S. population, the number of registered cars, and the assumed value of 1.5 people per car.
5. The procedure outlined in the appendix was used in calculating the risk associated with, and the number of people who fly in, certified air route carriers for 1967. For a given year, the number of people who fly is estimated from the total number of passenger boardings and the assumption that the average passenger makes six round trips per year (data from *3*).
6. The method of calculating risk for general aviation is outlined in the appendix. For a given year, the percentage of people involved is defined by the number of active aircraft (see *3*); the number of people per plane, as defined by the ratio of fatalities to fatal crashes; and the population of the U.S.
7. Group risk per exposure hour for the involved group is defined as the number of fatalities per person-hour of exposure multiplied by the number of people who participate in the activity. The group population and the risk for motor vehicles, certified air route carriers, and general aviation can be obtained from Figs. 3–5.
8. In calculating "benefit awareness" it is assumed that the public's awareness of an activity is a function of *A*, the amount of money spent on advertising; *P*, the number of people who take part in the activity; and *U*, the utility value of the activity to the person involved. *A* is based on the amount of money spent by a particular industry in advertising its product, normalized with respect to the food and food products industry, which is the leading advertiser in the U.S.
9. In comparing nuclear and fossil fuel power stations, the risks associated with the plant effluents and mining of the fuel should be included in each case. The fatalities associated with coal mining are about ¼ the total attributable to fossil fuel plants. As the tonnage of uranium ore required for an equivalent nuclear plant is less than the coal tonnage by more than an order of magnitude, the nuclear plant problem primarily involves hazard from effluent.
10. This number is my estimate for maximum fatalities from an extreme catastrophe resulting from malfunction of a typical power reactor. For a methodology for making this calculation, see F. R. Farmer, "Siting criteria—a new approach," paper presented at the International Atomic Energy Agency Symposium in Vienna, April 1967. Application of Farmer's method to a fast breeder power plant in a modern building gives a prediction of fatalities less than this assumed limit by one or two orders of magnitude.
11. "Accident Facts," *Nat. Safety Counc. Publ.* (1967).
12. *FAA Statistical Handbook of Aviation* (Government Printing Office, Washington, D.C., 1965).