METHODS FOR THE EVALUATION OF ALTERNATIVE DISASTER WARNING SYSTEMS

EXECUTIVE SUMMARY

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A. Overview

Unlike many government programs, a disaster warning system requires the participation of two distinct decision-making parties: first, the government must decide on the type of transmission-reception system to employ; second, the individual must decide whether to purchase a receiver and, given a warning, whether to take action. This two-party nature of disaster warning decisions suggests that traditional "single-decision-maker" approaches to the evaluation of alternative systems may not be fruitful. For example, different warning systems may provide services that individual citizens desire to a greater or lesser degree. A complete analysis must take account of these differences in valuations on the part of individual citizens as well as differences in value from the perspective of the government decision-maker.

This report summarizes the results of a study of methods for estimating the economic costs and benefits of the transmission-reception and reception-action segments of a disaster warning system (DWS). Specifically, the objectives of this study were to:

- identify methods for the evaluation of the transmission and reception portions of alternative disaster warning systems;
- perform example analyses using the methods identified.

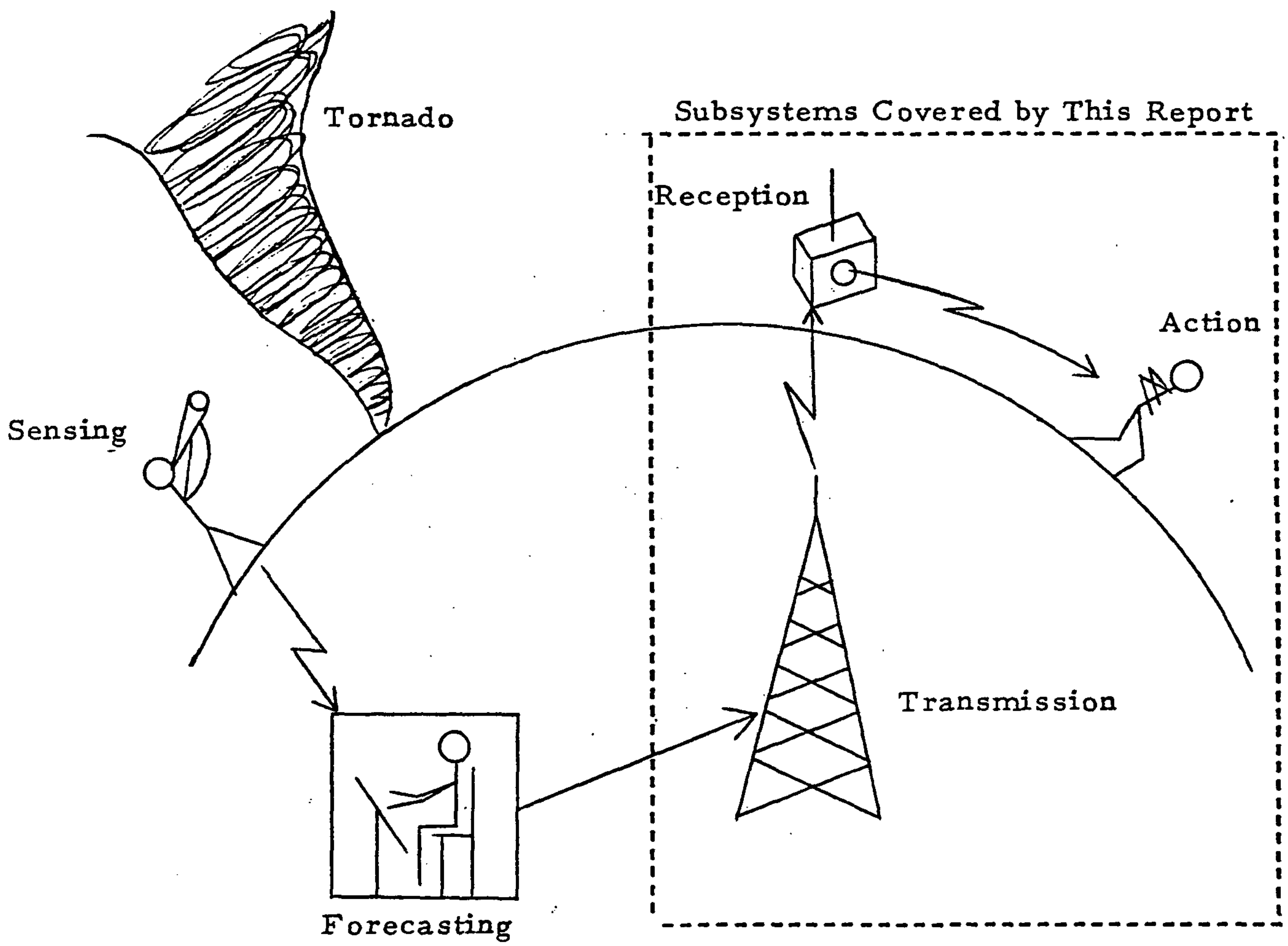
The extent of this task and the study findings become clearer if the individual components of a disaster warning system rather than the overall system are considered. A DWS can be thought of as being made up of the following, functionally distinct, components:

- <u>Sensing</u> - detection of a potential disaster before it occurs
- <u>Forecasting</u> - the use of sensor data to predict the occurrence of a disaster
- <u>Transmission</u> - sending the forecast to the public
- <u>Reception</u> - receipt of the forecast by individuals
- <u>Action</u> - doing something to mitigate the losses that result from disasters.

Figure 1 depicts the relationship among these five components, and the dotted line encloses those functions that were considered in this study. While additional functions could be added (most notably post-disaster efforts), these five functions usefully delineate the bounds of a disaster warning system without cutting across the jurisdictional responsibilities of several agencies. In the study, the sensing and the forecasting components of the system were not considered. There were two related reasons for this. First, the design of transmission and reception components does not depend significantly on the design of the sensing and forecasting components. Second, since the sensing and forecasting components serve other purposes (namely, routine weather forecasting) they are generally taken as given.

Figure 1

The Five Components of a Forecasting-Warning System



reality would not serve as a useful guide for an actual application of the method in the real world. Just as clearly, however, an example that incorporates all the complexities associated with the evaluation of disaster warning system components would not provide a clear illustration.

B. History of Disaster Warning

The first step of the study was a review of existing disaster warning technologies. This review was done by examining (1) designs for systems that had been implemented, or considered for implementation, and (2) previous evaluations of these systems.

Current technologies reviewed included the Emergency Broadcast System (EBS), National Warning System (NAWAS), NOAA Weather Wire (NWWS), and NOAA Weather Radio (NWRS). Two other systems that were reviewed were the Disaster Warning Satellite System (DWSS) and Defense Information Distribution System (DIDS). For each alternative, the system concept was described, system operation discussed, and values for several descriptive characteristics (e.g., coverage, cost, etc.) provided. These descriptive characteristics provided both a relative comparison of the systems and a framework within which costs of the systems could be calculated.

As a part of the study, previous analyses of disaster warning systems were also reviewed to identify methods used by others in the evaluation of disaster warning systems. Three applications of cost-effectiveness analysis and one application of benefit-cost analysis were examined. Two of the cost-effectiveness analyses, the Office of Telecommunications Policy report of 1971 and the General Accounting Office report of 1976 illustrated the dependence of the conclusions of the analysis on the assumed requirements. A Computer Science Corporation report provided an excellent example of the sensitivity of the relative cost of systems to requirement definitions.

A study prepared for the Department of Commerce was the only one of the four analyses reviewed that attempted to measure benefits. The method used was to estimate the property savings and lives saved associated with alternative systems. Although this measure generally underestimates true benefits (see below) this study represents a valuable first step in the proper evaluation of alternative disaster warning systems.

C. Methods for Disaster Warning System Evaluation

Given the diverse and diffuse nature of the benefits generated by a DWS, how can we compare government costs, private costs, and the benefits that accrue as a result of a DWS being implemented? Before the individual methods are described, we will discuss the methodological framework that was used throughout the study. Naturally, no methodological tool can make the determination of what system the government "should" invest in. However, economic evaluations, by providing information to the decision maker about relative costs and benefits of alternative systems, can aid in the decision-making process.

In particular, the general methodology of benefit-cost analysis can be extremely useful in providing information to the decision maker. Its usefulness arises in three ways: first, it provides a convenient framework for analyzing the economic benefits and costs of a project; second, it provides theoretically-based methods and measures for estimating the magnitudes of these benefits and costs; finally, it is combined generally with a criterion for comparing the benefits and costs that, while not free of value judgments, provides useful information to the decision maker.

Conceptually, at least, it is an easy matter to estimate the costs of system alternatives. Of course, it is important to ensure that the true opportunity costs of resources are used in the calculation. For example, the opportunity costs of facilities used must be included -- even if no new facilities are required -- as long as facilities used have an alternative public or private use.

It is somewhat more difficult, both in concept and practice, to estimate the benefits of alternative transmission-reception-action segments of a DWS. This portion of the system derives its value from the information that it provides to decision-makers, in this case, households, businesses, governments, institutions, etc. that are the target audience for natural disaster warnings. How to go about placing a value on this information -- and the system which conveys it -- is a difficult problem.

The fact that the disaster warning system can be divided into transmission and reception segments suggests that some of these problems can be simplified by using different methods for each segment. We have, therefore, identified three methods for the evaluation of alternative disaster warning systems, each suitable for a specific segment. For the transmission-reception link, equal capability cost analysis provides a suitable method. For the reception-action link, and the benefits to be derived by the individual from a disaster warning system, consumers' surplus is an appropriate measure and can be derived directly from the demand curve, if it is known, or can be calculated from a demand curve derived through the use of decision theory. Each of these methods is described below.

1. Equal Capability Cost Analysis

In the previous discussion, the importance of benefits estimation in a benefit-cost analysis has been emphasized. There may be times, however, when benefits estimates are not available or they are suspect. Also, as is sometimes the case for disaster warning systems, transmission systems with the same population coverage, reliability, etc., (and hence with roughly equal benefits) may have to be compared. In such a situation the best system is the one with the lowest cost.

The "equal capability cost comparison" approach can be used to evaluate the relative cost-effectiveness of two such systems without having to consider a multi-dimensional effectiveness measure. Thus, we avoid the need to trade off, say, population coverage with geographic coverage, etc.

Equal capability cost analysis consists of the following steps:

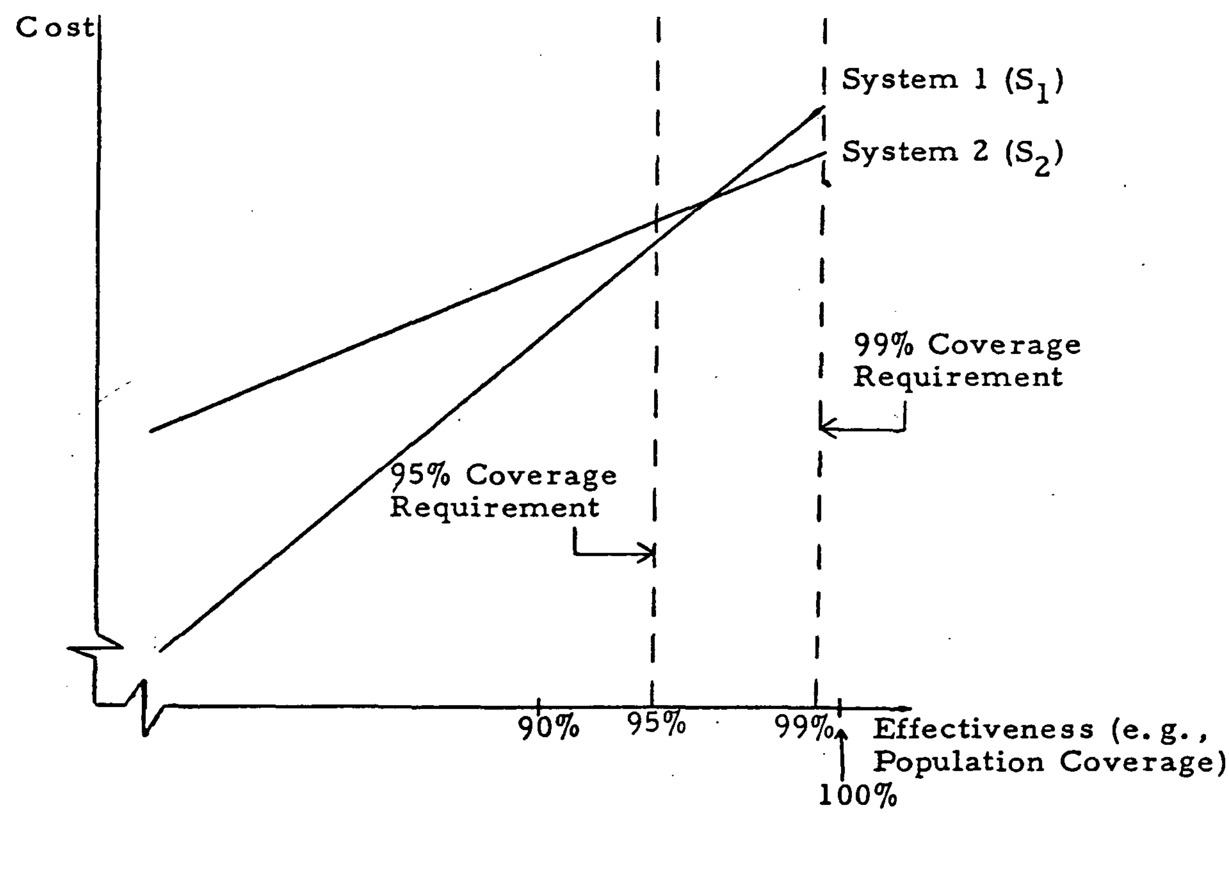
- specify the requirement(s) each DWS alternative is to meet

- design each alternative to meet each requirement in the least-cost manner
- calculate the costs associated with each alternative
- perform sensitivity analyses

Graphically, the equal capability cost comparison approach can be depicted as in Figure 2, which shows the relationship between

Figure 2

Graphical Depiction of Equal Capability Cost Analysis



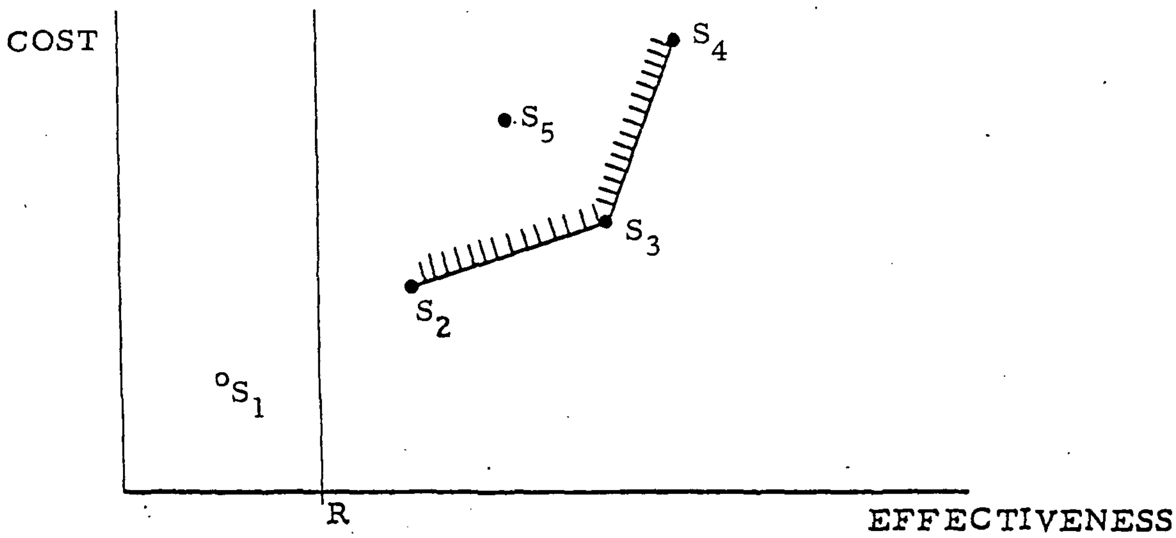
the costs of two systems and one measure of effectiveness (e.g., population coverage). As can be seen from Figure 2, at different levels of effectiveness, the relative costs of the two systems are different. This could be caused, perhaps, by different technologies such as broadcast versus landlines transmission. At any level of effectiveness the costs of the two systems can be compared. Because they offer the same level of effectiveness, and hence, the same level of benefits, the system with the lower costs at the given required effectiveness is the cost-effective system. Note, however, that in certain regions, altering the requirements by a relatively small amount (e.g., from 95 percent coverage to 99 percent coverage in Figure 2), the conclusions of the analysis change. This is the reason that a sensitivity analysis is an important part of the method.

Reliance on cost alone obviously simplifies the analysis. Of course, simplifications such as the avoidance of specific tradeoffs do not come without a price. Often in attempts to design two or more systems to "equal capability" the designs must be molded to meet the assumed (required) capability, which often results in a hybrid system design for which a minimum cost design is more difficult to identify.

One way to avoid these problems (i.e., sensitivity to stated requirements and the possible nonoptimality of design) is to employ cost-effectiveness analysis. This is depicted graphically in Figure 3. There, five systems are being evaluated with a minimum level of required effectiveness at R. Because S_1 has less than the required level, it can be ignored. Of the others, S_5 is dominated because another system, S_3, has more effectiveness at less cost. The remaining systems all lie on the minimum cost frontier for different levels of effectiveness. Thus, the decision-maker is faced with the two dimensional tradeoff of effectiveness and costs.

Figure 3

Graphical Depiction of Cost-Effectiveness Analysis



S_i = SYSTEM i.

2. Benefits Analysis

One way around the multi-dimensional tradeoff problem is to denominate effectiveness (or benefits) in the same terms as costs. In this way net benefits can be calculated.

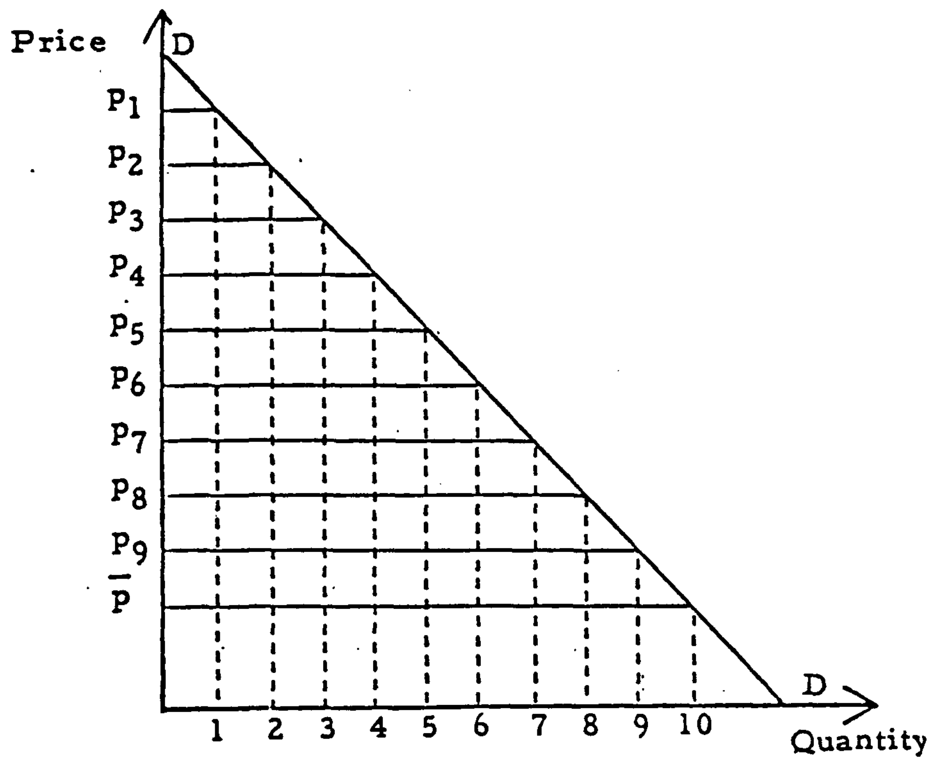
A generally accepted principle of benefit-cost analysis is that the value of anything is measured simply by what people are willing to pay for it. If, for example, a household buys a home receiver capable of receiving disaster warnings for $25, then we may infer that the value which the household attaches to the services provided by the receiver is <u>at least</u> $25.

Net willingess-to-pay (what people are willing to pay less what they actually pay) is thus a measure of economic benefits to project beneficiaries, over and above any user-charges that may be levied upon them. This measure is accepted generally in the economics profession as the appropriate way to value benefits. Benefit-cost analysis consists of comparing net willingness-to-pay with any costs not covered by user charges.

As a practical matter, it is necessary to work with approximate estimates of net willingness-to-pay. This is because it is almost always impossible to perform the kind of experiment or to observe the kind of situation that one needs to make an exact estimate. The approximation most frequently adopted is to measure <u>consumers' surplus.</u> The basic idea behind consumers' surplus is to use points along the demand curve as indications of maximum willingness-to-pay for successive units of product. This is illustrated in Figure 4, which presents the market demand curve for a product. In this diagram, $\overline{p}$ is the market price and 10 is the quantity purchased. By examining the market demand curve, DD, we find that consumers would be willing to pay p_1 for a total of one unit. To be induced to buy a second unit, the price would have to be lowered to p_2. This amount (p_2) is (approximately) the (gross) willingness-to-pay for the second unit, and so forth.

Figure 4

Illustration of the Determination of Consumers' Surplus



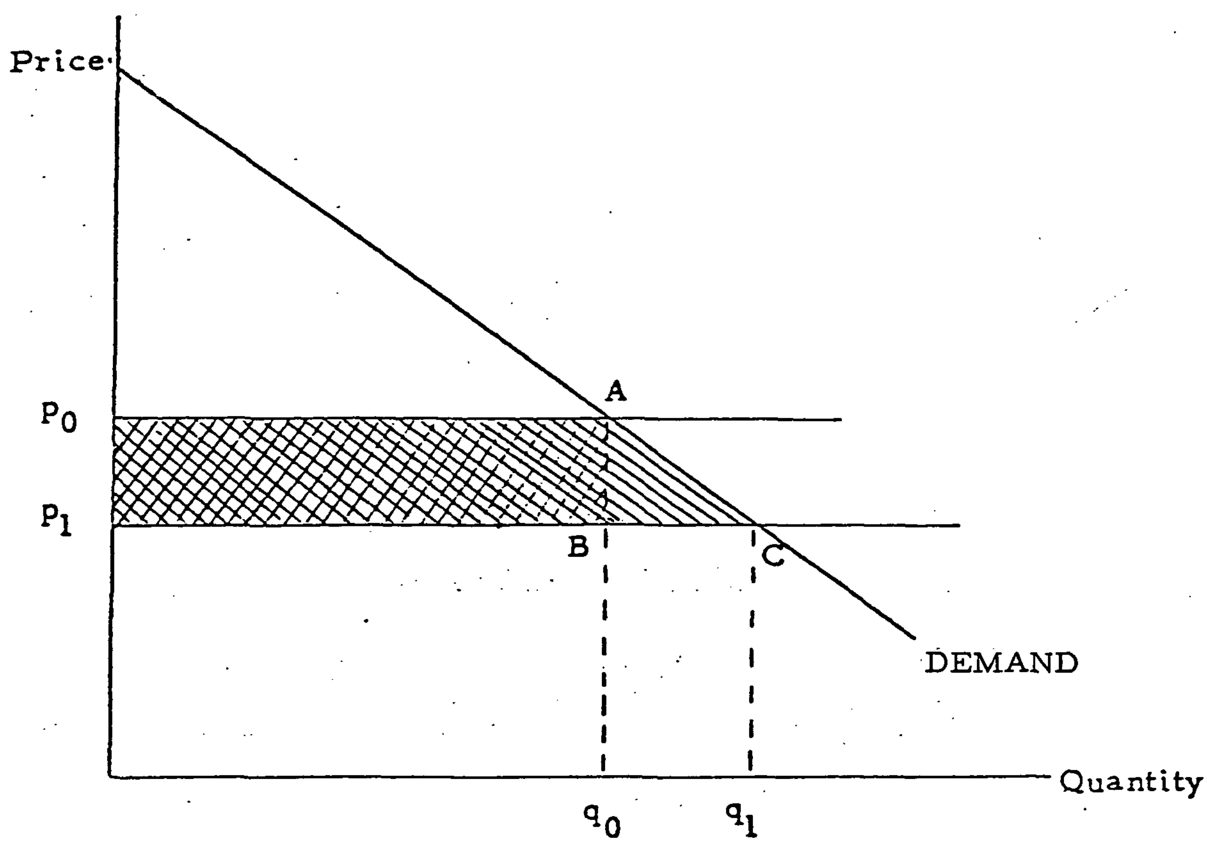
If N units are sold, the consumers' surplus approximation to net willingness-to-pay is to take the gross willingness-to-pay and subtract out the amount actually paid by consumers.

An intuitive appreciation for this measure can be gained by considering the benefits of a government project that lowers the cost of an existing product or service. This situation is pictured in

Figure 5. There, demand for the good is given by D and the price before the government program is p_0. At price p_0, q_0 units will be consumed. Let the government project result in a reduction in price to p_1. At this price, q_1 units will be sold. A measure of benefits that would often be used in this situation is "cost-savings." Each of the units sold would be sold for $(p_0 - p_1)$ dollars less. Total cost-savings would, therefore, be $q_0(p_0 - p_1)$ (the cross-hatched area in Figure 5).

Figure 5

Cost-Savings and Consumer Surplus



The increase in the consumers' surplus measure includes the same area but, in addition, takes into account the benefits accruing to those who purchase units of the good at the lower price but not at the higher price. These additional benefits are shown as the triangular-shaped region ABC in Figure 5. In the case of a price-reducing investment, consumers' surplus includes cost-savings in its measure of benefits.

Knowledge of the market demand curve, therefore, can be used to measure approximately the net willingness-to-pay on the part of individual's for the services of the home receiver. This figure can then be compared directly to the cost of any portions of the system not covered by user charges to determine the economic value of the particular disaster warning system.

Without the knowledge of a market demand curve, other methods must be used to derive a demand curve for the calculation of consumers' surplus. An obvious method is to conduct a market survey. Such surveys, however, are costly and time-consuming. Further, they must be redone every time the system is reconfigured. In the next section, we describe a method for deriving a market demand curve that avoids many of these problems.

3. Decision Theory

Without knowledge of the market demand curve, the following steps could be followed to derive such a demand curve. First, analyze the decision process an individual might go through in deciding whether or not to purchase a home receiver. Second, find the maximum price at which the individual would just buy the receiver. Third, incorporate underlying variations in the distribution of individuals' incomes and tastes to derive the distribution of maximum prices over the population. Finally, calculate the consumers' surplus from the demand curve derived from the previous steps.

The basic method for the first three steps is statistical decision theory. The essence of this theory is that decisions must be made even when there is uncertainty. However, an individual can often purchase information (often imperfect) about the occurrence of uncertain events by which to aid his decision.

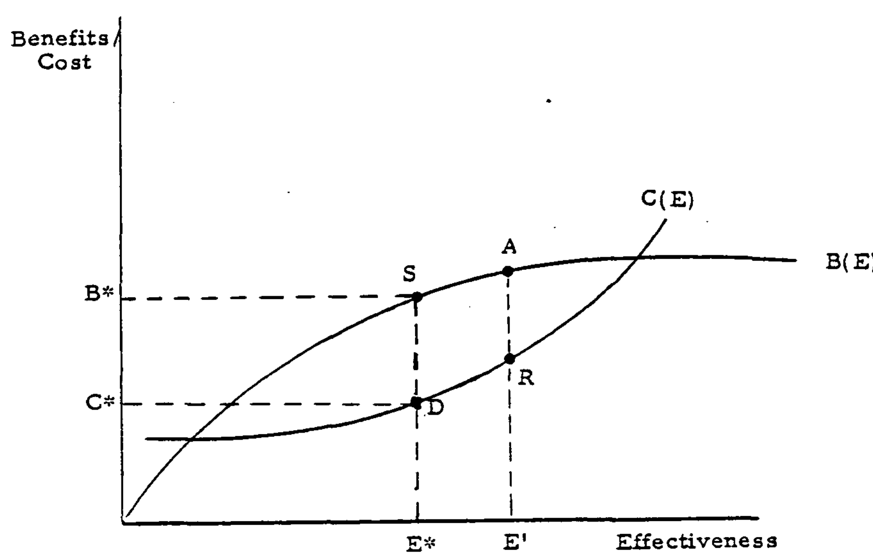
The uncertain events that were of concern in the study were, naturally, the effects of natural disasters, which differ in their intensity, duration and geographical extent. The decision maker, in this context, is the individual consumer. He decides, given information about the occurrence of a natural disaster, not only whether or not to buy a receiver, but what, if any, preventive action to take. Finally, the cost of information is the cost of the home receiver. Note that it is the information provision aspects of home receivers that make this method particularly suitable for this demand assessment. The individual is assumed to value the receiver only to the extent that it provides information and not for the receiver itself.

D. Summary

The individual methods described above each address either the cost or the benefits estimation problem. The natural culmination of a decision problem in the benefit-cost framework is the integration of these methods to provide a complete picture to the decision-maker. In Figure 6, the complete benefit-cost problem is illustrated. The methods we have identified can be used in developing the cost function (C(E)) and the benefits function (B(E)). Specifically, equal capability cost analysis provides an estimate of the minimum cost of providing a specified level of effectiveness, which is the definition of the cost function. Similarly, consumers' surplus represents the benefits of a specified level of effectiveness. The demand curve from which consumers' surplus is calculated may be estimated using decision theory if other information on consumer demand is lacking.

Figure 6

Solution of the Complete Benefit-Cost Problem



In this final step of benefit-cost analysis, then, we choose that level of effectiveness where increase in benefits associated with a small increase in effectiveness is just equal to the increase in cost (in Figure 6, that is at E*). That is the point where net benefits are maximized.

It is only natural that in a study that has as broad a subject as developing methods for analyzing disaster warning systems, certain facets should be emphasized while others treated more briefly. In the study, the emphasis was on the description and illustration of methods that aid the decision maker in analyzing the economic benefits associated with alternative systems.

The reason for this emphasis was not that costs are somehow less important in a benefit-cost analysis. Rather, it was that cost analyses are more closely associated with engineering designs and that methods of cost estimation are reasonably well understood. We do not ignore costs entirely, however. The equal capability cost analysis method illustrates how cost analysis alone can be used to perform an evaluation of alternative systems under certain conditions.

More specifically, the study provided the following findings:

- unlike many government investment alternatives, a disaster warning system often requires an investment on the part of the individual. Therefore, the cost of the transmission portion of the system alone is not a sufficient criterion on which to base a government investment decision;

- because the methods we propose incorporate the "private" decision and the individual's benefit-cost calculus, the economic benefits and costs of disaster warning systems can be analyzed with the methodological base we present;
- given the receiver demand curve, consumer surplus is one measure of the economic benefits to be derived from a disaster warning system that, while not value-free, does have intuitive appeal and is a generally accepted measure of benefits;
- statistical decision theory, because it provides a way of incorporating the inherent uncertainty associated with natural disasters is one method of assessing potential consumer demand that does not require an extensive and expensive market survey;
- by making explicit the benefits and costs associated with the individual's receiver acquisition decision, statistical decision theory can often be useful in generating additional features that may provide greater economic benefits;
- by removing much of the problem of unequal effectiveness inherently associated with different transmission systems, the equal capability cost analysis method of comparing alternative transmission systems can be usefully applied when the requirements for the system are clearly defined;

- all methods have certain characteristics that make them more or less appropriate in specific situations. Therefore, the strengths and weaknesses of each of the methods described in this report should be considered before implementation of specific methods is attempted.

Finally, the methods described and illustrated in the report provide the user with a set of proper, and practical, tools with which to evaluate alternative disaster warning systems. However, it is important to emphasize that, as with all analytic tools, the methods proposed are only an aid (albeit an important one) to the decision maker.