NBSIR 78-874

DISSEMINATING STANDARDS OF TIME AND FREQUENCY: ISSUES IN THE EVALUATION OF ALTERNATIVE SYSTEMS

Richard H.F. Jackson

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U.S. DEPARTMENT OF COMMERCE, Juanita M. Kreps, Secretary
Sidney Harman, Under Secretary
Jordan J. Baruch, Assistant Secretary for Science and Technology

NATIONAL BUREAU OF STANDARDS, Ernest Ambler, Director

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Disseminating Standards of Time and Frequency:
Issues in the Evaluation of Alternative Systems

Richard H. F. Jackson

Since 1923 the National Bureau of Standards (NBS) has broadcast standards of time and frequency over dedicated radio stations. Recently, the Bureau's Time and Frequency Division (TFD) has implemented programs of cost reduction at these radio stations. In addition, TFD undertook a study to identify and evaluate alternative modes of disseminating these standards in a search for methods to reduce costs further and to improve the quality of services offered. The primary purpose of this report is to document the economic issues involved in this study by discussing the problem in terms of both cost-benefit analysis and cost-effectiveness analysis. Preliminary cost studies for some of the dissemination alternatives are also included.

Key words: Cost-benefit; cost-effectiveness; dissemination; frequency standard; time standard.

Acknowledgment

The author gratefully acknowledges the many helpful comments of Howard E. Morgan on economic issues, and of Roger E. Beehler and D. Wayne Hanson on the technical aspects of alternative dissemination systems.

1. INTRODUCTION: THE PROBLEM

Since 1923 the National Bureau of Standards (NBS) has broadcast standards of time and frequency over dedicated radio stations. During that time, the radio stations have broadcast from various locations, and even their number has varied. At present, there are three radio stations operated by the NBS Time and Frequency Division (TFD) from two different locations in the United States. Stations WWV and WWVB have been located near Fort Collins, Colorado, since 1966. WWV currently broadcasts on frequencies 2.5, 5, 10, and 15 MHz, while WWVB operates on 60 KHz. Station WWVH has been located since 1971 on the island of Kauai, Hawaii, currently broadcasting on frequencies 2.5, 5, 10, and 15 MHz. For a pictorial display of the respective regions of coverage from Colorado and from Hawaii, see figure 1.1.

In recent years, TFD has formulated and implemented programs of cost reduction at the stations, employing labor-saving automation and discontinuing some broadcast frequencies.* As part of a continuing effort both to reduce costs further and to improve the quality and extent of these NBS services, TFD undertook a study to identify and evaluate selected alternative methods of disseminating standards of time and frequency.

This report is provided by the Applied Mathematics Division (AMD) of NBS. Its primary purpose is to further and focus discussion of the issues involved in evaluating dissemination alternatives. The aim is to raise questions and to identify potential pitfalls, not because it is possible at present to resolve all such issues, but because it is necessary to ensure that all critical factors have been identified. Consequently, no recommendations are made in this report regarding what should be "the" method of analysis; the only intent is to present alternatives.

At the same time that cost reduction programs were being implemented, studies were in progress to determine the feasibility (and accuracy) of broadcasting via satellite.** This permitted the TFD to identify a number of alternative modes of dissemination. The possible alternatives identified thus far all involve satellite broadcasting, but differ in approach ("piggyback" onto an already planned satellite system, or lease communications time from a commercial satellite communications firm) and/or in configuration (number and position of satellites). The alternative methods differ in cost, reliability, and perhaps even feasibility. The alternative configurations affect coverage as well as reliability, accuracy, and costs. All alternatives, including the no-action course of continuing with the radio stations, have various costs, benefits, and levels of effectiveness associated with them. Thus, there is need for some type of analytical study--be it cost-benefit, cost-effectiveness, or simple comparisons of predicted costs--to provide a systematic way to evaluate the numerous considerations involved with choices among alternatives.

The balance of this report is devoted to identifying analytic approaches useful in analyzing alternative means of dissemination. An additional aim is the identification of topics requiring satisfactory resolution before beginning an evaluation study.

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*Broadcasting on frequencies 20 and 25 MHz at Fort Collins and on 20 MHz at Kauai was discontinued as of February 1, 1977.

**See (10) for more on those experiments.

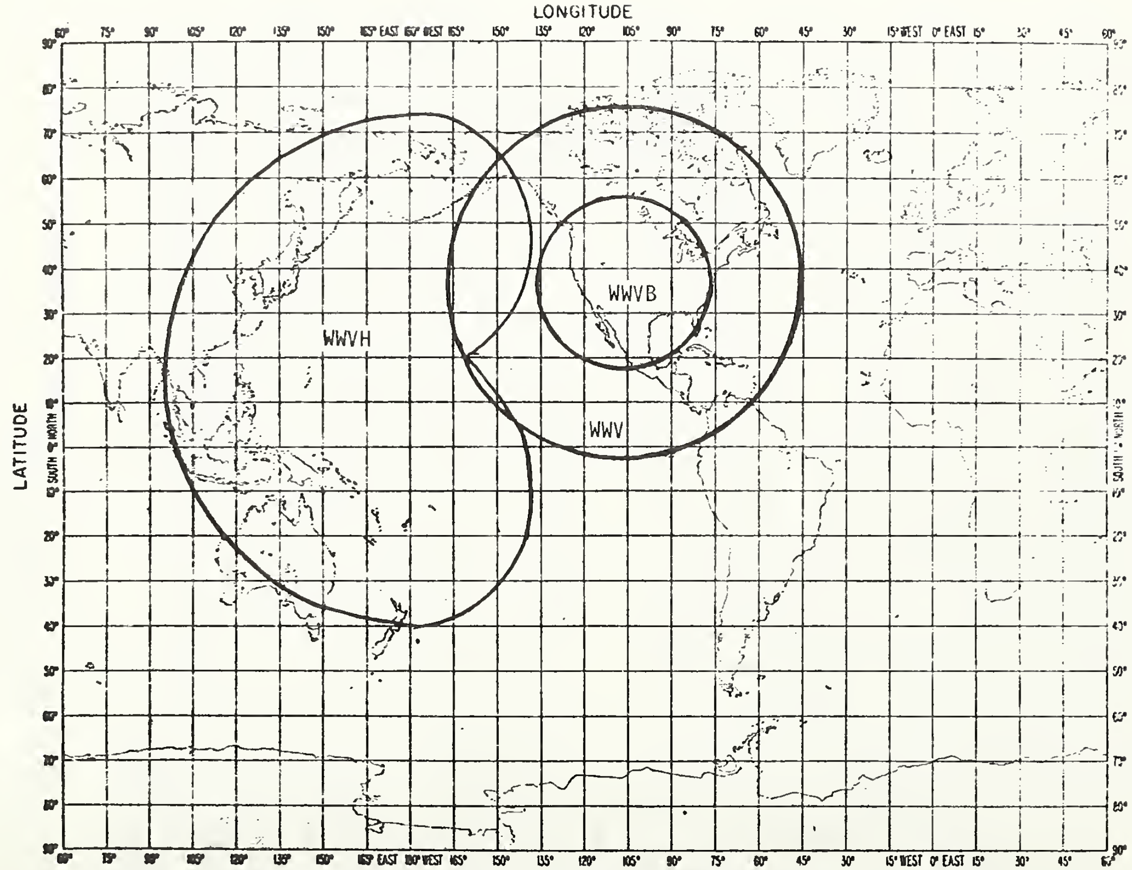

FIGURE 1.1 COVERAGE MAP SHOWING REGIONS OF RELIABLE RECEPTION (95% OR BETTER) FROM THE THREE NBS STATIONS WWV, WWVB, AND WWVH.

There are a total of eight sections in this report. Following this introductory portion, section 2 presents fundamental concepts of cost-benefit analysis and relates them to the problem. Section 3 does the same for the "cost-effectiveness" approach to evaluation. Section 4 presents considerations regarding cost data for the ground-based alternatives in dissemination, and Section 5 does the same for satellites. Section 6 provides a short discussion of data concerns, and section 7 presents some conclusions. Section 8 lists references. Data used in preparing the graphs in section 4 are tabulated in the Appendix.

2. COST-BENEFIT ANALYSIS

The intent in this section is to identify those elements of traditional cost-benefit analysis (CBA) most pertinent to evaluating alternatives in time and frequency dissemination. No detailed presentation of CBA will be given here; for such a discussion, the reader is referred to (2, 14, 15, 20, 21, 22). However, we include an attractive definition of CBA provided by Prest and Turvey (22):

> "A practical way of assessing the desirability of projects, where it is important to take a long view (in the sense of looking at repercussions in the further, as well as the nearer, future) and a wide view (in the sense of allowing for side-effects of many kinds on many persons, industries, regions, etc.), i.e., it implies the enumeration and evaluation of all relevant costs and benefits."

Discussion of the "enumeration and evaluation of all relevant costs" will be left for sections 4 and 5, since that kind of cost analysis will be an intrinsic part of any study and, as such, can be described in separate sections. On the other hand, the actual enumeration and evaluation of relevant benefits cannot be undertaken yet; this will occur at a later stage in the evaluation process. What will be done here is to present the concept of benefit-evaluation and suggest possible approaches for application to a study of alternatives in time and frequency dissemination.

Obviously, if CBA is the selected approach, then an early effort must be launched to identify the benefits associated with the choice of each alternative. For example, a major benefit of satellite dissemination is that stronger, more reliable signals (due to the reduced variation in propagation path) are broadcast, making it possible for all users within the coverage area to receive time signals that are accurate to 1 microsecond consistently and with little additional processing. (WWVB can provide absolute time-of-day information to approximately 500 microseconds. The phase of the received signal can be tracked to within a fraction of a microsecond, giving information on whether a user's clock is gaining or losing with respect to NBS. This resolution allows measurement sensitivity of parts in 10^{11} in one day and parts in 10^{12} averaged over a few days. See (10) for more on accuracies.) On the other hand, a possible benefit of the ground-based system is that it exists now and requires no major changes or capital investments and, consequently, no increased governmental support.

After the significant technical benefits associated with each alternative are identified, it is necessary to choose some value standard with which to measure the "worth" for each type of benefit. Although the actual "measure of benefit" most often used in the literature is dollar value, such a choice is not mandatory. One could, for example, consider public relations value as a measure of benefit and calculate the amount of "bad press" associated with each choice. The point is that there are nonmonetary possibilities, which should be investigated early in the project so that a decision on their use can also be made early. Nevertheless, in order to keep our discussion in this report within a readily acceptable conceptual framework, dollar value will be employed as a measure of benefit when it is necessary to specify one.

Once benefits have been identified, there begins the difficult task of gathering the data on which to base "scores" or numerical values quantifying the benefit-levels associated with each alternative. If dollar value is the measure of benefit used, then one method of obtaining information on user benefits is to survey the users of the time and frequency signals. This has been done before, and a detailed presentation of the results can be found in (1). Although much useful information was obtained from that survey, its results do not provide reliable estimates of the sizes of the populations of users and potential users of the signals. Such estimates are needed, however, if statistically valid estimates of benefits to the user population are to be obtained.

As an example, we sketch one possible approach to the design of a survey that conforms to accepted practices in probability sampling. An important initial step is to identify the categories of users; fortunately, this was accomplished in the earlier (1) survey. One then addresses each category with a view toward obtaining good estimates of the number of its members using the signals. Consider, for example, the categories "pleasure boating" and "power industry" that were identified in the survey.

In the case of pleasure boating, a valid approach might begin by obtaining a listing of all pleasure craft registered with the Coast Guard. Using random sampling, the researchers would choose a set of boat owners to contact. The size of that set would be determined by the levels of confidence desired in the estimates of (signal user) population size to be obtained. (Note that there are two populations involved: the population consisting of all pleasure boats, and its subpopulation of those owners who use the signals. The size of the former can be obtained from Coast Guard listings. Short of a blanket survey, the only way to estimate the size of the latter is by statistically based random sampling.)

With the set of interest determined, the members of that set are contacted. Methods for dedicated follow-up must be built in, since the validity of the estimates of population size obtained depend on the response rate. Each member of the set would first be asked whether the signals are used. If so, then detailed questions on value and benefit can be broached. (On the other hand, if the signals are not used, information on why not is also useful.) In this way, estimates of the size of the population of users are obtained, as well as benefits and perhaps even costs to users.

A completely different situation obtains in the case of the power companies. If the total number of such companies is not too large, random sampling might be discarded in favor of contacting each company to obtain a complete enumeration.

These examples should not be construed as recommendations for addressing the categories mentioned above. Rather, they are meant to illustrate how each category must be considered separately to determine the data-collection technique most appropriate for it.

In addition to discovering who and how much through a survey, it is important to discover why. It is not uncommon for surveyors to receive affirmative responses to questions regarding a need for a new service, when in fact, there is no real need but rather a willingness to obtain something at no cost. Obviously, this possibility should influence the survey questions and the means selected for analysis and interpretation of responses.

Surveying to obtain needed information is difficult and time-consuming, but not impossible. If appropriate statistical tools are used correctly and sufficient thought is given to precisely what information is needed and how the responses will be analyzed to yield that information, <u>and</u> if this is all done early enough to be useful, then a powerful tool in benefit evaluation can be realized.

Once the population of users has been identified and some of its defining characteristics obtained, the same machinery for gathering information could later be utilized by TFD in connection with other proposed changes in the dissemination services.

There are many different kinds of costs associated with the different kinds of surveys and interviews that could be performed, and the quality and value of the information obtained also vary. Choice among these possibilities therefore becomes a question of trade-offs. In this connection, it should be remembered that surveys need not be done in-house; there are many capable market survey firms whose sole function is to perform population surveys.

Another possible benefit can be identified. It would accrue not to the users of the system but to the government. It has, however, been the subject of some controversy, since it involves charging users for some dissemination services.* If some type of satellite system is chosen as the method of dissemination for the future, then as mentioned earlier, more dependable signals would be available, providing access to greater accuracy. To achieve this benefit, a method must be devised to charge those users who desire access to the "improved accuracy." This can be done, for example, by encoding the signal and selling the decoders. All users would not be charged, only those desiring the more dependable accuracy. The level of accuracy currently available at no charge to users would continue to be available at no charge.

There is some justification for such a policy because a clear and definable new service is being provided to a restricted number of users; recent governmental directives (Office of Management and Budget Circular Number A-25) require that, where possible, government agencies should seek reimbursement in such cases. Additionally, some economists argue that direct billback assures that a resource (time signals in this case) is used in the most effective way possible. Since the code would probably be changed on a regular basis, a complete and up-to-date mailing list could be kept so that users could be kept informed. This would provide TFD with a much more complete description of the number and type of users of its services: a form of data base useful for possible future market surveys.

On the other hand, it could be argued that if there is any area in which the federal government ought to be involved and in which it ought to provide a service at no charge, it is that of providing basic standards. And one of the most basic of standards is time.

A discussion of CBA should address the question of what exactly to do with all the costs and benefits once they have been assembled. The traditional approach is to compute net costs (C-B) and choose that alternative with the smallest such value. Even this natural procedure has been subjected to criticism (see, e.g., p. 29 of (20)); and, of course, it can only be done when the measure of benefit decided upon is some readily quantifiable value like dollars. In other cases, the typical approach is simply to discuss all aspects in detail and to choose the alternative felt to come closest to the ideal of "minimizing cost and maximizing benefit."

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*It should be noted that charges are a benefit to government only in the sense that some costs are recovered. Since charges reflect a user's "willingness to pay," they are also a partial measure of value or benefit.

3. COST-EFFECTIVENESS ANALYSIS

In this section, cost-effectiveness analysis (CEA) is addressed in the same way as was CBA in the previous section. That is, since a full-scale effort to execute such an analysis would be premature, we aim to define CEA in terms of the problem of choosing among alternatives in time and frequency dissemination. This discussion of CEA is included not because CEA is necessarily an appropriate method of analysis in this case but because completeness is necessary so that the reader can be clear on the differences between CEA and CBA. The goal, therefore, is to provide the reader with an understanding of what it means to perform a CEA in this area. Nevertheless, just as in section 2, a definition of CEA will be given first. Karl Seiler (25) defines CEA as being "that procedure by which the costs of alternative means of achieving a stated effectiveness, or, conversely, the effectiveness of alternative means for a given cost, are compared in a series of numerical indices."

A natural interpretation, in the context of time and frequency dissemination alternatives, is to assume that some minimum level of effectiveness is required of any system chosen. The analysis would then focus on identifying that system which would produce the required effectiveness at minimum cost. In the case at hand, this approach seems more appropriate than the reverse one of maximizing effectiveness for a given cost.

In any event, one of the first efforts of a CEA would be to identify possible choices for the "measure of effectiveness" to be used. This effort is analogous to benefit identification in CBA. However, in CEA, one is searching for some readily quantifiable aspect of dissemination common to all proposed systems. Just as in CBA, the identification effort should be done early and be sufficiently exhaustive that both management and analysts agree on the appropriateness of the choice.

With this need in mind, three possible effectiveness measures are noted here:

1) accuracy of received signal;
2) number of users reached by the signals; and
3) mean strength of signal when received.

These examples are certainly not exhaustive. They are provided to stimulate more thought toward effectiveness critera.

In considering measures of effectiveness, the reader should note that the measures must be applicable to <u>all</u> dissemination alternatives being considered and that each choice of measure implies certain needs and problems of data collection. Furthermore, it may be necessary to develop a measure based on a combination of factors; e.g., expected coverage per square mile of time signals accurate to .1 milliseconds and of frequency signals accurate to 10^7. Performance specifications can be established using several measures.

The simplest version of a CEA of dissemination alternatives would be one using a particular measure of effectiveness, e.g., accuracy. If it were determined that the required accuracy during the time interval of interest is 1 microsecond (currently available from WWVB under favorable conditions), the objectives of the study would be to identify the system providing that accuracy at minimum overall cost to government and to users. Costs incurred by users transferring to a new system must be included. A possible technique for reducing these costs is to provide a long transition period, enabling any new system to overlap with the old. This is referred to as "phasing" and is discussed further in section 5.

4. ANALYSIS OF COSTS FOR THE CURRENT SYSTEM (WWV, WWVH, WWVB)*

In this section, the cost of continuing the current ground-based system of dissemination into the future time interval of interest will be addressed. The intent is not actually to predict the costs, but rather to discuss possible procedures for such prediction.

4.1 The Life Cycle Cost Model

There are many aspects to costing out a system, whether existing or proposed. A convenient and acceptable technique to use in organizing costs of alternative systems is to view each from the standpoint of its life cycle cost (18). This approach provides a mechanism for including, as input to decision-making, all costs incurred throughout the lifetime of a system under consideration. This is in contrast to considering initial cost only and is accomplished by determining the costs associated with the following stages in the life of a system:

1) research and development (including capital investments and implementation);
2) operation and maintenance; and
3) salvage value.

Once determined, costs are generally discounted to present value and summed, yielding a life cycle cost. In mathematical terms, the objective function for life cycle costing is

$$LC_o = F + \sum_{t=1}^{\ell} \frac{\sum_{i=1}^{n} U_{it}}{(1+r)^t} - \frac{S_\ell}{(1+r)^\ell}$$

where

LC_o = present value of the system,
F = front-end costs (from (1) above),
U_{it} = category i in-use costs at age t,
S_ℓ = salvage value at end of useful life of system,
r = discount rate,
ℓ = time period considered to be useful life of the system, and
n = number of in-use cost categories.

In order to illustrate the value of the life cycle cost (LCC) approach to evaluating alternative investment decisions, consider two machines having the same design quality and both meeting the same performance standard. In Table 4.1, it can be seen that although Machine B has higher initial (front-end) cost than Machine A it also has lower annual operating (in-use) cost. Consequently, it has a lower life cycle cost than Machine A. All too frequently, buyers of industrial equipment and consumers buying durable goods consider only the initial cost of the product. As can be seen by the example, failure to recognize other elements of cost may yield an incomplete picture of the total cost of systems under consideration.

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*Credit is due Paul D. Domich of the NBS Applied Mathematics Division for his work in preparing graphical displays and investigating methods of prediction that are discussed in this section.

The life cycle cost model will be used throughout the remainder of this report as a vehicle for presentation and discussion of the costs associated with alternatives in the dissemination of time and frequency signals.

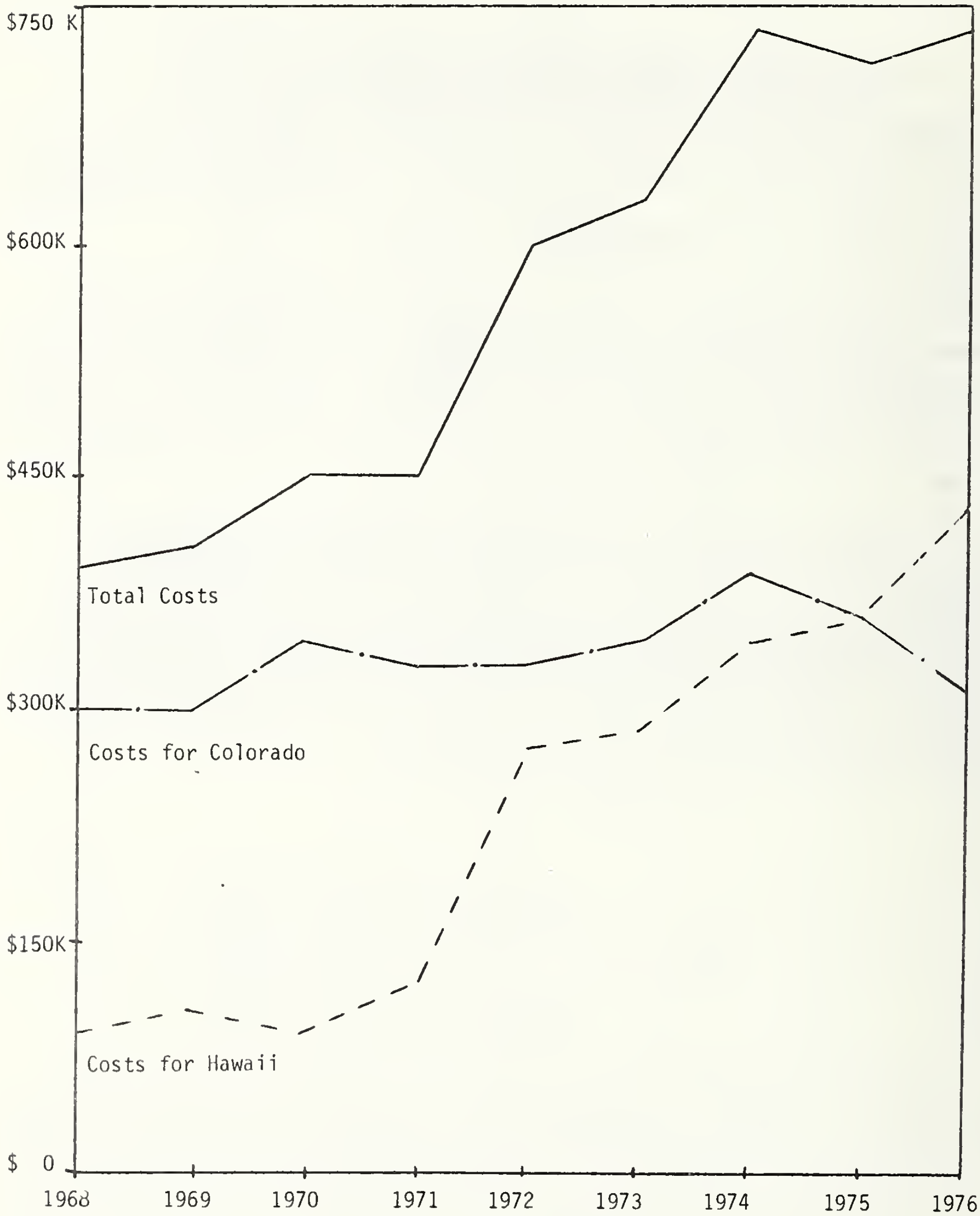
Table 4.1 Life cycle cost of two machines with same design quality. (Source: Howard E. Morgan, "Economic Considerations in Failure Prevention," NBS Special Publication 423, April 1976.)

	Machine A	Machine B
Initial Cost	\$ 5 M	\$ 6 M
Annual Operating Cost (includes downtime)	\$ .3M	\$ .2M
Service Life	40 yr	40 yr
Salvage Value	\$ .1M	\$ .5M
Discount Rate	10 %	10 %
Life Cycle Cost	\$7.87M	\$7.74M

4.2 Historical Cost Data

The prediction of costs for the ground-based systems requires obtaining a clear picture of the current and past situations. Data on initial capital outlays and on yearly operation and maintenance costs for stations WWV, WWVB, and WWVH have been collected and are given in table 4.2 and figure 4.1. In the case of a future system, the cost data in table 4.2 would be included in the first term in the life cycle cost equation as a front end cost. However, in this case, the funds are already spent ("sunk costs"). Since sunk costs enter F for both a future system and a future continuation of the present system, they cancel out in any comparison of the two. They will, however, be useful later in this section when we consider capital reinvestments.

Figure 4.1. Annual operating costs* of stations in Colorado (WWV, WWVB) and Hawaii (WWVH), and their sum, 1968-1976.



*In all graphs, values for 1976 do not include expenditures during the transition period from the June 1 fiscal year base to the October 1 fiscal year base.

Table 4.2 Initial capital investments for Time and Frequency Division's radio stations WWV, WWVB, and WWVH.

Colorado (WWV, WWVB)				Hawaii (WWVH)		
Year	Building	Land	Equipment	Year	Building**	Equipment
1962	8,360	69,420	180,200	1969	5,500	445,100
1963	68,850	8,130	25,850	1970	167,100	163,900
1964	8,210	130	1,840	1971	310,700	113,300
1965	2,460		305,500	1972		
1966	166,160		114,930	1973		
1967*	10,650		10,130	1974		30,000
Totals	264,690	77,680	638,450		483,300	752,300

*Initial capital investments ended in 1967. Capital outlays after that period become part of the in-use costs.
**Including land costs.

The annual operation and maintenance costs shown in figure 4.1 for the years 1968 to 1976 have been broken down by geographical location (Colorado and Hawaii) for convenience, and also to illustrate their distinctly different patterns. (Such differences are useful in that they sometimes indicate a need for different methods of analysis or prediction.) The effects of the cost reduction programs begun by TFD in 1974 are clearly indicated. Also shown is the cost effect of relocating WWVH in 1971, the purposes of which were to upgrade the quality of services to that offered by WWV in Colorado, to provide modernized equipment, and to provide a more secure site.

To gain a clearer picture of the factors affecting cost, the totals at each location were further broken down into three cost categories (corresponding to U_{it}, i=1, 2, 3, for some fixed t in the life cycle cost equation):

1) labor;
2) electrical power; and
3) miscellaneous;

which are depicted in figures 4.2 and 4.3. Category (3) includes water, oil heat, trash removal, rental cars and other similar miscellaneous items that represent a small percentage of total costs. Categories (1) and (2) are the only major, identifiable groups.

Those breakdowns, in addition to being useful for purposes of understanding, are also valuable in obtaining accurate estimates of annual operating costs in constant dollars. For example, to obtain annual costs in constant 1968 dollars, one obtains inflation rates for each year after 1968 and reverses the effect of inflation, i.e., "deflates" the observed cost for that year. However, to apply only one such deflator (like the consumer price index) to total annual

Figure 4.2. Annual operating costs in Colorado (WWV, WWVB): Total and by category.

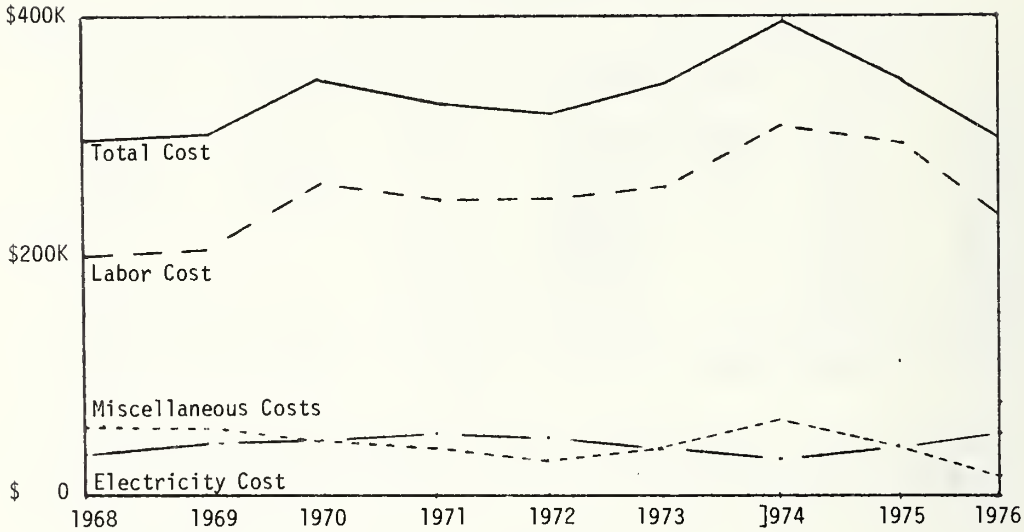
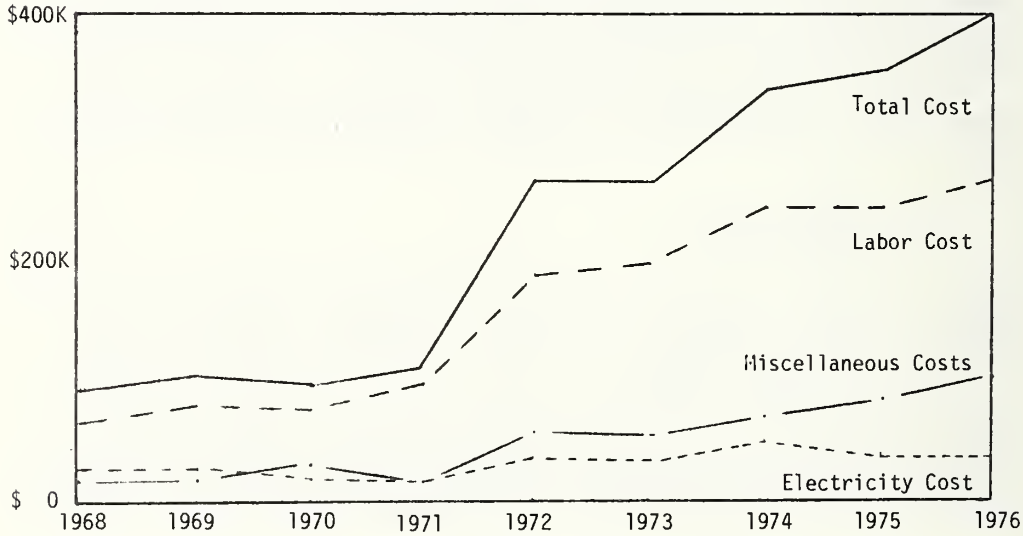


Figure 4.3. Annual operating costs in Hawaii (WWVH): Total and by category.



operating costs is not quite accurate. Deflators like the consumer price index are actually conglomerations of effects over subcategories of expenses. A more accurate picture can be obtained by applying the appropriate subcategory index to the breakdown categories mentioned above. Table 4.3 is a list of the indices available for the categories of labor, electrical power, and miscellaneous (consumer price index was used for the last of these).

Table 4.3. Economic deflators to be applied to labor, power usage, and miscellaneous other costs (1968 = 100.0).

Year	Federal Employees* Compensation Index	Industrial Power** Index:500 kw Demand	Consumer Price*** Index
1968	100.0	100.0	100.0
1969	106.2	101.3	104.8
1970	119.8	105.6	111.6
1971	131.7	116.3	116.4
1972	147.9	122.8	120.2
1973	159.1	131.4	127.7
1974	167.9	170.8	141.7
1975	181.8	207.8	154.7
1976	195.0	224.9	163.6

* Source: Survey of Current Business.
** Source: Bureau of Labor Statistics, Office of Price and Living Conditions.
*** Source: Survey of Current Business.

Figures 4.4 and 4.5 show annual operating costs of stations WWV, WWVB, and WWVH, in constant 1968 dollars, broken down by major subcategory and deflated with the indices in table 4.3. (The values for total costs in each case were obtained by summing the other three values.) It is interesting to note how linear some of the category values become, e.g., electrical power for both locations and labor at WWVH after the 1972 expansion. It is also interesting to note the difference between breaking down total cost, applying appropriate indicators, and summing to total deflated cost; and the alternative approach of simply applying the consumer price index to total cost. This difference is graphically illustrated in figure 4.6. By 1976, the difference is more than 20% and widening.

4.3 The Prediction of Future Costs

While these displays of the effects of past inflation and of TFD's successful prior efforts to reduce costs are interesting, the primary concern is to obtain "good" estimates of future costs for the current system. A note of warning from Edward Quade in (24) is appropriate: "While one may be able to forecast coming events in the sense of mapping out possible futures, there is no satisfactory way to predict a single future in terms of which to work out the best system or determine an optimum policy."

One way to predict future costs is to use linear regression to fit straight lines or curves to observed data and apply the resulting functional relationships to extrapolate future values. The assumption required is that factors affecting relationships in the past will also obtain in the future: an assumption that might not be valid.

Figure 4.4. Real-dollar costs in Colorado (WWV, WWVB): Total and by category.

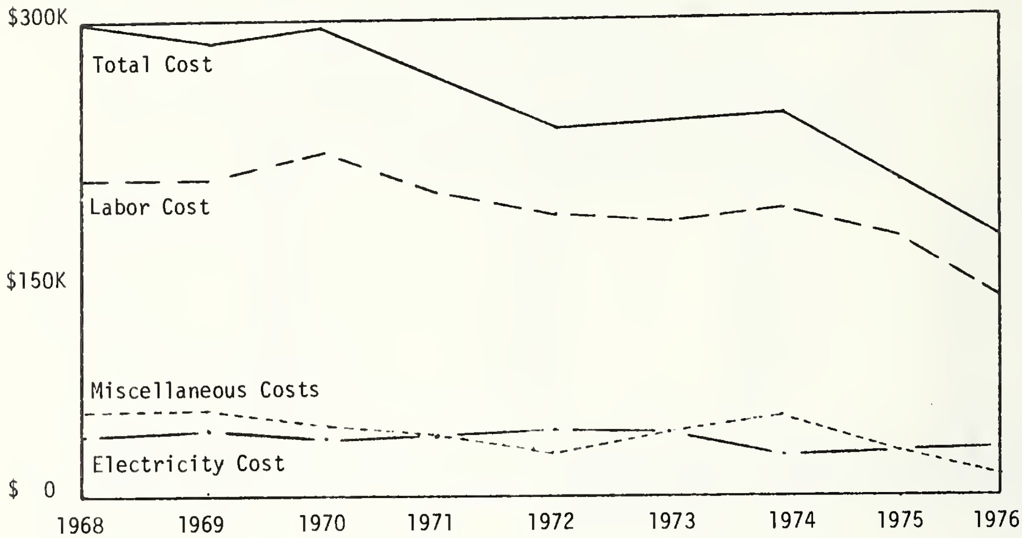


Figure 4.5. Real-dollar costs in Hawaii (WWVH): Total and by category.

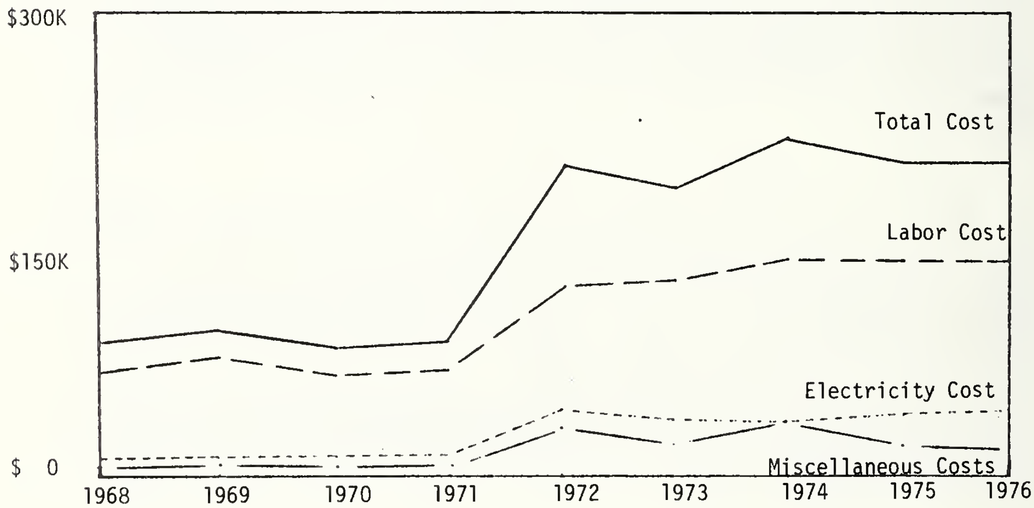
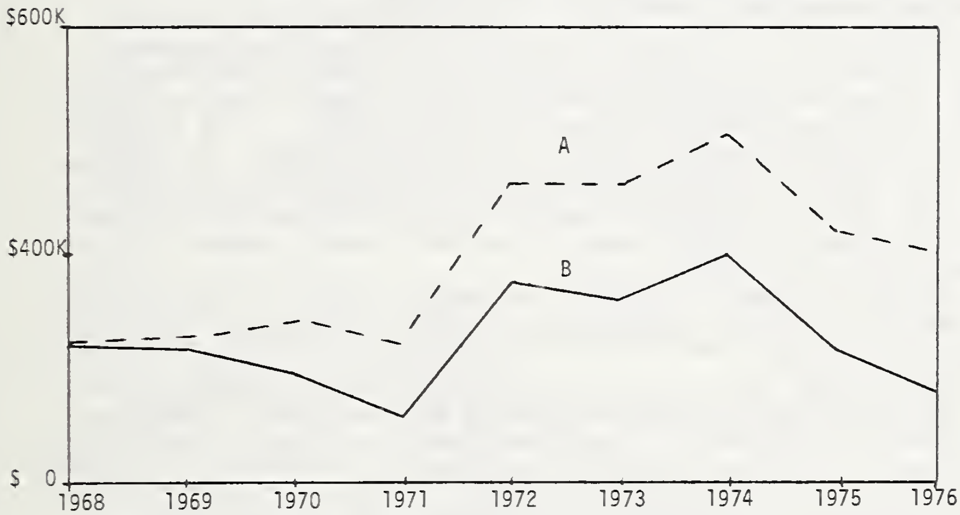


Figure 4.6. Deflated total annual operating costs (WWV, WWVB, WWVH), using "all-at-once" (A) and "subcategory breakdown" (B) methods of deflating.



The major difficulty with forecasting in this way is that it depends heavily on system performance data from the past. Fluctuations in the graphs of figures 4.2 through 4.5 resulting from cost reduction programs and expansions of service have an undue degrading effect on the quality of forecasts. Such fluctuations are not expected to occur in the future: there is general agreement among the staff of TFD that after the cost reduction program is completed in 1977 or 1978, few operating changes will be made. This means that additional significant changes in power costs due to cutbacks and in labor costs due to automation are not anticipated, and there is justification for assuming that the real (deflated) dollar costs for 1977 can be used as a basis for estimating future costs.

Since the ultimate goal in using the life cycle cost equation is to obtain total costs in constant dollars, the use of 1977/1978 cost data as a basis for estimating constant dollar costs in the future has merit.

Observed economic deflators for three cost groups are provided in table 4.3. These are historic data available from sources within the federal government. Projections of these deflators into the future might be made by building a complex econometric model using projections of basic economic goods and services and relying on established (or hypothesized) relationships. This is a complicated and expensive process which at best yields uncertain results. An accepted practice within the federal establishment (suggested by the Office of Management and Budget (OMB)) is to use an across-the-board annual inflation value of 6%. In this case, the historical deflator data can be used to reference historic cost data to some common base year; whereas future costs would be predicted using an assumed inflation value of 6% per year.

The OMB also suggests using 10% as the discount rate (r in the LCC equation) for comparing alternative investments by the federal government. This discount rate is to account for interest earned from alternative investments and does not account for inflation.

So far in this section, only recurring costs of operating and maintaining the existing stations WWV, WWVB, and WWVH have been considered. Although the front end costs in the life cycle model are viewed as sunk costs, the depreciation aspects of these sunk costs must be considered in the analysis. For example, at some time in the future, a power transmitter will have to be replaced, and the time and cost of replacement must be included in the life cycle cost of the current system. (In fact, plans are currently underway to replace the power transmitters for WWVB in Colorado, to be installed by 1979, at a cost of $520,000. While this might become a sunk cost before the anticipated study is begun, it does illustrate the need to identify and include such costs.

The first step in estimating depreciation costs is to identify those elements of the initial capital investment that have a finite lifetime. One then determines the length of that lifetime. Finally, the future costs of replacement at the end of that lifetime are predicted. Frequently, these costs are amortized over the life of the project.

The identification of major components to be depreciated should not be difficult: we have already cited two classes--buildings and power transmitters. Determining appropriate "lifetimes" is more difficult. The economic life of a system is defined as the period of time after which it is no longer economically justifiable to continue its operation. This could be the same as physical life: the period of time after which it is more economical to replace than to repair. On the other hand, economic life could be identified with the technological life of a system: the period before a new system is available that makes the old system obsolete and thus uneconomical to operate. Economic life can be determined in many ways, but it must be determined consistently in the same project evaluation.

The final step in estimating depreciation costs is that of predicting replacement costs. Here we rely on the techniques described earlier in this section for forecasting operating and maintenance costs. Economic deflators have been obtained for the costs of power transmitters and for buildings used in the TV and radio broadcasting industries and are listed in table 4.4.

Table 4.4. Economic deflators for power transmitters and buildings used in the broadcasting industry.

	Radio and TV Transmission Equipment Index*	Public Utility Building Index**
1967	80.8	74.9
1968	80.9	78.1
1969	83.5	82.0
1970	85.1	87.9
1971	96.5	94.1
1972	100.0	100.0
1973	100.6	107.2
1974	104.0	126.5
1975	122.6	141.3
1976		149.9

* Source: Bureau of Economic Analysis, unpublished data.
** Source: Survey of Current Business.

5. ANALYSIS OF COSTS FOR SATELLITE-BASED SYSTEMS (WWVS)

The life cycle cost methodology presented in section 4 will also be used as a guide for the cost analysis of satellite-based transmission systems. There is a fundamental difference, however, between the analysis of satellite-based transmission systems and that of ground-based transmission systems; cost data are available for WWV, WWVB, and WWVH, but WWVS costs must be derived as well as predicted. Whereas the approach in section 4 was to collect past data and identify methods for predicting future costs, the approach in this section will necessarily be one of identifying areas where cost data must be collected. No discussion of prediction methods will be included in this section, since methods for cost prediction are the same as those presented in section 4.

To follow the dicta of life cycle costing, data must be obtained on front end costs, depreciation, operation and maintenance costs, and salvage value. The following four areas can be identified as contributing to front end costs:

1) identification and technical evaluation of each possible system;
2) research and development required by each system;
3) equipment costs for each system; and
4) launch costs.

There are some difficulties with including (1) above as a separate item distinct from (2). The difficulty lies with the fact that, as part of the process where all feasible alternatives are identified, some technical evaluation must be performed. Furthermore, any such evaluation is a lead-in to (2) above and should therefore be included as a front end cost. On the other hand, since the evaluation will have been performed even before the completion of the cost evaluation study, it could be more appropriatly considered as a sunk cost rather than a front-end cost. Presumably, OMB requirements will settle the issue of whether total system costs or marginal costs, from present time to future, are to be compared.

Some comments regarding (3) above are in order. Since it is important that time and frequency signals be continuous and uninterrupted, an important part of any potential satellite system is a backup system of some kind. This could take the form of complete copies of equipment, installed in another satellite, or could be built into the primary satellite in the form of redundant equipment. There are, of course, additional costs to be incurred in either case. In the latter case, costs of redundancy are easily quantifiable, since they are directly related to weight, which directly affects launch costs. The analysis of this trade-off is particularly suited to the application of mathematical optimization methods. The objective function could be launch cost, to be minimized subject to constraints requiring some minimum level of reliability. Reliability would be defined in terms of mean times between failure for each component, and the solution of such a model would be an optimal combination of redundant components providing the required level of reliability at minimum cost.

Comments should also be made here in reference to (4) above. As with most of the spacecraft-related costs, it is likely that NASA can provide cost estimating relationships (CER's) from which we can estimate the cost to launch the NBS equipment. A difficulty with CER's, however, is that they are developed on the basis of past data and cannot take into account new technology planned for the future, e.g., the space shuttle. Cost savings resulting from use of the space shuttle will be difficult to determine, but, for completeness and fairness, should be considered.

The second term in the LCC equation is the cost of operation and maintenance, and, again, reliance on NASA's data is paramount. If the space shuttle is available during the lifetime of the satellite broadcast system, then the maintenance problem becomes one of repair rather than replacement. However, it is not clear how frequently the shuttle will be launched, how much it will cost, what its workload will be, and, consequently, how much "downtime" should be anticipated for the satellite system. On the other hand, in the no-shuttle case, it is also uncertain when a backup satellite would be activated, since the NBS equipment would be only a small portion of some satellite package. These are just some examples of the items to be considered when investigating operation and maintenance costs.

The last term in the LCC equation is concerned with salvage value. Today, satellites are unrecoverable and consequently have no salvage value. However, if the space shuttle becomes a working reality, then one could consider retrieving satellites at the end of their useful lifetimes.

The first part of this section included a discussion of the costs related directly to satellite systems. We now turn to other associated costs that must also be considered in any study of alternatives in time and frequency dissemination.

The first of these associated costs is that which is absorbed by the users of the time and frequency signals, as a result of a change in the method of distributing those signals. It is difficult to determine at present exactly how many of what types of users will be affected by a change in the system configuration, to the extent that new equipment must be purchased. Certainly, the survey approach based on probability sampling theory that was outlined in section 2 would be helpful in answering this question. The costs to users of the system must be included in the analysis.

To illustrate this point, consider the case of private users mentioned at the end of section 3. TFD staff estimate that receivers capable of receiving satellite signals accurate to .1 millisecond will cost approximately $200 and those capable of receiving signals accurate to 1 microsecond will cost approximately $2000. Although the conversion cost to each private user is not unreasonable compared to the cost of other electronic equipment, the sum over all such users is a nontrivial increment to the overall cost of the system.

Of course, all such user equipment has a finite expected lifetime. Thus, equipment depreciation should be considered in estimating user costs for switching over to satellite-based alternatives. This could be accomplished by allowing a lead time for the switchover equivalent to the lifetime of current user equipment, permitting what amounts to a gradual and "natural" conversion from one system to the other. This would require parallel operation for a time of both ground-based and satellite-based systems, which would be more costly to NBS. However, the total cost of the system might be reduced.

This issue of time phasing is one that bears more consideration. Given a number of different alternatives to time and frequency dissemination and the likelihood that user equipment lifetimes will only be estimates, it is doubtful that there will be an obvious choice for the "phasing" time period mentioned above. Yet a year's difference one way or the other represents a considerable sum in the NBS budget. It would seem worthwhile, then, to investigate optimal phasing more carefully; the cost study effort should include development of a model to evaluate and optimize phasing possibilities. Such a model would probably rely on simulation, where the inputs would be the endpoints of the phasing interval being considered, data on numbers of, and configuration for, the satellite system, and cost data for both systems. The outputs would be dollar costs to NBS, to users, and overall system cost for use in the cost study.

Another cost analysis issue is how to weight costs to the various user groups. This is a way of accounting for the fact that the value of $200 to a private user differs from its value to a large corporation. Since costs to users will come from a diverse group, weighting these costs might be necessary, but assessing weights can be a difficult task requiring more thought. (One way is to perform a sensitivity analysis in the model by assigning nominal weights and perturbing them to determine effects.) On the other hand, weighting different effects is necessary only in certain circumstances, e.g., when estimating "typical user cost." Since our concern is with total system cost, weights might not be necessary.

In concluding this section, some comments on cost estimating relationships (CER's) are in order. It seems reasonable to assume at this point that most of the CER's required for a cost analysis of satellite dissemination alternatives will be available from NASA (see, e.g., (9)). It does not seem worthwhile to develop special ones for this study. On the other hand, an effort should be made to provide assurance that the general relationships developed by NASA are indeed applicable in the specific cases being investigated by NBS. Such an effort should include sensitivity analysis of the CER's and the development of estimates of uncertainty.

6. DATA NEEDS

Besides identifying the data required to support the evaluation of time and frequency dissemination alternatives, it is also necessary to investigate methods of processing and maintaining these data. Such an investigation is especially useful when performed early in the project. The main point to be made here is that data problems (handling, editing, analyzing) should be considered as an integral part of project planning. This will avoid the embarrassment of, for example, developing a model that requires data accuracies greater than can be achieved.

In the case of a time and frequency dissemination alternatives study, it is not possible at this early stage to identify and specify each type of data that will be required. However, in the previous sections of this report, the following data categories have been identified:

a) cost data on the ground-based systems;
b) cost data on satellite systems (to include data used in CER's);
c) cost data on leasing satellite space;
d) data on costs to users;
e) data on benefits to users;
f) effectiveness data;
g) economic deflators;
h) data in support of phasing studies; and
i) reliability data.

7. CONCLUSIONS

It seems appropriate to conclude this report by remarking that its value is transient, since it is primarily a reference point for future analyses. It will have served its purpose if future analyses are facilitated by the systematic layout of problems, decision points, and other considerations related to the evaluation of alternatives in time and frequency dissemination.

The evaluation of time and frequency dissemination alternatives should not be expected to provide absolute answers regarding either benefits or costs. Due to uncertainties in data, difficulties in ascribing economic values, and inadequacies of forecasting techniques, such answers are difficult to achieve. The best that should be expected is a comparison of the relative costs and benefits or of the relative cost effectiveness of the alternative systems being considered.

Close cooperation is a most important prerequisite in evaluating alternatives for public investment from two points of view:

1. Studies of public investment alternatives deal with economics, statistics, optimization, data processing as well as the particular subject area under consideration, in this case standards of time and frequency. No one discipline can provide all the skills necessary for a thorough job of assessing alternatives. It is mandatory, therefore, that an interdisciplinary team be assembled to analyze the alternatives.

2. The preparing organization, the reviewing organizations, and the decision makers should agreed on the evaluation criteria. Such agreement is necessary to identify quantitative factors, to describe and measure uncertainties, and to document properly all aspects of the study.

   A quote from p. 9 of (21) serves to underline this point. "It is very important that before embarking on any investment-decision process, all parties (e.g., NASA, Office of Management and Budget, and user agencies) to the decision must agree on the criteria to be used." Early agreement on major issues such as criteria, methodology, and detail is of the utmost importance, since data base development, model development, model verification, and model use cannot properly proceed without such agreement. Furthermore, these endeavors are time consumers and require much lead time, unlike the "mere" calculation of cost-effectiveness and cost-benefit.

If the participants in the study meet early, seek and achieve agreement on these issues, maintain close cooperation throughout the study, and document all assumptions, then the evaluation of time and frequency dissemination alternatives will be helpful to management in making investment decisions. This is the ultimate goal of any study of costs, benefits, and effectiveness.

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APPENDIX: DATA TABLES

This appendix contains tables of data used in constructing graphs in section 4. All cost data were obtained from budget records of the Time and Frequency Division.

Table A.1. Annual operating costs in Colorado (WWV, WWVB), 1968-1976.

	Total	Labor	Electric	Miscellaneous
68	$298384.	$202173.	$38907.	$57304.
69	288832.	200160.	40816.	47856.
70	297148.	219052.	40238.	37858.
71	260154.	189617.	37901.	32636.
72	228825.	171092.	35605.	22128.
73	230240.	165399.	31499.	33342.
74	239461.	174090.	20935.	44436.
75	196149.	154906.	19733.	21510.
76	153320.	119760.	23066.	10494.

Table A.2. Real-dollar costs in Colorado (WWV, WWVB), 1968-1976 (1968 = 100.0).

	Total	Labor	Electric	Miscellaneous
68	$298384.	$202173.	$38907.	$57304.
69	303951.	212485.	41354.	50112.
70	347141.	262653.	42491.	42057.
71	331423.	249497.	44071.	37855.
72	323361.	253096.	43742.	26523.
73	346255.	263375.	41392.	42488.
74	391018.	292098.	35758.	63132.
75	35673.	281649.	41027.	33497.
76	313934.	233451.	51834.	17458.

Table A.3. Annual operating costs in Hawaii (WWVH), 1968-1976.

	Total	Labor	Electric	Miscellaneous
68	$89564.	$69568.	$ 8422.	$11574.
69	101133.	80361.	8607.	12165.
70	97133.	77373.	10494.	9266.
71	114062.	97380.	8283.	9399.
72	277338.	185306.	54870.	37162.
73	279320.	200036.	50558.	28726.
74	346356.	248779.	68369.	50206.
75	363013.	247299.	82807.	32006.
76	242549.	270160.	100903.	29793.

Table A.4. Real-dollar costs in Hawaii (WWVH), 1968-1976 (1968 = 100.0).

	Total	Labor	Electric	Miscellaneous
68	$ 89464.	$ 69568.	$ 8422.	$11574.
69	95813.	75700.	8495.	11618.
70	82801.	64529.	9937.	8335.
71	88466.	73248.	7123.	8095.
72	200999.	125267.	44664.	31069.
73	186782.	125623.	38474.	22686.
74	211548.	136352.	39995.	35201.
75	196720.	136510.	39830.	20380.
76	201215.	138592.	44901.	17722.

Table A.5. Total annual operating costs (WWV, WWVB, WWVH), actual and deflated values, 1968-1976 (1968 = 100.0).

	Actual Dollar		Deflated Dollar
68	$387948.	68	$387948.
69	495984.	69	384645.
70	444274.	70	379949.
71	445485.	71	348620.
72	600699.	72	429824.
73	626575.	73	417022.
74	738374.	74	451009.
75	719186.	75	392869.
76	738483.	76	354535.

NBS-114A (REV. 7-73)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET	1. PUBLICATION OR REPORT NO. NBSIR 78-874	2. Gov't Accession No.	3. Recipient's Accession No.
4. TITLE AND SUBTITLE Disseminating Standards of Time and Frequency: Issues in the Evaluation of Alternative Systems			5. Publication Date March 1978 6. Performing Organization Code 205.02
7. AUTHOR(S) Richard H. F. Jackson			8. Performing Organ. Report No.
9. PERFORMING ORGANIZATION NAME AND ADDRESS NATIONAL BUREAU OF STANDARDS DEPARTMENT OF COMMERCE WASHINGTON, D.C. 20234			10. Project/Task/Work Unit No. 2776119 11. Contract/Grant No.
12. Sponsoring Organization Name and Complete Address (Street, City, State, ZIP) National Bureau of Standards, 325 Broadway, Boulder, Colorado Insitute for Basic Standards, Time & Frequency Division			13. Type of Report & Period Covered Final, 1/76 - 4/77 14. Sponsoring Agency Code
15. SUPPLEMENTARY NOTES			

16. ABSTRACT (*A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.*)

Since 1923 the National Bureau of Standards (NBS) has broadcast standards of time and frequency over dedicated radio stations. Recently, the Bureau's Time and Frequency Division (TFD) has implemented programs of cost reduction at these radio stations. In addition, TFD undertook a study to identify and evaluate alternative modes of disseminating these standards in a search for methods to reduce costs further and to improve the quality of services offered. The primary purpose of this report is to document the economic issues involved in this study by discussing the problem in terms of both cost-benefit analysis and cost-effectiveness analysis. Preliminary cost studies for some of the dissemination alternatives are also included.

17. KEY WORDS (*six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons*)

Cost-benefit, cost-effectiveness, dissemination, frequency standard, time standard.

18. AVAILABILITY	19. SECURITY CLASS (THIS REPORT)	21. NO. OF PAGES
XX Unlimited [ ] For Official Distribution. Do Not Release to NTIS	UNCLASSIFIED	33
[ ] Order From Sup. of Doc., U.S. Government Printing Office Washington, D.C. 20402, SD Cat. No. C13 X Order From National Technical Information Service (NTIS) Springfield, Virginia 22151	20. SECURITY CLASS (THIS PAGE) UNCLASSIFIED	22. Price $4.50

USCOMM-DC 29042-P74