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A CROSS IMPACT METHODOLOGY FOR THE ASSESSMENT OF U.S. TELECOMMUNICATIONS SYSTEMS WITH APPLICATION TO FIBER OPTICS DEVELOPMENT

Volume I

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FINAL REPORT

PREPARED FOR:

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SECTION 1

INTRODUCTION

1.1 PURPOSE

The purpose of this research effort was to develop a methodology which could be utilized by NASA to aid in making decisions about the most appropriate space communications technology for R&D support. At any time, there are many possible space communications technologies which might be advanced. In general, it is not possible to support all or any significant fraction of the possible technological options. It is necessary, therefore, for NASA to make choices among those options open to it, selecting only those space communications technologies for development which promise the most payoff for the nation.

Rationality in decision making implies a connection between the means chosen and the ends or goals sought. A decision maker would be considered irrational if he claimed to be pursuing a specific goal, yet took an action which hindered the achievement of his goal or even rendered that goal impossible of achievement. This consideration applies to decisions about space communications R&D. NASA administrators wish to chose those technological options which are most likely to lead to achievement of their goals, or at least not hinder achievement of their goals.

Unfortunately, selection of means to achieve goals is difficult when a complex system intervenes between means and goals. It may not be immediately apparent what the overall consequences of any option chosen will be, let alone which of several options will lead to the most desirable outcome. In many cases, complex systems behave in a "counter-intuitive" fashion, in the sense that an action which would appear, to the untrained intuition, to have one effect may turn out to have exactly the opposite effect.

This issue of complexity is pertinent to decisions about space communications R&D. The U.S. telecommunications system is large and complex. The various elements of that system are to some extent in competition with one another to provide specific services to the public. They also, however, support one another by providing complementary capabilities which allow the system as a whole to provide services which could not be as easily provided by any single element, if they could be provided at all. Moreover, each of the elements of the system is constantly undergoing change, both in magnitude (total public served) and in the technological means by which services are provided.

A successful space communications R&D program implies the deliberate introduction of change in one element of the telecommunications system. The consequences of that deliberately introduced change, however, can be evaluated only in the context of the entire system, including the other changes which will or might also take place in the elements of that system. An aid to rational decision making about space communications R&D must recognize and incorporate the complexity of the telecommunications system, and include expected and possible changes in that system.

The purpose of this research effort, then, was to develop a methodology which would allow NASA decision makers to trace out the consequences of specific changes in the telecommunications system. The methodology specifically had to take into account the complexity of the system, and had to incorporate expected or possible changes in that system. Both the competitive and the complementary aspects of the system had to be included. The methodology would assist in making rational decisions by portraying the various consequences of individual changes, permitting NASA decision makers to determine the relative merits and drawbacks of specific space communications technologies.

1.2 APPROACH

Our approach to developing a methodology to aid decision making was to develop a model of the telecommunications system, which takes into account potential interactions among future technological and economic events. NASA decision makers could then utilize the model to analyze specific technologies within the context of the overall telecommunications system. To serve this purpose, the model would have to reflect the true complexity of the telecommunications system, and provide outputs which were clearly understandable, in terms of distinguishing between the consequences of alternative decisions.

In developing a model, it is necessary to follow a middle path between a model which is too simple to adequately describe the issues confronting a decision maker, and one which is so complex that its operation is difficult to comprehend and its output is so voluminous as to be confusing. We selected the cross impact model as a type of model which followed this middle path. A cross impact model is not a complete model of the telecommunications system (e.g., it does not incorporate the location of every transmitter and receiver), but does not inherently limit the depth of detail of the analysis. Thus, the model could be as rich in detail as necessary, but no more so than necessary.

The cross impact model is described in detail in Section 2 of this report. In addition, Appendix 1, the User's Guide, describes the inputs necessary to operate the cross impact model, provides a description of the computer program, and list the program including the output of a sample problem.

The cross impact model requires as input, forecasts of the growth and development of each of the elements of the telecommunications system. Broadcast satellites were the primary focus of this study, and most of the forecasting effort was devoted to projecting the growth to be expected in satellite performance and availability. The forecasts of satellites are given in Section 5 of this report. In addition, forecasts of the other major elements of the telecommunications system were made. These are given in Section 4 of this report. Many of the forecasts were, in turn, based on demographic and economic projections, which depicted the demand for various services. These basic projections are given in Appendix 6.

Determining the consequences of an innovation in telecommunications requires a means to forecast the rate at which that innovation will be adopted in those markets for which it is appropriate. Thus, it was necessary, as part of this research, to develop market penetration models for telecommunications innovations. Section 6 of this report describes the market penetration model used, and Appendix 4 provides the details of the model as applied to each of several market sectors.

The projections of each of the major elements of the telecommunications system, the interactions among those elements, and the projections of market penetration, when incorporated into the cross impact framework, comprise the model of that system. This model is described in Section 8 of this report. That section discusses each of the major elements of the system, and describes the manner in which forecasts for one element are changed as a result of events occurring in other elements.

Part of the research involved demonstrating the methodology on a sample case study. In conjunction with the sponsor, the decision was made to use Fiber Optics transmission as the test case. The results of this analysis are presented in Section 9 of this report. That section describes the events added to the model to represent application of Fiber Optics, and the interactions of these events with the remainder of the model. The section also presents the consequences of introduction of several Fiber Optics applications, and illustrates how the outputs of the model can be utilized to gain an understanding of the effects of introducing changes in the telecommunications system.

Even though introducing a space communications technology might on net balance be beneficial, NASA intervention may not be required. NASA decision makers also need to be able to determine whether NASA action is appropriate in connection with a specific item of technology. Modern economics has developed an extensive body of theory to determine when government intervention in the market is appropriate or desirable. Part of this research effort was to incorporate that theory into a scoring model which could be utilized by NASA decision makers to rate or rank alternative technology options in terms of the need for and appropriateness of government sponsorship. The scoring model is presented in Section 7 of this report.

1.3 RESULTS

The end result of this research effort is a cross impact model which can be utilized to trace out the consequences of the introduction of specific telecommunications technologies. These consequences can then be evaluated in economic and social terms to determine whether they are relatively more or less desirable than the consequences of the introduction of some other specific telecommunications technology. The model is, thus, directly usable by NASA decision makers who are concerned with choices among space communications technology options.

In addition to the model itself, the research effort produced forecasts of the future development of the major elements of the U.S. telecommunications system. While these forecasts were required for input to the model, they also have utility in themselves, as indicators of the potential development of each element of the telecommunications system. In particular, the assumptions incorporated into the forecasts serve to identify those factors which cause change in each of the elements of the telecommunications system.

The particular form of the model, namely a cross impact model which includes events and their estimated likelihood of occurrence, allows the model to serve another function beyond that of simply ranking or rating the relative merits of possible space communications technology options. The model makes it possible to identify low-likelihood "surprise" futures which may be either highly undesirable or highly desirable. While these surprise futures are, of course, implicit in the events and interactions input to the model, they often require the occurrence of several unlikely events, and, therefore, are not usually apparent from a casual inspection of model inputs. Thus, the model can serve the purpose of alerting decision makers to outcomes which might otherwise be completely unexpected and unprepared for.

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SECTION 2

CROSS IMPACT MODELS

2.1 INTRODUCTION

A forecast is a statement about some event to take place in the future. In particular, a forecast is a statement about when the event will occur (if it does), and the probability that it will occur. A forecast may range in complexity from a simple statement giving a single date and a single probability of occurrence for an event, to a statement giving a span of time within which the event may occur, the probability of occurrence at all, and the conditional probability of occurrence during subperiods within the span of time. In all cases, however, a forecast can be expressed in terms of a time for occurrence and a probability of occurrence.

The timing and probability assigned to the occurrence of some future event may themselves depend upon the occurrence or nonoccurrence of events which also lie in the future (but, of course, prior to the event of interest). In order to make a forecast for the event of interest, it is necessary to make assumptions about the occurrence or nonoccurrence of these intermediary events. If an intermediary event which was assumed to occur fails to occur, the assumption is invalidated and the forecast based on that assumption may also be rendered invalid. Thus, any forecast which is based upon assumptions about events not specifically included in the forecast may be affected ("impacted") by the actual outcome, occurrence or nonoccurrence, of those events.

The cross impact technique is specifically intended to take into account the cross impacts between events included in a forecast. A cross impact model begins with a set of forecasts about separate events. These forecasts will have been generated independently of one another, and may, in fact, be generated by different means. For each such independently generated forecast, it is necessary to identify all the assumptions made about prior, intermediary events.

That is, it must be asked whether the timing and probability assigned to a specific event were based on the assumed occurrence of some other identified event, or instead based on the assumed nonoccurrence of that other event. Moreover, if the timing of occurrence of this other event can have an impact on the timing and probability of the specific event being forecast, then any assumptions made about the timing of occurrence must also be rendered explicit.

Once the assumptions have been made explicit, then it is possible to determine the cross impacts among the set of forecasted events. That is, if one of the events were to occur, it is possible to determine whether that occurrence would have any effect on some other event, by determining whether the occurrence of the first event invalidates any assumptions which were included in the forecast of the second event. If the occurrence of the first event is consistent with the assumptions involved in the forecast of the second event, then no changes in estimated timing or probability for the second event need to be made. If, however, the occurrence of the first event is inconsistent with the assumptions involved in the forecast of the second event, then the estimated timing and probability of the second event must be changed, which is to say the forecast for the second event must be changed. The amount of change needed in timing and probability then are the "impact" of the first event on the second.

The cross impact technique then views the future of the world as an interconnected collection of potential events whose projected probabilities of occurrence are raised or lowered, and whose times of occurrence are advanced or delayed, by the occurrence or nonoccurrence of other events with the passage of time. A cross impact model, then, is a collection of future events, each with a given probability and timing, and a set of cross impacts from some of the events to others. A complete specification of a cross impact model must include, for each event, the impacts of both occurrence and nonoccurrence of that event on all other events included in the model (in a typical model, most of these impacts are zero).

The use of a cross impact model reflects this basic view of the future, and involves production of a simulated future history for the set of events. Operation of the model begins by selecting the earliest event in the set, and testing it for occurrence or nonoccurrence by drawing a random number. Depending upon the random number drawn, the event is determined to have occurred or not occurred. Following the test of the first event, the necessary changes are made in the timing and probability of all other events which are impacted by the first event. The result of this set of impacts may include changing the chronological sequence of the remaining events. Once all cross impacts from the first event have been accounted for, the second event in chronological sequence is tested for occurrence or nonoccurrence, and the appropriate changes made in timing and probability of the remaining events. This process continues until all events have been tested and their outcome determined. The last event tested, of course, cannot impact any other event. The result of a single run of the model is a scenario, in which certain events occur and other events do not occur.

A single run of the cross impact model is not particularly informative. If there are n events if the model, there are 2^n distinct possible scenarios, each differing from all the others in occurrence or nonoccurrence of at least one event. Moreover, the average probability of each such run is 2^{-n}, which for large n will be a very small number. Thus, the cross impact model is not used just for single runs. Instead, the model is run many times, using the same set of initial dates and probabilities for the events, but drawing a different set of random numbers for each run. The number of runs must be large enough for statistical validity of the results. Typically, 100 runs may be made.

This large number of runs then gives a statistical picture of the future for the set of events and interactions in the model. Results may be examined in terms of frequency of occurrence for individual events, frequency of cooccurrence for pairs of events, and the distribution of times of occurrence for individual events.

Analysis of this statistical picture of the future will be described in more detail below.

2.2 MODEL CONSTRUCTION

The construction of a cross impact model begins with the identification of discrete events which have the potential for occurring within the time span of interest. This selection must include those events of interest for the purposes to which the model will be put, and events which may not be of inherent interest themselves but which may affect events which are of interest. In some cases, the "event" of interest is not a discrete event, but a trend. The trend can be made discrete by selecting specific points from it. Thus, if a new technology has the potential to displace an older technology in a specific market, the trend in market share of the new technology may be represented in the model by a set of discrete events such as 10% penetration, 50% penetration, and 90% penetration of the market.

After the events are identified, the next step is to specify the cross impacts among the events. For each event in the model, it is necessary to determine which other events it can impact upon. The impacts must be stated in terms of change in timing and change in probability for the impacted event. The effects of both occurrence and nonoccurrence of the impacting event must be considered.

Changes in timing of an impacted event must be expressed in terms of a time period for delay or advance. That is, the impact may be stated in terms such as, if event A occurs, event B is advanced by two years from the time forecast for it without taking event A into account. The determination of the amount of advance or delay is made externally to the cross impact model. The cross impact model does not determine what the impact of one event is on another; this impact is an input to the model. These impacts, provided as input to the model, may be generated by a wide variety of means. They may be derived from other models, they may be derived from an analysis of the dependency of one event on another, or they may be derived judgmentally. One of the advantages of the cross impact model is its ability to accept and utilize estimated cross impacts from a variety of sources. As an example of how a change in timing can be estimated, consider a technology which is displacing an older technology in a particular market. The market penetration of the new technology will be described by a growth curve (this is discussed in more detail in Section 6). The growth curve will be characterized by a number known as the T-time (it takes four T-times to go from 1% market penetration to 99% market penetration). Assume that the occurrence of a specific event is judged to slow the penetration of the market by the new technology, and this slower penetration is represented by a new growth curve with longer T-time. Then the times for 10%, 50%, and 90% penetration of the market can be computed using the new, slower growth curve. The time differences between achievement of these penetration levels with and without the occurrence of the impacting event then represent the impacts of this event. The impacts can be expressed directly as a specific number of years delay for each of the three events: reaching 10%, reaching 50%, and reaching 90% of the market. In this case, the impacts are determined by a combination of judgment (change in T-time) and the use of a growth curve model for market penetration.

In addition to changes in timing, an impacting event may change the probability of an impacted event. However, a conceptual problem can arise as to whether a potential future event can be assigned a probability in the first place. Only if a probability can be assigned in the first place does it make sense to talk about changing the probability of the event. In this report, we explicitly adopt the viewpoint presented by Tribus [1], and treat probability as the quantification of inductive logic. Assigning a numerical probability to an event means to encode numerically all the information available about that event. When more information is obtained about the event, such as learning the outcome (occurrence or nonoccurrence) of some related event, encoding the

[1] Myron Tribus, "Rational Descriptions Decisions and Designs", Pergamon Press, New York, 1969.

additional information results in a change to the number assigned as the probability of the event. Ordinarily, the chief reason for encoding information about an event is to be able to communicate that information to other persons. However, as Tribus shows, an encoding scheme which satisfies certain requirements (consistency, continuity, and universality) must be equivalent to Bayes' rule for combining probabilities. Hence, once our state of information about an event is encoded numerically, we can treat this number as though it were a classical probability, and utilize it in a Monte Carlo simulation scheme. Moreover, we can alter this number as a consequence of obtaining additional information. Thus, during a particular simulation run, once the outcome for an event has been determined, the information about occurrence or nonoccurrence can then be utilized to alter the probabilities assigned to other events (for the remainder of that run only, of course). Thus, during a single simulation run, each event is tested in turn for its outcome, and the information thus obtained is used, according to the cross impacts supplied as input, to alter the probabilities assigned to other events.

A specific feature of the cross impact model is that the input data is limited to pairwise impacts only. That is, the model builder is required to specify the impact of event A on event B. He is not asked to specify how the impact of event A on event B is altered by the outcome of event C. In terms of information demanded of the model builder, it is explicitly assumed that these higher order interactions are negligible. It might be argued that these higher order impacts should be included to make the model more realistic. However, any argument for demanding not just pairwise impacts but impacts with the events taken as triplets, for instance, could logically be extended to higher and higher orders. Ultimately, if there were n events in the model, the model builder could be required to specify impacts of order (n - 1) for each event. This is asking too much. In general, it is not possible to provide that much information about a situation. Thus, as a practical matter, the cross impact model is specified in terms of pairwise impacts.

The model builder is not required to specify higher orders of impact, because, in general, it will not be possible for him to do so.

In the actual running of the model, there may well be multiple impacts on the same event. However, the input data specified only the individual impacts, taken one at a time, on the impacted event. The model must be able to combine impacts in order to carry out a simulation. Since the effect of multiple impacts is not specified by the input data, it must be computed by an appropriate algorithm during the simulation run. Many algorithms for combining impacts have been proposed in the literature [2 - 6]. All the proposed methods are supported by rationales which allege they represent the way impacts are "really" combined in the world; all are different; none are obviously superior to the rest. The algorithm utilized in the cross impact model is based on one of those found in the literature, but it has been simplified to make its operation more transparent. The algorithm actually involves two separate algorithms; one for changing probabilities, and one for changing timing.

Consider first the changing of probabilities. Let P be the initial probability of an event, and denote by β the magnitude of impact on P. Positive values of β increase P; negative values of β decrease P; and β is restricted to lie in the range of -1 to 1. The final probability of the event is given by:

$$P' = P + (1 - P)\beta \qquad \beta > 0$$

$$P' = P + \beta P \qquad \beta < 0 \;.$$

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[2] T.J. Gordon & H. Hayward, "Initial Experiments with the Cross Impact Matrix Method of Forecasting", FUTURES, December 1968.

[3] Norman C. Dalkey, "An Elementary Cross Impact Model", TECHNOLOGICAL FORECASTING & SOCIAL CHANGE, Vol. 3, 1972.

[4] Murray Turoff, "An Alternative Approach to Cross Impact Analysis", TECHNOLOGICAL FORECASTING & SOCIAL CHANGE, Vol. 3, 1972.

[5] J.C. Duperrin and M. Godet, "SMIC 74--A Method for Constructing and Ranking Scenarios", FUTURES, Vol. 7, No. 4, 1975.

[6] Olaf Helmer, "Problems in Futures Research", FUTURES, Vol. 9, No. 1, 1977.

In practice, the equations are used in reverse. An event has an initial probability P and after impact by another event is to have a different probability P'. These values for P and P' can be used to compute β. The value of β is then provided as input to the model. If only the one impact affects the event of interest, the input value of β changes the probability to the value P' used to compute β. In this case, the specific algorithm used to compute the change in probability is of no significance, since any algorithm will simply give back the value of P' which was used to compute the input value of β. The important issue is that of multiple impacts. We argue that an individual impact should make an adjustment in probability which is related to the "distance to go". That is, if the probability is to be increased, the magnitude of the increase should be related to the value (1 - P); if the probability is to be decreased, the magnitude of decrease should be related to the value P. The relationship given above is about the simplest possible which has this property. Furthermore, it should be a matter of indifference whether an event E, or its opposite (the negation of E), is inserted in the model. Thus, the final probability of E after the impact should be the same whether E or negation of E is the event in the model. The relationship given above is one of the few which also have this property. Hence, both its simplicity and its logical consistency support its use as the algorithm for computing changes in probability. Thus, suppose an event E_1 is impacted by two other events E_2 and E_3, in that order, which have impacts β_2 and β_3, respectively, with both less than zero (i.e., both decrease the initial probability). The final probability is then

$$\begin{aligned} P'' &= P' + \beta_2 P' \\ &= P + \beta_1 P + \beta_2(P + \beta_1 P) \\ &= P(1 + \beta_1 + \beta_2 + \beta_2\beta_1) \ . \end{aligned}$$

The effects of additional impacts, both increasing and decreasing the probability of E_1, can be combined in the same way. The important point is that the algorithm for changing probability matters only when there are multiple impacts. When an event can receive only one impact during a simulation run, any algorithm must give back the probability values used in computing the impact factor input to the model. When an event receives multiple impacts, the algorithm must satisfy certain criteria, including simplicity and logical consistency. We have used one of the simplest possible algorithms which also is logically consistent.

Consider next the changing of the timing of an event. Much the same arguments apply to this algorithm as were applied above to the algorithm for changing probabilities. The following relationship is used:

$$Y_2' = Y_2 + (Y_2 - Y_1)\alpha \qquad \alpha < 0 \text{ (advancing date)}$$

$$Y_2' = Y_2 + (Y_3 - Y_2)\alpha \qquad \alpha > 0 \text{ (delaying date)}$$

where

Y_1 = current year of the simulation, and, therefore, year of impacting event;

Y_2 = year of impacted event, which is to be changed to Y_2'; and

Y_3 = time horizon of the simulation, part of initial data input.

This algorithm also changes the timing of an event by an amount related to "distance to go". In the case of an advance of the impacted event, the amount of the advance is a constant fraction of the interval between impacted and impacting event; in the case of a delay of the impacted event, the amount of delay is a constant fraction of the interval between impacted event and a time horizon which has been selected as the last year of the simulation, such that all events of interest occur well before the time horizon. Again, if an event can receive only one impact during a simulation run, the form of the algorithm is irrelevant; any acceptable algorithm must give back the values used to compute the input value of the impact factor. The algorithm above satisfies the criteria of simplicity and logical consistency when utilized to combine the timing changes resulting from two or more impacts.

2.3 OUTPUT SCENARIOS

As pointed out above, each individual run is, in fact, a scenario, involving a synthetic future history in which certain events occur and others do not occur. In a model with n events, there are 2^n possible scenarios, each differing from all others on the occurrence of at least one event. For any model of practical use in decision making, n will be large, and 2^n an immensely large number. It would not be possible to examine even as many as 1% of all the possible scenarios in a large model. Even with the number of output scenarios being limited to merely enough for statistical validity of the results, there are too many scenarios to examine each in detail. What is needed is some means of identifying a few typical scenarios, or groups of similar scenarios, so these may be examined in detail. We next examine how this is done in the model we have developed.

If we designate occurrence of an event by a "1" and non-occurrence by a "0", we can describe each scenario as a sequence of 1's and 0's. Consider a cross impact model with only three events. There are eight possible scenarios as outcomes, which will be designated: 0,0,0; 0,0,1; 0,1,0; 1,0,0; 0,1,1; 1,0,1; 1,1,0; 1,1,1. These can be represented as the eight vertices of the unit cube, as shown in Figure 2.1 (i.e., a cube with edges one unit long). This can be generalized. If there are n events in a cross impact model, each possible scenario is one of the vertices of the unit hypercube in n-dimensional space. If two scenarios differ on only a single event, they will occupy adjacent vertices on the unit hypercube. If they differ on only a few events while being identical on many others, they will occupy nearby vertices on the unit hypercube.

Not all the scenarios are equally likely to come about in the real world. Because of the differing probabilities of individual events, and the linkages among events represented by the cross impacts, some of the scenarios are much more likely to happen than are others. From a standpoint of more immediate interest, some of the scenarios are more likely to show up in the output of a Monte Carlo simulation than are other scenarios. That is, some of the

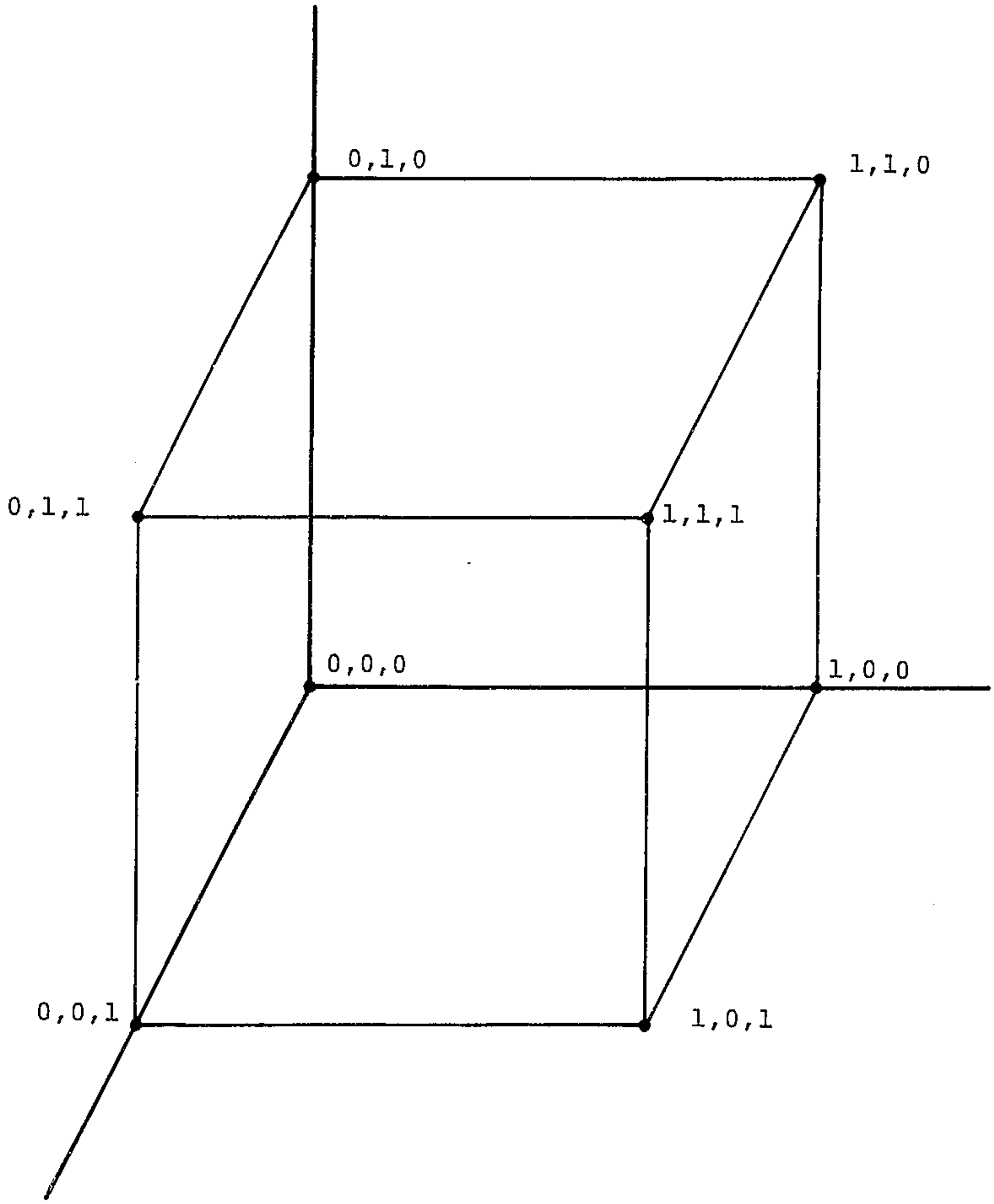

Figure 2.1. Cross Impact Model Outcomes as Vertices of the Unit Cube.

scenarios are more likely to be found among the outputs of the cross impact model than are others. Moreover, if two scenarios differ by only a single event, or by only a few events, while being identical on many events, their overall probability of occurrence will be approximately the same (whether relatively high or relatively low by comparison with other scenarios).

Recognizing that scenarios which are similar (in the sense of differing on only a few events) will have about the same probability of occurrence, and will lie near each other on the unit hypercube, we see that the surface of the unit hypercube will be divided into different regions, with the scenarios in any region being roughly alike, and having approximately the same probability. The problem of finding typical scenarios, or groupings of similar scenarios, becomes one of identifying these distinct regions on the surface of the unit hypercube.

Cluster analysis is a means for grouping items on the basis of their similarity with one another, or their closeness to one another. A complete description of cluster analysis methods, including suitable computer programs, can be found in Reference 7. Selection of a cluster analysis method means selection of a "distance measure" which gives a numerical measure of the distance between any pair of the items to be subjected to clustering, and selection of a rule for adding items to already existing clusters.

The distance measure used in the clustering procedure must meet two different types of criteria. First, it must be intuitively satisfactory to the user, in that if two items are judged as being similar, the distance measure must assign a small number to the distance between them, while if two items are judged as being dissimilar, it must assign a large number to the distance between them. That is, the ranking of the assigned distance numbers must agree with the user's judgment of the relative similarity of each pair of items. If a measure is not intuitively satisfactory, the clusters will be unacceptable. Second, the distance measure must

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[7] Michael R. Anderberg, "Cluster Analysis for Applications", Academic Press, New York, 1973.

satisfy a set of mathematical criteria which make it "distance-like". These are: the distance from a point to itself must be zero; the distance from point A to point B must be the same as the distance from point B to point A (i.e., direction of the route must not change the distance measure); for any set of three points, considered as the vertices of a triangle, the length of any two sides of the triangle must be greater than the third side. If a distance measure fails to be distance-like, by failing to satisfy one or more of these criteria, it will produce unacceptable clusters, or may cause the program to fail to run.

The distance measure selected for use with the cross impact output scenarios is simply the number of events on which two scenarios differ. This is intuitively satisfactory, in that the more events on which two scenarios differ, the more unlike they are. This distance measure also satisfies the mathematical criteria. From the Pythagorean Theorem, it can be seen that the squared distance between any two vertices on the unit hypercube is equal to the number of edges on the shortest path between the vertices, where the path is restricted to the edges and may not cross a face diagonally. Thus, the number of events on which two scenarios differ is also the squared Euclidean distance between them, when they are viewed as vertices of the unit hypercube.

The simplest rule for forming clusters is to add points to a cluster on the basis of their nearness to the edge of the cluster. This rule minimizes the computer storage required. However, this rule can result in clusters which are long and "snake-like". For the purpose of clustering scenarios on the basis of similarity, it seems more desirable to have clusters which are compact, and in which each point added to a cluster is similar to all other points already in the cluster, not merely similar to a few points on the nearest edge. Thus, even though it increased the requirements for computer storage, the clustering rule selected added points to clusters in such a way as to minimize the mean squared distance among the points in each cluster. Thus, the clusters tend to be compact rather than extended.

Once most of the scenarios have been incorporated into clusters, the program begins merging clusters, following the same rule of minimizing the mean square distance among scenarios in the clusters. The clustering process continues until all scenarios have been merged into one cluster. The scenarios are thus grouped into nested sets, on the basis of common patterns of occurrence or nonoccurrence of events. As larger clusters are formed, naturally the scenarios within a single cluster tend to be less and less alike. The final cluster, which contains all scenarios, merely represents the culmination of this process.

The model output includes a stage-by-stage description of the clustering process, so that at each stage, the clusters can be identified. Moreover, specific clusters can be traced forward to see what other clusters they are merged with, or backward to see what clusters were merged to form them. Having the program carry the clustering process to completion in this way simply means that the user does not need to determine a "stopping rule" ahead of time. He can examine the complete clustering history, and select those clusters of interest for additional analysis.

2.4 SELECTION OF CLUSTERS FOR ADDITIONAL INVESTIGATION

Clusters could be viewed as aggregations of similar scenarios as explained earlier. Now the question is to select an adequate and succinct measure to represent the whole cluster. Individual members of clusters are characterized by a sequence of 0's and 1's which indicate the occurrence or nonoccurrence of events. Because such characterizations can be handled easily by computer, a simple statistic such as the mean vector or centroid of a whole group of scenarios is appropriate to describe the characteristics of clusters. That is, the centroid of a cluster (which simply means the average frequency of occurrence for each event) is selected to represent the cluster. In addition, the variance of the cluster is calculated at each clustering stage. It denotes the degree of dissimilarity among members in clusters, and is one consideration in selecting clusters for additional analysis. The more unlike each other the cluster members are, the greater is the variance of the cluster, since it is the mean square distance of the cluster members from the centroid.

A typical distribution of the variance of clusters is illustrated in Figure 2.2. The distribution of the variance of clusters is an increasing function of clustering stages. In Figure 2.2, one may observe the sharp change in average slope after about the 90th clustering stage. The clusters formed at late stages of the clustering process contain highly dissimilar members and are not of much practical interest. On the other hand, clusters formed early in the clustering process possess small variances and small numbers of members as well.

The number of members included in each cluster is another consideration in selecting clusters for additional analysis. Clusters having small variance may be too small to be worth examining in detail. The typical sizes of clusters before stage 50 are 2 and 3 in the example of Figure 2.2. The average size of clusters between stage 51 and stage 80 is about 5. The size continues to increase as the clustering process proceeds. The number of members of the clusters increases rapidly at late stages of the clustering process. Average sizes for stage 81 to stage 90, and stage 90 to stage 99, are 13 and 34, respectively. Clusters aggregating about 10% to 20% of specified sample runs are more meaningful for practical purposes.

Thus, the range of clusters to be selected for analysis is bounded on the lower end by cluster size, in that clusters which are too small are not worth investigating, and on the upper end by cluster variance, in that cluster variance should be small enough to indicate that members of each cluster are highly similar. In the example illustrated in Figure 2.2, clusters generated between stages 70 and 90 are fruitful candidates for further investigation.

The centroid of a cluster indicates the average frequency of occurrence for events in the cluster and for this reason has been selected as the statistic to represent clusters. Furthermore, the final cluster contains all scenarios, and its centroid is there-

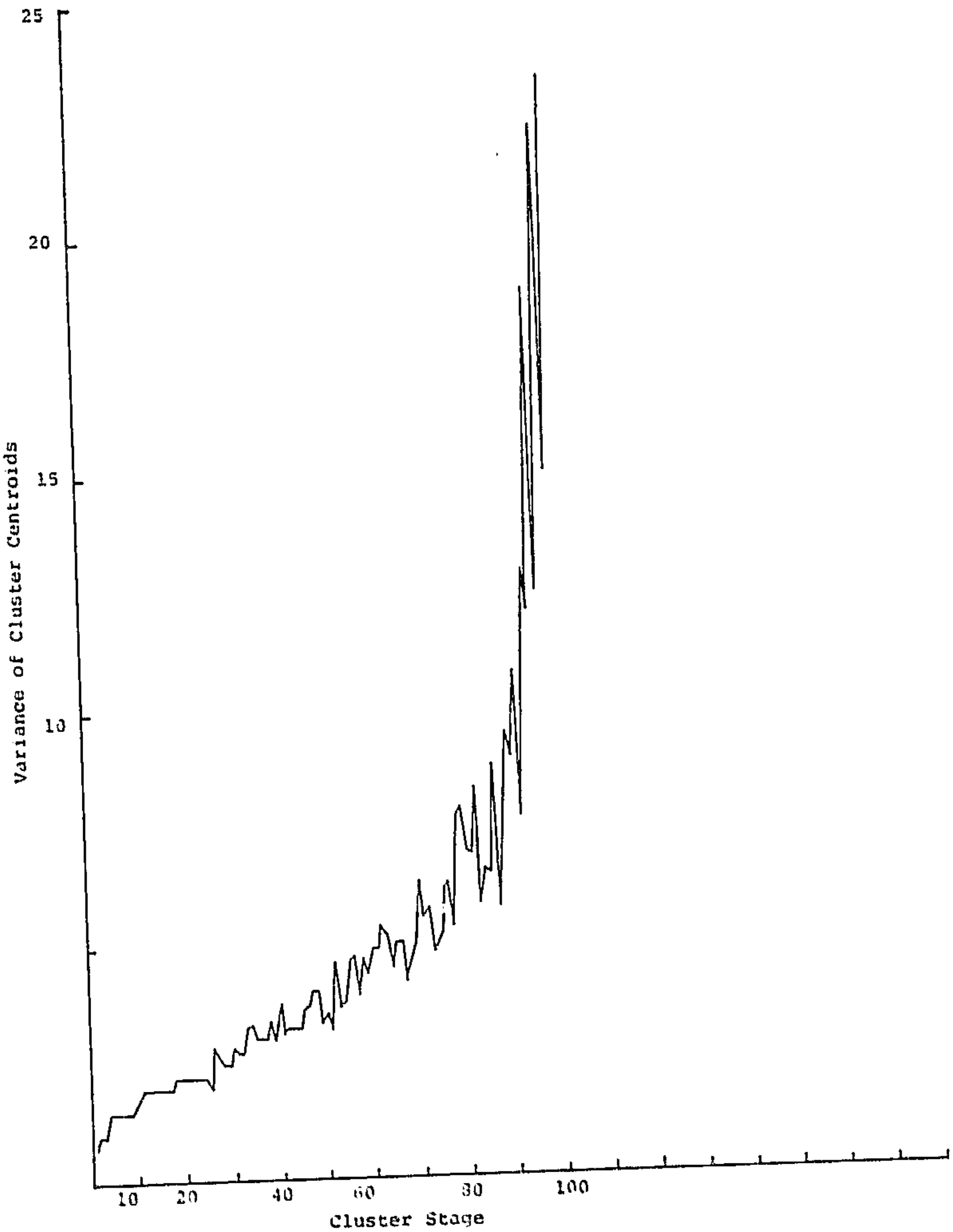


Figure 2.2. Distribution of Variance of Cluster Centroids

fore the average frequency of occurrence for events in all runs. The significance of an individual cluster lies in the extent to which its centroid deviates from the overall averages. The pattern of deviation from the overall average is what makes the cluster distinct from the others. This pattern of deviation is then important in trying to identify critical events which, by occurring much more or much less often than average, cause other deviations from the average to occur. Significant levels of deviation (such as 20%) may be imposed in the effort to extract contrasts of cluster characteristics. This is presently performed by manual observation of the printout of deviations; the computer program could be altered to provide this screening. A simple graph, such as Figure 2.3, portraying significant contrasts of cluster centroid deviations from the final centroid, has proved useful in identifying critical events of each selected cluster.

2.5 REPEATABILITY OF CLUSTERS

One important and desirable feature for a forecasting methodology is its repeatability. This property enables forecasters to expect the same or similar forecasting results provided the same methodology and the same inputs are used. If the cluster method did not give repeatable clusters, it would mean that the "typical scenarios" obtained from the clusters would be merely artifacts of the method, and would not represent meaningful outputs. Thus, it is necessary to show that two separate sets of runs have similar clusters in them. This can be done by correlating the cluster centroids obtained from one set of runs with the cluster centroids obtained from another set of runs. The result of correlation analysis on two sets of runs for general communication satellite systems is presented in Table 2.1.

The results include scenarios produced by the specified cross impact model and their subsequent clusters formed by the cluster analysis method. Monte Carlo simulation was used to generate scenarios in the cross impact model. A random seed number was

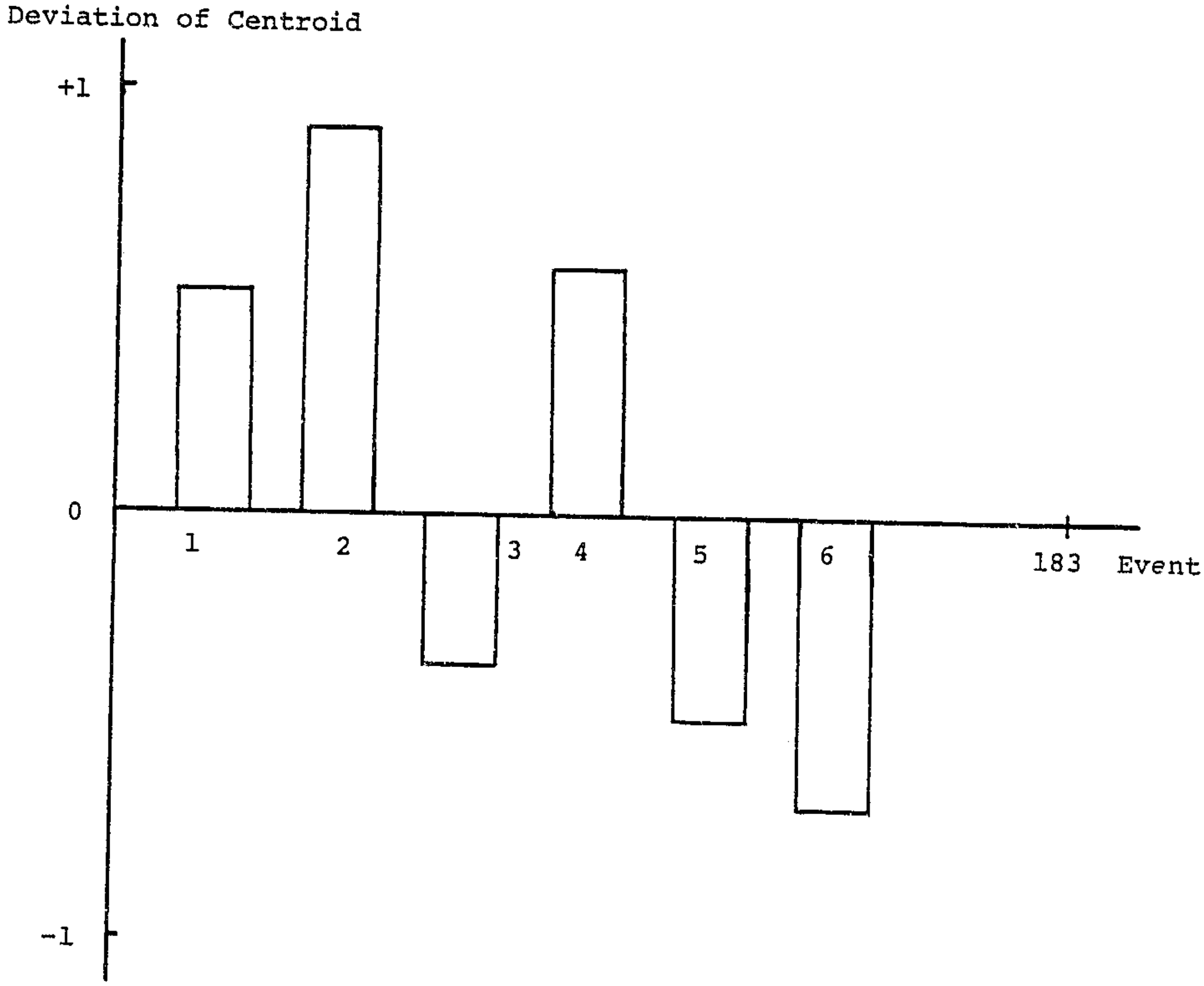


Figure 2.3 Deviation of the Centroid of a Typical Cluster

TABLE 2.1

CORRELATION COEFFICIENTS BETWEEN CLUSTERS OF TWO RUN SETS

RUN SET

Cluster Stage (RUN SET B)	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98
80	-0.207	0.082	-0.204	0.956	-0.693	0.958	-0.542	0.280	0.953	-0.253	-0.672	-0.215	0.219	-0.652	-0.705	-0.508	0.083	-0.811	0.811
81	-0.087	-0.150	-0.092	-0.363	-0.131	-0.361	0.055	-0.252	-0.357	-0.054	-0.150	0.896	-0.231	0.572	-0.106	0.841	-0.251	0.447	-0.447
82	-0.192	-0.219	-0.211	-0.421	0.471	-0.426	0.889	-0.200	-0.446	-0.187	0.471	0.054	-0.229	0.240	0.642	0.173	-0.316	0.559	-0.559
83	0.268	-0.282	0.222	-0.603	0.[illegible]03	-0.623	0.382	-0.389	-0.620	0.279	0.907	-0.232	-0.380	0.332	0.849	0.069	-0.227	0.639	-0.639
84	-0.072	0.713	-0.022	0.236	-0.495	0.252	-0.446	0.928	0.241	-0.088	-0.482	-0.429	0.925	-0.618	-0.522	-0.608	0.851	-0.744	0.744
85	0.013	-0.421	-0.004	-0.648	0.504	-0.654	9.411	-0.512	-0.649	0.028	0.532	0.389	-0.523	0.842	0.553	0.720	-0.492	0.835	-0.835
86	0.110	-0.380	0.084	-0.603	0.640	-0.620	0.790	-0.437	-0.619	0.117	0.642	0.047	-0.456	0.525	0.753	0.339	-0.382	0.740	-0.740
87	0.249	-0.170	0.275	-0.623	0.811	-0.619	0.320	-0.325	-0.618	0.284	0.865	-0.272	-0.288	0.302	0.796	0.029	-0.135	0.578	-0.578
88	-0.198	0.122	-0.190	0.958	-0.672	0.960	-0.567	0.266	0.958	-0.242	-0.687	-0.217	0.228	-0.651	-0.724	-0.509	0.098	-0.825	0.825
89	0.786	0.061	0.810	-0.212	0.005	-0.204	-0.346	-0.093	-0.198	0.864	-0.009	-0.205	-0.033	0.110	-0.108	-0.049	0.406	-0.107	0.107
90	-0.026	0.819	0.010	0.211	-0.507	0.224	-0.477	0.894	0.227	-0.041	-0.503	-0.445	0.950	-0.608	-0.548	-0.611	0.899	-0.764	0.764
91	0.274	-0.246	0.261	-0.648	0.910	-0.654	0.374	-0.381	-0.652	0.296	0.936	-0.262	-0.359	0.336	0.871	0.054	-0.197	0.646	-0.646
92	0.063	-0.313	-0.086	-0.540	0.588	-0.552	0.910	-0.328	-0.563	-0.056	0.589	0.055	-0.355	0.394	0.745	0.266	-0.372	0.688	-0.688
93	-0.128	-0.284	-0.138	-0.161	-0.230	-0.158	-0.011	-0.347	-0.153	-0.100	-0.251	0.964	-0.354	0.512	-0.207	0.843	-0.393	0.377	-0.377
94	0.180	0.780	0.219	0.142	-0.472	0.157	-0.535	0.810	0.161	0.186	-0.471	-0.469	0.879	-0.539	-0.539	-0.583	0.945	-0.741	0.741
95	0.221	-0.337	0.205	-0.730	0.889	-0.737	0.434	-0.473	-0.734	0.244	0.919	-0.076	-0.460	0.549	0.874	0.285	-0.321	0.791	-0.791
96	0.117	-0.374	0.095	-0.745	0.874	-0.756	0.725	-0.473	-0.759	0.136	0.895	-0.025	-0.476	0.555	0.939	0.317	-0.392	0.857	-0.857
97	0.056	0.478	-0.031	0.777	-0.731	0.786	-0.684	0.599	0.787	-0.085	-0.741	-0.393	0.605	-0.748	-0.802	-0.666	0.543	-0.977	0.977
98	-0.117	0.374	-0.095	0.745	-0.874	0.756	-0.725	0.473	0.759	-0.136	-0.895	0.025	0.476	-0.555	-0.939	-0.317	0.392	-0.857	0.857

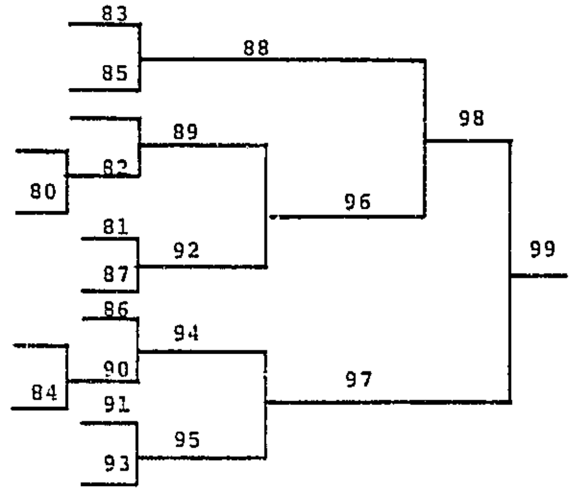
employed to initiate the Monte Carlo simulation. The random numbers generated are not identical between two sets of runs since different random seed numbers are used. As mentioned earlier, random numbers are used to test for occurrence or nonoccurrence of events which collectively characterize a scenario.

It has been suggested that the correlation analysis technique be used to examine the similarity between clusters produced by two different sets of runs. What kind of results can one expect from the correlation analysis? If the clusters were repeatable, we would expect at least one large correlation in each row and column of the cross correlation table, with the remainder being small correlations. In other words, under the hypothesis of the repeatability of clusters, at least one large positive correlation coefficient, e.g., 0.70 or over, between clusters of two sets of runs should be observed on the cross correlation table. Furthermore, more than one large correlation may exist due to the fact that a cluster from one set of runs correlates well not only with a similar cluster from the other set but also with subsets and supersets of that similar cluster.

Table 2.1 presents the result of the correlation analysis on the clusters formed during the last 19 stages of 2 sets of runs of a forecasting model concerning general satellite communication systems. These clusters posses characteristics which are more general as well as having higher probabilities of occurrence because of large size. Thus, a correlation analysis involving only these last 19 clusters from both sets of runs could be considered adequate for checking the repeatability of clusters. One may observe that more than one large correlation coefficient appears in each row and column in Table 2.1. Clusters associated with large correlation coefficients for the same row or column belong to the same path of the cluster tree shaped in the cluster analysis.

Simplified cluster trees of the two sets of runs are presented in Figure 2.4. Clustering stage 89 of run set B has three large correlation coefficients (0.786, 0.810, and 0.864) related

(a) Run Set A



(b) Run Set B

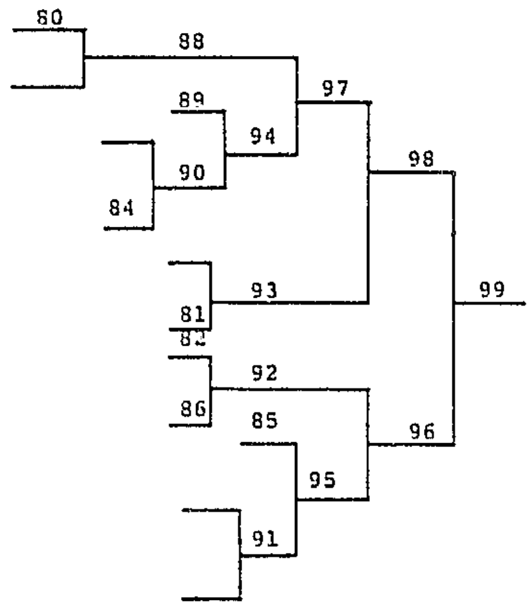


Figure 2.4. Simplified Cluster Trees

to the clustering stages 80, 82, and 89 of run set A, respectively. These three stages of run set A are in the same path of the cluster tree illustrated in Figure 2.4a. In other words, cluster 80 is a subset of cluster 82, and cluster 82 in turn is a subset of cluster 89. Similarly, subclusters and superclusters can be identified for run set B.

The high incidence of large correlation coefficients in Table 4.1 has adequately shown the repeatability of clusters. Therefore, one may confidently say "typical scenarios" obtained from the clusters are meaningful outputs.

2.6 MODEL OUTPUTS

This section describes in detail the output from the cross impact model. A complete printout from a sample problem, utilizing dummy data, is shown in Appendix 1. References are to pages in that Appendix.

2.6.1 Input Data

Input is shown on page A1-18. The first block of print-out represents the events entered into the model. They are identified as TESTEVENT1 through TESTEVENT6, and are listed in the first column. The prefix 1 on each event identifies the input card as an event card. The second column identifies whether the events are members of a set. Sets are related events which have different impacts. Only one event of a set may occur in any one run. None of the test events are members of a set. When two or more events are members of a set, they are assigned the same number in the second column. Sets are numbered in sequence, with all events in a set having the same set number. The third column gives the first year in which an event may occur (barring a shift during a run, as a result of an advancing or delaying impact). The fourth column lists the number of years during which an event may occur (again barring a shift during a run). All of the events shown may occur in only a single year, and with no impacts, this will be the year in column 3. If an event can occur in more than one year, the appropriate number (not greater than 10) must appear in column 4.

The fifth column gives the probability of occurrence of the event (which also may be altered by impacts during a run). The sixth through fifteenth columns give the conditional probability of occurrence during each year of a span of time. For instance if column 4 shows than an event can occur any time during a period of 3 years, columns 6, 7 and 8 must show the conditional probabilities of occurrence in those three years (one or more of the probabilities may be zero; the sum must total 1.00). The only exception to this is that members of a set have their conditional probability of occurrence in the sixth column. Each member of the set must be assigned a probability of occurrence, and these conditional probabilities must sum to 1.00.

2.6.2 Time of Occurrence

The first portion of the output is shown on pages A1-19 and A1-20. The first column is the event name. Each column entry is the fraction of the runs in which the event occurred in the year given at the top of the column. The table is a histogram, giving relative frequency of occurrence by year. The last column, on A1-20 after the column for the year of the time horizon, is the total frequency of occurrence of the event in all runs. For instance, TESTEVENT1 occurred in 45% of all runs.

2.6.3 Frequency of Joint Occurrence

The frequency with which two events occurred in the same run is given in the table beginning on page A1-B-18. TESTEVENT1 and TESTEVENT2 never occurred in the same run; TESEVENT1 and TESEVENT3 occurred together in 20% of the runs; TESTEVENT2 and TESTEVENT3 occurred together in 29% of the runs. TESTEVENT2 and TESTEVENT4 were shown in the input as having probability of occurrence of 1.00 each. Thus it would be expected that the frequency of joint occurrence would be 1.00 instead of the .29 shown in the table. The reason for the deviation is the impacts on TESTEVENT2 and TESTEVENT4 of TESTEVENT1 and TESTEVENT3 respectively. Thus the deviation of a frequency of joint occurrence from that which would have been expected on the basis of their input probabilities indicates an interaction, which can be traced through a chain of impacts which were also provided as input. The frequency of joint occurrence is known as the Russell & Rao coefficient (7).

2.6.4 Conditional Frequency of Joint Occurrence

In some cases, it is of interest to know not just how often two events occurred together, but how often they both occurred in those runs in which at least one occurred. This is known as the Jaccard coefficient (see Ref. 7), and is given on page A1-30. For instance, of those runs in which at lease one of TESTEVENT1 and TESTEVENT3 occurred, both occurred in just over 27%. In general, the Jaccard coefficient will be larger than the Russell & Rao coefficient, since it counts only those runs in which at least one of the events occurred.

2.6.5 Scenario Cluster Tree

As described earlier, the runs are merged into nested clusters on the basis of their similarity to one another. As shown above, these nested clusters can be diagrammed in tree form. Such a tree diagram is also part of the model output, and is displayed on pages A1-28 and A1-29. The numbers shown in the left margin and again at the base of the tree are arbitrary numerical designators assigned sequentially to the runs as the simulation is repeated the required number of times. They have no significance except to identify a specific run. The numbers across the top and bottom of the tree diagram are a measure of the squared error S associated with the formation of a given cluster at a particular stage of the clustering process. S is the mean square distance of points from cluster centroids for all points included in a cluster up to that stage in the clustering process. As more points are merged into clusters, naturally this measure of error or "force-fit" increases. The value of S at each cluster stage is given on pages A1-26 and A1-27. The column heads IS gives the scaled value of S used on the tree diagram. This scaling is done by dividing the difference between the minimum and maximum values of S into 25 equal intervals. Each cluster stage is then assigned to one of these intervals, according to the value of S at that stage, and is displayed in the cluster tree as occurring at a specific scaled value. The range included in each scale interval is also given on page A1-25.

2.6.6 Run Cluster Centroids and Variances

Each cluster is characterized by its centroid, which is treated as being representative of that cluster. The cluster centroids are printed on pages A1-21 through A1-24. The column headed "stage" gives the stage of the clustering process, and runs sequentially from 1 to 99. The next column, headed I, is the smallest run number included in the cluster. This number is used internally within the program to identify the cluster (these run numbers are those mentioned above in the discussion of the cluster tree). The column headed NUMBR(I) is the number of runs in the cluster. The column headed VARIANCE gives the variance of the cluster. As stated earlier, this is the mean square distance of the runs in the cluster from the cluster centroid. The block of data under the heading CLUSTER CENTROID is the centroid. The entries are the average number of times a given event occurred, among all the runs in the cluster. The cluster formed at stage 1 has only two runs in it, so the only possible average values for an event are 0.0, 0.5 and 1.0. The entries start with TESTEVENT1 at the left end of the row, running through TESTEVENT6 at the right end of the row. If there were 10 events, a second row is formed running from event 11 through event 20, etc.

2.6.7 Cluster Deviations from Average

While the cluster centroid can be considered a typical representation of a cluster, it is not directly meaningful. It must be interpreted by comparison with the average frequency of occurrence for each event in all 100 runs. What is of interest is whether a given cluster shows average, higher than average, or lower than average frequency of occurrence for a given event. The average frequency of occurrence has already been mentioned as being printed out at the end of the "Frequency of Occurrence by Year" table. However, it also appears as the centroid of Cluster 99, which includes all runs. Thus, the deviation of cluster centroids from the average over all runs is shown on pages A1-35 through

A1-38, under heading "Deviation of Cluster Centroid from Final Cluster Centroid." This is computed simply by subtracting the centroid of cluster 99 from the centroids of the preceding clusters. The remaining entries on these pages are simply repetitions of the identical entries on the table of centroids.

A graphical presentation of these deviations of cluster centroids is shown on pages A1-39 through A1-44. Cluster stages 81 through 98 are included in this graphical display. Each "*" represents a deviation of .05. If the display is to the right of the centerline for each cluster stage, this represents a positive deviation. A negative deviation is shown by a display to the left of the centerline. The events are identified by name in the left-most column on the page.

2.6.8 Event Cluster Tree

An important element of the model output is the identification of events which are related in the sense that they tend to occur together. One portion of the program output is related specifically to the similarity of events. This is the event cluster tree, shown on page A1-33. This cluster tree is formed in much the same way as the scenario cluster tree. The similarity measure used to determine the degree of relationship between two events is the Jaccard coefficient (p. A1-30). The matrix of Jaccard coefficients is subjected to cluster analysis in the same manner as were the simulation runs (individual scenarios). The cluster stages are listed on p. A1-32, and the bounds for the 25 scale intervals are shown on p. A1-31. The event cluster tree is interpreted in the same manner as is the run cluster tree. Events which are joined together in clusters early in the clustering process are similar (have large Jaccard coefficients) in that if one of them appears in a scenario, the other tends to appear also. As the clusters grow larger, they tend to contain events which, taken pairwise, have large Jaccard coefficients. Eventually, of course, all events are forced into a single cluster. Thus, it is possible to select meaningful clusters part-way through the clustering process, to identify those sets of events which are highly similar, but which as sets are different in their patterns of occurrence from events in other clusters.

SECTION 3

APPLICATIONS AND TRAFFIC

3.1 INTRODUCTION

This section presents estimates of the telecommunications traffic which might arise from the development and commercialization of various potential applications. In each case, the application is described, and the basis for computing potential traffic load is specified. The various applications are grouped by major users. No implication is intended that, because several applications are grouped together, they should be satisfied by the same technical means. In most cases, the traffic load is computed in terms of equivalent wide-band satellite channels. Again, no implication is intended that satellites provide the most effective means of satisfying a given application. The expression in terms of satellite channels is intended to be utilized in comparing and adding various demands which might be imposed on satellites. Alternative means might be more effective for specific applications, however.

3.2 CONVERSION STANDARDS

Certain standards are assumed for channel capacities, bandwidths, etc. These are presented here, and will be utilized later in this section.

3.2.1 Voice Channel

A voice channel is taken to be 4 kHz. The digital capacity of this channel is taken to be 4800 bits/second. If the voice transmission is digital rather than analog, however, the required channel capacity is 64,000 bits/second. This is computed as requiring sampling at 8 kHz, with samples requiring 8 bits for transmission. Thus, to send a single voice transmission by digital means will require 64,000/4800 or 13-1/3 voice channels.

3.2.2 Wide-Band Channel

A wide-band channel is taken as the equivalent of one video channel, or 6 MHz. This is equivalent to 1500 simplex voice channels, and therefore the data capacity of a wide-band channel is 7.2 million bits/second.

3.2.3 Teletype

Teletype, or other similar transmission means, is taken as 30 characters per second. Each character is assumed to require 6 bits for transmission. Thus, the teletype is taken as 180 bits/second.

3.2.4 Facsimile

One page is taken as 22 x 28 cm (8-1/2 x 11 inches). The resolution is taken as 40 scans per cm (approximately 11 scans per inch). Thus, one page contains 985,000 (approximately 1 million) picture elements (pixels). At two levels of gray (e.g., black or white), one bit of information must be transmitted per pixel. Thus, one page requires one million bits. For higher quality facsimile, with 64 levels of gray (suitable for reasonable-quality pictures), 6 bits must be transmitted for each pixel, requiring 6 million bits per page.

3.2.5 Reading

Reading speed is taken as 200 words per minute. Each word is assumed to be 5 letters or 6 characters (including the space). Each character requires 6 bits for transmission. Thus, the average reading rate requires a channel capacity of 100 bits/second.

3.3 BUSINESS OFFICES/ESTABLISHMENTS

The following applications and traffic demands are those which originate in business offices and establishments, or arise from their activities.

3.3.1 Electronic Paychecks

Direct electronic transfer of paychecks from businesses to employee banks would present the following data load. In 1975, there were 76,080,000 employees in nonagricultural establishments (including government). A paycheck requires 240 bits. Thus, 80 million paychecks require 1.92×10^{10} bits. If all paychecks are transmitted in an 8-hour period, the data rate is 6.67×10^{5} bits/second, equivalent to .093 wide-band channels.

3.3.2 Check/Credit Card Verification

Currently there are 61.4×10^{9} retail transactions per year. We assume that 50% of these require verification of checks or credit cards. At 240 bits per transaction, this is 7.37×10^{12} bits/year. Allowing 7 days per week, 12 hours per day, the data rate becomes 4.67×10^{5} bits/second, equivalent to .065 wide-band channels.

3.3.3 Data Base Search

In 1975, there were 12,780,000 professional or technical workers in the population, and 8,612,000 managers or administrators. We assume that each of these persons makes one data base search per month. Each search takes 15 minutes, and the searches are spread out over 12 hours per day, 21.67 working days per month. Data rate is limited to the user's reading rate (even if it is transmitted more rapidly, there will be idle time while the user catches up with the transmission). This comes to 2.06 million bits/second, equivalent to .286 wide-band channel.

3.3.4 Computer Conferences

A computer conference involves persons at two or more locations, utilizing terminals equivalent to teletypes, who transmit messages to a computer for storage and later transmission to other participants in the conference, and receive messages stored by the computer for them. Not all persons in the conference need be "on line" simultaneously. We assume that managerial and administrative personnel spend 1 hour/day in computer conferences, spread over a 12-hour day. For 8.6 million people, this requires 1.29×10^{8} bits/second, equivalent to 18 wide-band channels.

3.3.5 Telecommuting by Employees

Telecommuting is a possible substitute for travel to and from the workplace. Instead of travelling to the workplace, the worker transmits information which is then provided to others at the workplace. It is assumed that all information transmitted to others is processed by a clerical worker. There are 15.2 million clerical workers in the population. Each is assumed to spend 4 hours per day of "word processing" at 100 words/minute, spread over a 12-hour day. This comes to 2.5×10^8 bits/second, equivalent to 35.15 wide-band channels. This number might be doubled if the material is sent back to the originator for checking, and tripled if it is then sent on to a third party.

3.3.6 Point-of-Sale Electronic Funds Transfer

If all 61.4×10^9 retail transactions per year involve electronic funds transfer, at 240 bits per transaction, spread over 7 days per week and 12 hours per day, the traffic comes to 9.35×10^5 bits/second, equivalent to .13 wide-band channels.

3.3.7 Video Conference

Video conferences could be conducted as a substitute for business trips. We assume that 20% of U.S. air trips are made for business purposes. A factor of 4 increase in the U.S. air travel volume between 1974 and 2000 is projected. In addition, only 50% of business trips will be expected to be substituted by video conference at saturation stage. Thus, the traffic volume generated by the application of video conference could be estimated as 30,000 wide-band channels. This estimate is close to one made in another study.[1]

3.4 SPECIAL BUSINESS APPLICATIONS

The following applications are specialized in nature, being peculiar to particular business operations.

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[1] Future Systems Inc., 1977. A 25-Year Forecast for Commercial Communications Satellites and the Congestion of the Geostationary Arc, Gaithersburg, Maryland.

3.4.1 Pipeline Network Status

There are about 285,000 km of pipe used for petroleum transportation; about 442,000 km of pipe used for gas transmission; and about 2,170,000 km of pipe used for gas gathering and distribution. We assume another 2,170,000 km of pipe for water gathering and distribution. This is approximately 5 million km of pipeline. We assume a sensor every kilometer, which reports 10 bits of information every hour. The sensors thus generate 1.38×10^4 bits/second, equivalent to .00192 wide-band channels.

3.4.2 Railroad Car Location

There are about 1,400,000 freight cars in the U.S. We assume these are to report their location twice daily. The location is to be reported precise to 30 meters, requiring 36 bits for location, and an additional 20 bits to identify the car. We assume a total of 60 bits per car. Spread over 24 hours, this comes to 1944 bits/second. If all reporting is concentrated in two one-hour periods, the rate becomes 23,333 bits/second, equivalent to .00324 wide-band channels.

3.4.3 Train Location for Traffic Control

There are about 30,000 locomotives in operation in the U.S. We assume an average of 3 per train, including those out of service for maintenance. Thus, on an average day, there will be 10,000 trains operating. Train location is to be reported accurate to 30 meters, which requires 36 bits. An additional 14 bits are required to identify the train. If each train reports every second, the traffic load is 5×10^5 bits/second, equivalent to .07 wide-band channels.

3.4.4 Facsimile to/from Trains

We assume 10 pages per day per train (manifests, orders, etc.). The pages are assumed text only, requiring 10^6 bits per page. The resulting 10^{11} bits per day would require .16 wide-band channels if transmission were distributed uniformly throughout the day. With an assumed 3:1 peak to average factor, the requirement rises to .48 wide-band channels.

3.4.5 Audio to/from Trains

We assume one 10-minute conversation every hour from each train. This requires 1670 two-way voice channels. Allowing a 3:1 peak to average factor, this comes to 5010 two-way voice channels, equivalent to 6.68 wide-band channels. If the transmission is digital instead of analog, this becomes 89 wide-band channels.

3.4.6 Truck Location

There are approximately 220,000 trucks and tractors in the U.S. These are to report twice daily, each report requiring 54 bits. If all reporting is done in a 1-hour period (twice daily), the traffic generated will require 3300 bits/second, or .000458 wide-band channels.

3.4.7 Audio to/from Trucks

We assume one 10-minute conversation per hour per truck. On a level-load basis, this requires 36,667 two-way voice channels. With 3:1 peak to average factor, this comes to 110,000 two-way voice channels, or 147 wide-band channels. If the transmission is digital instead of analog, this increases to 1956 wide-band channels.

3.4.8 Facsimile to/from Trucks

We assume one page per day per truck, at 10^6 bits/page. Assuming a 3:1 peak to average factor, the channel requirement becomes 1.06 wide-band channels.

3.4.9 Taxicab Location

There are approximately 150,000 taxicab drivers in the U.S. If we assume each has his own cab, 150,000 cabs must be located. Location requires 36 bits for position information plus 18 bits for identification of the cab. If each cab location is reported once per minute, the traffic load is 135,000 bits/second, equivalent to .019 wide-band channels.

3.4.10 Audio to/from Cabs

There are approximately 5000 radio stations licensed for taxi use. This implies that the traffic load is at most equivalent to 5000 two-way voice channels. This becomes 6.67 wide-band channels. If transmission is digital rather than analog, the requirement rises to 88.9 wide-band channels.

3.5 ELECTRONIC STOCK EXCHANGE

The electronic stock exchange involves computerized matching of offers to buy and offers to sell, with offers being made from individual brokerage offices throughout the country. According to the New York Stock Exchange Fact Book, the average number of shares per sale is about 500, and the maximum number of shares sold in one day (for 1976) was 44,513,000, implying a peak load of 89,025 transactions. We assume 50 characters per bid or offer. A completed transaction then requires 200 characters (bid, offer, and reply to both bidder and offerer). A completed transaction then requires 1200 bits. If the selling activity is spread uniformly over a 12-hour day, this traffic is equivalent to .00034 wide-band channels. This capacity figure would be increased by the number of unconsummated bids and offers, but no estimates are available for the magnitude of these incomplete transactions. Even if they were 10 times the number of completed transactions, however, the total channel capacity required would be quite small.

3.6 BANKS/FINANCIAL INSTITUTIONS

The telecommunications services considered for banks and financial institutions involve transmission of data about business transactions. This data transmission replaces currently used methods of data transmission involving physical transportation of records or documents.

3.6.1 Electronic Check Clearing

In 1975, the Federal Reserve System cleared 12 billion checks. The total number of checks written in 1976 was about 28 billion, and was growing at 7% per year. We assume that this growth will continue until the year 2000, and that 50% of all checks will require clearing between cities. Clearing a check requires about 240 bits. Thus, by 2000, the annual traffic will be 2.44×10^{13} bits. If banks operate 6 days per week, and this traffic is transmitted in 6 hours following bank closing, the traffic becomes 3.62×10^{6} bits/second, equivalent to .503 wide-band channels.

3.6.2 Electronic Bill Paying

In 1975, there were 70,078,000 households in the U.S. We assume each household pays the following bills monthly: electricity, telephone, water, and 3 charge accounts. We assume that one-half of all households pay the following bills monthly: fuel and mortgage or rent. We assume 240 bits per bill, and that payments are made during a 12-hour period on 20 working days per month. The traffic becomes 136,262.8 bits/second, equivalent to .0189 wide-band channels. If all bill paying is concentrated in one day, the requirement is .379 wide-band channels.

3.6.3 Check Verification

(This is an alternate computation to the one given above, involving check and credit card verification.) We assume one-tenth of all checks need verification at retail stores, hotels, etc. By 2000, this becomes 6.5 billion checks. We assume 240 bits per check, 15 hours per day for business purposes nationwide, and 365 days per year. The traffic then is 79,148 bits/second during the working day, equivalent to .011 wide-band channels. Application of a 3:1 peak to average factor raises this to .033 wide-band channels.

3.7 PROFESSIONAL PERSONS

The applications described below are those likely to be needed by professionals such as doctors, engineers, architects, etc.

3.7.1 Mobile Two-Way Radio

In 1974, there were 12,780,000 professional and technical workers in the U.S. Assume each makes one 10-minute telephone call per day in a mobile or portable mode. Assume a 12-hour working day, and a 3:1 peak to average factor. This comes to 532,500 two-way voice channels, or 710 wide-band channels. If the transmission is digital instead of analog, the requirement becomes 9467 wide-band channels.

3.7.2 Computer Conferences

We assume each technical or professional worker spends one hour per day in a computer conference, transmitting at 30 characters per second. These conferences are spread over 12 hours of the day. This comes to 1.917×10^8 bits/second, or about 27 wide-band channels.

3.7.3 Electronic Library

We assume each technical or professional worker requires 10 pages per day, all of which (at least potentially) may include high-resolution graphics. Thus, each page requires 6×10^6 bits. We assume utilization is spread over 12 working hours. This comes to 1.775×10^{10} bits/second, or 247 wide-band channels. Note that if the transmission were reduced to text alone, demand would be only 41 wide-band channels.

3.8 HOUSEHOLDS/INDIVIDUALS

The applications described below are those likely to be called for by households and individuals, and mainly involve personal rather than business or professional uses.

3.8.1 Electronic Library

In 1972, a total of 518,600,000 books were sold in the U.S. (other than children's books, religious books, and others for which the use of an electronic library is not appropriate). We assume each of these had 250 pages, with 550 words/page, and 6 characters/word. If all these books were read electronically from a library instead of being purchased, and reading were restricted to a 16-hour day, the transmission requirements would be 1.221 x 10^8 bits/second, equivalent to 17 wide-band channels.

3.8.2 Computer Conferences

Computer conferences involving members of households will have aspects different from those for professional purposes. Household computer conferences might include aspects more like conventional letter-writing, and might also involve such activities as "postal" chess matches, bridge games, and similar recreational activities. In these games, the player may compete against the computer, or may compete against other players, with the computer "dealing the cards" or providing other functions involving random selections and concealment from one or more players. We assume the total population over age 16 spends one hour per day in computer conference. In 1975, this would have been 156,400,000 persons. Transmission speed is 30 characters/second. Total transmission rate then is 1.76 x 10^9 bits/second, equivalent to 244 wide-band channels.

3.8.3 Burglar and Fire Alarms

In 1975, there were 70,078,000 households. We assume each household had one burglar alarm and one fire alarm, reporting to some central location. Each alarm is polled once per hour to verify that it is still functioning. Half the total time is utilized in polling, allowing half the time for transmission of alarms (e.g., the system may poll for half a second, "listen" for half a second, then resume polling, etc.). We assume 30 bits are required for identification of the household and the alarm status. Transmission rate is 1.168 x 10^6 bits/second. Doubling this to allow for the 50% duty cycle, the transmission requirement is equivalent to .32 wide-band channels.

3.8.4 Electronic Mail

There were 66.1 billion pieces of first class and second class mail sent in 1976. The average number of pages in this mail is assumed to be two pages. Each page of letter is assumed to contain 10^6 bits of information. We also assume a 3 to 1 peak to average ratio. Only half of the total volume of first class and second class mail is expected to be transmitted via the electronic mail service at saturation level. Traffic volume of electronic mail then becomes 85 wide-band channels.

3.8.5 Picture Phone

Long distance telephone traffic in 1985 is projected to be about 83 million calls per day. The wide-band channel requirement for the picture phone service in long distance calls is very sensitive to its technical and operational assumptions. Furthermore, there is a great deal of uncertainty involved in making technical and operational assumptions in picture phone services. Consequently, it is difficult to come up with a satisfactory traffic estimation for the picture phone service in the U.S. Nevertheless, several estimates for the traffic volume of picture phone are presented below.

If we assume an average length of long distance picture phone calls is 10 minutes, a 5 to 1 peak to average ratio, and 2 wide-band channels for each call, then the requirement of wide-band channels for the whole picture phone service in the U.S. is 5.76 million wide-band channels. This traffic volume could be dropped to 57,600 wide-band channels if we introduce a 10 to 1 signal compression ratio consideration, reduce the length of calls from 10 minutes to 5 minutes, and decrease the peak to average ratio from 5 : 1 to 1 : 1. This low requirement of wide-band channels takes into consideration technical and economic factors in operating picture phone services. The requirement of wide-band channels could be reduced to 19,200 based on the assumption that fiber optics long distance facilities will serve about two thirds of the entire market.

3.9 SCHOOLS/EDUCATION

Some specialized applications for schools and educational purposes are treated below. In 1974, school enrollments were 31.1 million elementary students, 15.4 high-school students, and 8.8 million college students. These numbers will be utilized in computing traffic loads.

3.9.1 Access to Data Bases

We assume high-school and college students spend 15 minutes per week for data base access, spread over 5 days of 12 hours. Average transmission rate is equal to reading rate. This application then requires 10^7 bits/second, or about 1.4 wide-band channels.

3.9.2 Computational Support

We assume that each student spends 30 minutes per day utilizing computational support, at the teletype transmission rate. Usage is spread over 12 hours per day. Traffic then is 4.15×10^8 bits/second, or 57.6 wide-band channels.

3.9.3 Electronic Library

We assume high-school and college students spend 30 minutes per day utilizing this service, for material which includes 3 pictures. Usage is spread over 8 hours per day. The text transmission requires 1.796×10^{10} bits/second, equivalent to 2457 wide-band channels. The pictures and graphics require 3.46×10^{10} bits/second, equivalent to 4800 wide-band channels. Total requirement is 7257 wide-band channels.

3.9.4 Computer Aided Instructions

We assume each student spends 2 hours per day utilizing computer aided instruction, at a transmission rate of 200 words per minute, distributed throughout a school day of 8 hours. The requirement becomes 1.38×10^9 bits/second, or 192 wide-band channels. If the transmission includes one graphics frame or picture every 5 minutes, with a 32-level gray scale, this adds 2.1×10^{11} bits/second, equivalent to 29,347 wide-band channels. The total then becomes 29,539 wide-band channels.

3.10 PUBLIC SERVICE APPLICATIONS

The following applications include a wide range of activities carried out by governmental organizations which, in some broad sense, benefit the public, and do so at the expense either of the taxpayer or of the supporter of some volunteer or charitable organization.

3.10.1 Transfer of Data

The application of data transfer covers student records, patient records, data transfer of universities and libraries, data transfer of state and local governments, environmental communication, information service, and data transfer for public safety.

Every freshman in high school or college needs a copy of school records as he attends the new school. Similarly, every senior in high school or college is assumed to send out an average of five applications to prospective employers or college admission offices in their efforts of seeking employment or high education opportunities after graduation. Each record consists of an average of four pages of information. Transmitting one page by facsimile requires 10^6 bits. Schools and universities are assumed to be operated 8 hours a day and 250 days per year. Hence, the requirement of communication satellite capacity for student record transfer will be 2.83 wide-band channels

There are approximately 15.3 x 10^6 medical records to be transferred to hospitals at new residences each year. In addition, another 215.46 x 10^6 medical records needed to be transferred between hospitals because some out-patient visits are referred to other hospitals for some reasons. Each medical record is assumed to be ten pages long. Hospitals are operated 24 hours a day and 365 days per year. The requirement of communication satellite capacity for transferring patient records could then be computed as 10.38 wide-band channels.

The volume of mail for state and local governments was estimated to be 2174.2 x 10^6 pieces in 1974. Each piece of mail is assumed to contain an average of two pages. Transmitting one page by facsimile requires 10^6 bits. Thus, the requirement on the communication satellite capacity is estimated to be 19.15 wide-band channels for data transfer by state and local governments.

It is assumed that there are a million terminals for interactive searches of data bases throughout the country. These are teletype terminals capable of transmitting 30 characters per second. Terminals are operated 5 hours daily. The ultimate channel requirement on the communication satellite capacity can then be estimated as 6.94 wide-band channels to provide such information services.

We assume that there are 10,000 teletype terminals connecting universities and libraries throughout the country for data and message services. Each terminal is capable of transmitting 30 characters per second. Terminals have an average of 5 hours usage rate per day. Thus, the application of data transfer of universities and libraries requires 0.069 wide-band channels on the communication satellite capacity.

It is assumed that a sensor device is installed for every 10 square kilometer area for environmental communication purposes. The daily traffic volume is estimated to be 745.83 x 10^6, equivalent to 0.002 wide-band channels.

The total transaction volume of public safety data in the U.S. is projected as 144.14 x 10^6 hits per month. Each transaction is assumed to have an average of 377 charactdrs of information volume. Data transfers for public safety are assumed to be operated 24 hours per day and 365 days per year. The requirements on the communication satellite capacity could be calculated as 0.023 wide-band channels.

The total traffic volume for the application of data transfer is then estimated as 39.39 wide-band channels.

3.10.2 Telemedicine

The national average for acute cases is 1.5 per person per year. It is assumed that in rural areas, 10% of all acute cases will require telemedicine. Thus, with a rural population of 54 million, there will be 8.1 million uses of telemedicine per year. In cities, with a population of 180 million, it is assumed that 1% of acute conditions will require telemedicine during transportation of the patient by ambulance. This comes to 2.7 million uses of telemedicine in cities per year, for a total national usage of about 11 million telemedicine incidents per year. It is assumed that each telemedicine incident will require 0.5 hours of video transmission from patient to doctor. The telemedicine is presented through a form of slow scan television. A 3 to 1 peak to average ratio is also used in computing the requirement of satellite telecommunication capacity for the application of telemedicine. Thus, the traffic volume for telemedicine in the U.S. comes to about 4 wide-band channels.

3.10.3 Educational Broadcasting

Each local educational broadcasting facility serves 1000 people, except that in Alaska each facility will be assumed to serve 100 people. These facilities may be school, town halls, etc. We assume 11 channels are beamed to each of the 6 time zones. Thus, the total demand on the satellite system will be 66 wide-band channels.

3.10.4 Public Safety

In 1970, there were about 70,000 fixed public safety stations, and 700,000 mobile public safety stations. If this existing system were to be replaced by satellite communications, it would require 140,000 simplex voice channels, or about 93 wide-band channels.

3.10.5 Disaster Management

We assume the following predisaster distribution of stockpiled portable earth terminals, capable of providing two-way voice communication through a satellite:

each state - 30 units to be sent to disaster areas

each city over 2.5 million population - 30 units for its own use each city with population between 250,000 and 2.5 million - 10 units for its own use

each city with population between 25,000 and 250,000 - 1 unit for its own use

This comes to a total of 3004 units. If all units were in use at once, they would require only slightly more than the equivalent of 4 wide-band channels.

3.10.6 Remote Testimony

There were 88,545 cases processed in the United States District Courts in 1974. These include criminal cases, pretrial civil cases, and civil cases before pretrial. It is assumed that remote testimony, utilizing one-way video and two-way audio, would be utilized in 5% of such cases. It is assumed that a witness will testify for one hour. On the assumption that courts operate 8 hours per day, 5 days per week, 52 weeks per year, a total of 2.13 wide-band channels would be required to carry the necessary remote testimony.

3.10.7 Instrumented Hospital Bed

We assume the market for instrumented hospital beds includes all hospitals with fewer than 25 beds, and all hospitals operated by local governments. This comes to approximately 2000 hospitals. This is somewhat of an overestimate, since hospitals operated by large cities are likely not to need this capability. However, the figure of 2000 hospitals provides a suitable basis for computation. On the assumption of one telephone line per hospital, the total requirement comes to 1.33 wide-band channels for this service.

3.10.8 Continuing Education

We consider the following main users in the area of continuing education: elementary and high school teachers; medical personnel including medical doctors, dentists, pharmacists, registered nurses, and employees of the Public Health Service; engineers; lawyers; farmers and farm managers; and public safety personnel including police officers and fire fighters.

Each class is limited to 100 students, to permit real time questions from students to instructor. The facility requires one-way video and two-way audio. Each course has a three-hour schedule each week and may be programmed over a sixteen-hour span daily.

The number of elementary and high school teachers was 2,548,000 in 1972. There were 371,400 medical doctors, 119,700 dentists, 748,000 registered nurses, and 124,800 pharmacists in 1970. Engineer professions had a membership of 1.3×10^6 in 1970. The size of law profession was 260,000 in the same time. Another major potential group of users, farmers and farm managers, included 1,429,000 members. And, there were 915,000 police officers and fire fighters in 1973. Thus, an estimate total number of these potential main users is 7,815,900. Consequently, an estimate of ultimate demand on the satellite communication capacity is approximately 2096 video channels.

The channel requirements for these applications are summarized in Table 3.1.

3.11 SUMMARY

The applications considered above were selected for analysis on the grounds that they were either likely to be realized, or that they would demand significant channel capacity. On the basis of certain assumptions, considered to be reasonable, traffic loads and equivalent satellite channel capacity can be computed. Perhaps the most significant observation from the computations is that where the traffic is inherently digital to start with, required channel capacity is very small, unless the total number of users approaches the entire population. Where the traffic is inherently analog to start with (voice and graphics particularly), channel capacity required can be quite high, even with a comparatively small number of users.

TABLE 3.1 Traffic Volume of Telecommunication Applications

Application	Wide-band Channels
BUSINESS OFFICES/ESTABLISHMENTS	
Electronic Paychecks	.093
Check/Credit Card Verification	.065
Data Base Search	.286
Computer Conferences	18.0
Telecommuting by Employees	35.15
POS EFT	.13
Video Conference	30,000.00
SPECIAL BUSINESS APPLICATIONS	
Pipeline Network Status	.00192
Railroad Car Location	.00324
Train Location	.07
Facsimile to/from Trains	.48
Audio to/from Trains	6.68
Truck Location	.000458
Audio to/from Trucks	147.0
Facsimile to/from Trucks	1.06
Taxicab Location	.019
Audio to/from Cabs	6.67
ELECTRONIC STOCK EXCHANGE	.00034
BANKS/FINANCIAL INSTITUTIONS	
Electronic Check Clearing	.503
Electronic Bill Paying	.379
Check Verification	.033
PROFESSIONAL PERSONS	
Mobile Two-Way Radio	710.0
Computer Conferences	27.0
Electronic Library	247.0

TABLE 3.1 Traffic Volume of Telecommunication Applications (Continued)

Application	Wide-band Channels
HOUSEHOLDS/INDIVIDUALS	
Electronic Library	17.0
Computer Conferences	244.0
Burglar & Fire Alarms	.32
Electronic Mail	85.0
SCHOOLS/EDUCATION	
Access to Data Bases	1.4
Computational Support	57.6
Electronic Library	7257.0
Computer Aided Instructions	29,539.0
PUBLIC SERVICES	
Transfer of Data	39.39
Telemedicine	4.0
Educational Broadcasting	66.0
Public Safety	93.0
Disaster Management	4.0
Remote Testimony	2.13
Instrumented Hospital Bed	1.33
Continuing Education	2096.0

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SECTION 4

THE U.S. TELECOMMUNICATIONS SYSTEM

4.1 INTRODUCTION

This section of the report describes, and makes projections for, the U.S. Telecommunications System, except for satellites and special telecommunication services utilizing satellites, which are described in the next section. The following elements of the telecommunication system are described in this section: commercial television, cable television, telephone, home uses (videodisc, TV games, CATV games), and direct broadcast of TV, from satellites. Each of these elements is discussed in more detail below.

4.2 TELEVISION

The future growth of television is assumed to be driven by economics. Appendix 6 projects the revenues available to TV networks, on the basis of an assumed standard growth in Gross National Product (GNP), and a continuation of historical relationships between GNP and advertising revenues. TV revenues after 2000 are projected at a 4% per year growth rate. A projection of number of TV stations by year (based on growth proportional to growth in revenues) is as follows:

Year	TV Stations
1980	994
1985	1,174
1990	1,458
1995	1,794
2000	2,195
2010	3,249
2020	4,810
2030	7,121
2040	10,540

4.3 DIRECT BROADCAST

It is assumed that direct TV broadcast from satellites, at KU band (14/12 GH, may be introduced. A 3-degree beam will be adequate to cover one time zone, and at 55% efficiency would require slightly over 300 watts per wide-band channel.

The satellite projections in Section 5 show that small satellites never achieve enough power for 1 or 2 channels after about 1980; 6000 kg satellites can provide 6 channels after 1990 and 7 after 1995. Thus, if the steps are made to larger satellites, direct broadcast could become feasible in the 1980's, and with greater probability, in the 1990's. It should be noted that direct broadcast, if it is introduced, may utilize frequencies other than KU band. KU band was incorporated in the model to illustrate a feasible option.

The number of channels needed in direct TV broadcast is very small. Two channels per time zone across the U.S. continent, and two channels for Hawaii and Alaska, are projected at the initial introduction of direct TV broadcast at KU band. Thus, a total number of 10 channels may provide the entire direct TV broadcasting in the U.S. in 1995. The probability for this direct TV broadcast is a rather low figure of 0.1. The total number of satellite communication channels may rise to 30 in 2005, and 60 channels in 2015 as the application progresses into the future.

4.4 CABLE TELEVISION (CATV)

From 1955 to 1974, CATV penetration of households followed a standard growth curve with a T-time (see Section 6) of 13 years. Future penetration of households is projected at two rates: the historical growth with T-time of 13 years, and a reduced growth rate with T-time of 26 years. The number of households is projected to agree with the Census Bureau's Series 2 until 1990, followed by a growth rate which tapers downward from the Series 2 rate to 1% per year for the decade 1990 - 2000, and levels out at 1% per year after 2000. The product of the two factors, number of households and fraction of households with CATV, gives number of households with CATV. Of more direct interest, however, is the number of CATV systems, since these will demand satellite channels to distribute CATV programs.

Since 1910, the population of the average "urban place" (i.e., the total urban population divided by the number of "urban places") has remained about 21,000, which implies that new cities have been formed at about the same rate as the population has grown. It is assumed that this pattern will continue, and the population of the average urban place will be 21,000. Using projections of population (Appendix 6 to 2000; 1% per year thereafter), it is possible to estimate the number of urban places which will exist in the future. It is assumed that ultimately each urban place will have at least one CATV system.

Combining number of urban places with number of households with CATV, it is possible to estimate number of households per system. This relationship between number of systems and number of households per system is assumed to hold regardless of the growth rate of CATV. That is, it is assumed that if the growth rate of CATV slows down from its historical rate, the effect is to follow the same pattern, but at a slower pace.

Table 4.1 shows the projections of number of households in the U.S., the number of households with CATV and number of CATV systems, under both the high and low growth rate projections.

A new technology which will impact CATV distribution is use of fiber optic cables instead of the current coaxial cables (i.e., use of optical wave lengths to carry the video signal instead of carrying it at VHF radio frequencies). It is projected that optical fibers will become competitive with coax in 1985. After that time, all new installations are optical fibers, and the cable systems begin a 20-year replacement schedule for conversion of existing coax to optical fibers.

4.5 TELEPHONE

The projections of the telephone system treat three elements separately. These are: total number of telephones, local circuits, and long distance circuits. Projections are made for several aspects of each element.

TABLE 4.1

PROJECTION OF CATV RELATED EVENTS

	HIGH GROWTH			LOW GROWTH	
Year	Households*	Households with CATV*	Number of CATV Systems	Households with CATV*	Number of CATV Systems
1980	76,063	21,732	4,619	17,089	3,750
1985	82,421	40,794	5,998	25,579	5,000
1990	87,823	61,209	7,378	35,919	5,600
1995	93,092	78,546	8,918	48,762	6,200
2000	87,746	90,764	9,370	61,274	7,350
2010	107,972	107,340	10,685	86,378	9,200
2020	119,268	118,257	12,149	108,121	10,800
2030	131,747	126,683	13,773	123,810	13,200
2040	145,530	145,000	15,573	139,033	16,000

*in thousands

4.5.1 Number of Telephones

Since 1935, the number of telephones, as a fraction of the population, has been following a standard growth curve with T-time of 24 years. This growth curve is projected, and used in conjunction with population projections, to determine total number of telephones in the U.S.

4.5.2 Local Circuits

The number of local telephone calls has remained constant at about 3.8 per day since before 1950. It is assumed that this ratio will continue to hold, so that number of local calls can be projected as 3.8 per day per telephone. Thus, in conjunction with the number of telephones projected earlier, the number of local calls can be projected.

Conversion of the local telephone system from analog to digital is not expected to begin until the 1980's, reaching 10% in 1988. Complete conversion to digital mode will be achieved about 2010.

Conversion of the local telephone system from copper wire to fiber optics is expected to begin before 1980, reaching 5% by 1980. Conversion is expected to reach 100% by the year 2000. This will include installation of new connections in the form of optical fibers, as well as conversion of existing plant to optical fibers on a 20-year schedule.

4.5.3 Long-Distance Circuits

The number of long-distance calls made seems to be a function of personal income, and is projected on the basis of growth in GNP. The projections are shown in Appendix 6.

The long-distance circuits of the telephone system will go digital even sooner than the local circuits. By 1975, there were already 40 million circuit miles of digital trunking in existence. Moreover, military telephone systems are already going digital. For projection purposes, it is assumed that all new growth after 1980 is digital, and that existing analog long-distance circuits are converted to digital on a 20-year schedule. Thus, by the year 2000, all long-distance circuits will be digital.

Conversion of long-distance circuits to fiber optics is assumed to begin in 1985, with all new installations after that date being fiber optics, and conversion of existing plant to fiber optics on a 20-year schedule. In any given year, growth of the long-distance system should be such that the magnitude of new installation exceeds the conversion of existing plant. Thus, it would be possible to convert existing plant even faster than a 20-year schedule. However, this schedule is assumed for consistency with the remainder of the projection.

Table 4.2 shows local and long-distance calls by year, and the percentage of circuits which are digital or use fiber optics, for both local and long-distance telephone communications.

4.6 HOME USES

Three telecommunications-related devices are projected for home use. It is expected that each of these will be adopted by households, and their adoption will have an impact on the telecommunications system. These devices are TV games, CATV games, and videodiscs. Each is discussed below.

4.6.1 TV Games

Starting about 1975, a market has grown for devices which can be attached to a TV set and which display on the screen a game layout of some sort. Operation of controls on the game allows the players to simulate games such as ping-pong, hockey, etc., with the action appearing to take place on the game layout on the screen. Penetration of the home market for TV games is projected to follow a standard growth curve with T-time of 5 years. These games, thus, reach 10% of all homes in 1982, 50% in 1987, and 90% in 1992. Probabilities of .95, 185, and .75 are assigned to these three penetration levels, respectively.

TABLE 4.2

PROJECTION OF TELEPHONE RELATED EVENTS

Year	Phones/ Capita	Phones*	Local Calls/ Day*	Long-Distance Calls/ Day*	Total Calls/ Day	% Long-Distance Digital	% Long-Distance Fiber Optics	% Local Digital	% Local Fiber Optics
1980	.92	155.3	621	61.2	682	18.6	---	---	5
1985	.95	168.1	672	82.7	755	55.7	5	4	35
1990	.97	178.5	712	112.9	825	79.1	52	18	68
1995	.98	185.9	734	155.8	890	91.0	79	53	83
2000	.99	193.5	774	205	979	100.0	95	85	100.0
2005							100	97	
								99	

*in millions

4.6.2 CATV Games

A major drawback to the TV game has been the limited repertoire of an individual game, and the necessity of buying an add-on package of some kind to extend the range of games available. We expect that CATV system operators will sense an opportunity to capitalize on the TV game market by providing an equivalent service over their cables. If they establish a return channel on their cables, individual subscribers could play games utilizing a computer or similar device at the head end of the cable system. The repertoire of games would be larger, the cost per subscriber would be lower than if each subscriber had to buy a complete set of game programs for himself, and the use of a central game machine would also allow for the possibility of games among players at two or more locations. That is, a player in one household might compete against a player in another household, with both utilizing the cable return channel and the central game computer. We project that CATV games will be introduced after TV games have reached 10% of the market (and thereby indicated that they are not a transient fad). The market penetration of TV games is paced by the introduction of a return channel on CATV systems. Under the high growth rate regime for CATV, CATV games reach 10% of the market in 1990, 50% in 1997, and 90% in 2006. Under the low growth rate regime CATV, CATV games reach 10% of the market in 1991, 50% in 2003, and 90% in 2024.

CATV with return channels is expected to reach 10% of market penetration in 1990, 50% in 2000, and 90% in 2010 with probabilities of 0.50, 0.40 and 0.30, respectively. In the case of optical fibers in CATV, the market penetration of return channels is projected to be 10% in 1987, 50% in 2001, and 90% in 2016 under the low growth rate of optical fiber cable return channel.

4.6.3 Videodisc

This term is intended to mean some low-cost, mass-produced storage medium for video material, which can be played through a TV set at the convenience of the user, as a record is played on a phonograph.

While most of the current discussion is in terms of a recording-disc medium, we do not exclude tape cassettes, solid-state memories, or other media. The videodisc is expected to have a cost comparable to a color TV set, and hence, is projected to penetrate the market on a standard growth curve with a T-time of 8 years. Initial sales are expected in 1978. Market penetration should reach 10% in 1990, 50% in 1998, and 90% in 2006. Probabilities assigned to these levels of market penetration are .90, .75, and .60, respectively.

One revelant activity in using TV video material is video tape recording. This appears to have a growth pattern different from that of videodisc purchasing by TV viewers. The market penetration of TV video tape recording is assumed to attain 10% in 1989, 50% in 1997 and 90% in 2005. Both TV videodisc purchasing and TV video tape recording are included in the U.S. telecommunication system.

4.7 CATV Via FIBER OPTICS LOCAL LOOPS

CATV may use fiber optics local loops built by telephone companies. This is an alternative for CATV firms. CATV via fiber optics local loops could occur at the same time when fiber optics local loops are available. The market penetration of CATV via fiber optics local loops is projected to follow a standard growth curve with a T-time of 10 years. It will reach 10% in 1985 with a probability of 0.15, 50% in 1995 with a probability of 0.10 and 90% in 2004 with a probability of 0.05.

4.8 SUMMARY

These elements of the telecommunications system are projected to develop as described above. Two additional elements of the system, satellites, and special telecommunications services via satellite, are covered in Section 5 of this report.

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SECTION 5

PROJECTION OF HISTORICAL TRENDS IN TELECOMMUNICATIONS TECHNOLOGY

This section synopsizes the projection of trends related to progress in telecommunications technology for the period from 1975 to the year 2000, with some extensions beyond that period. The historical period used as a baseline for these projections covers the 16 year history of communication satellites from 1960 to 1975. The detailed development of these projections is presented in Appendix 5.

5.1 PROJECTION OF COMMUNICATION SATELLITE TRENDS

Projections of technological progress in the component elements of communication satellites are at least partly dependent upon such basic factors as the numbers and the weights of the satellite systems. Therefore, the starting point for this portion of the forecast is the determination of historical trends in communication satellite numbers and weights and a projection of these trends to the year 2000.

The history of communication satellites covers at most a period of only 16 years. Therefore, the projection to the year 2000 makes the forecast almost two times longer than the historical base. In general, it would be preferred that the trend baselines be at least as long as the period of the forecast. Since a 25-year data base obviously does not exist, less confidence may be placed in the projections for the last decade of the century. Nevertheless, even in the later period, the trends do indicate the general capabilities which should be achieved, and provide a useful basis for updating the forecast as additional data becomes available with the passage of time.

A key feature of this forecast is the establishment of internal consistency among the trends, i.e., whenever a given physical relationship naturally exists among two or more trends, the projections will maintain that relationship. For example, the trends in numbers of satellites, total weight of satellites, and average weight of satellites have an obvious mathematical relationship, and any projection of these separate trends must logically reflect such a relationship. This point is stressed particularly for two reasons: (1) the requirement that separately projected trends should result in a logical overall outcome is often overlooked or ignored, and (2) the attempt to establish the required "system trend budget balance" will often disclose areas or components where technical progress is critical to the achievement of long-range goals.

The establishment of projected dates for the achievement of various levels of performance in communication satellite technology also provides material for the specification of events for the cross-impact matrix in subsequent portions of this assessment.

5.1.1 Projection of Communication Satellite Weight

The projection of the total weight of communication satellite systems in orbit and operational is a significant starting point, since it is an essential factor in the total capacity for communication which may be available. Obvious tradeoffs, of course, exist, since increased component efficiencies can lower the total weight required for a given amount of communication capability. However, in general, with a reasonable projection of total weight, it is likely that increased efficiences will be used to expand communication capability for exploitation of expanding market potentials.

The trend of total U.S. communication satellite system weight in orbit and operational is included in Figure 5.1. The 1975 weight of 9,773 kg is projected to increase to approximately 67,600 kg by 2000, for an increase of nearly 700% at an average annual rate of 8% per year.

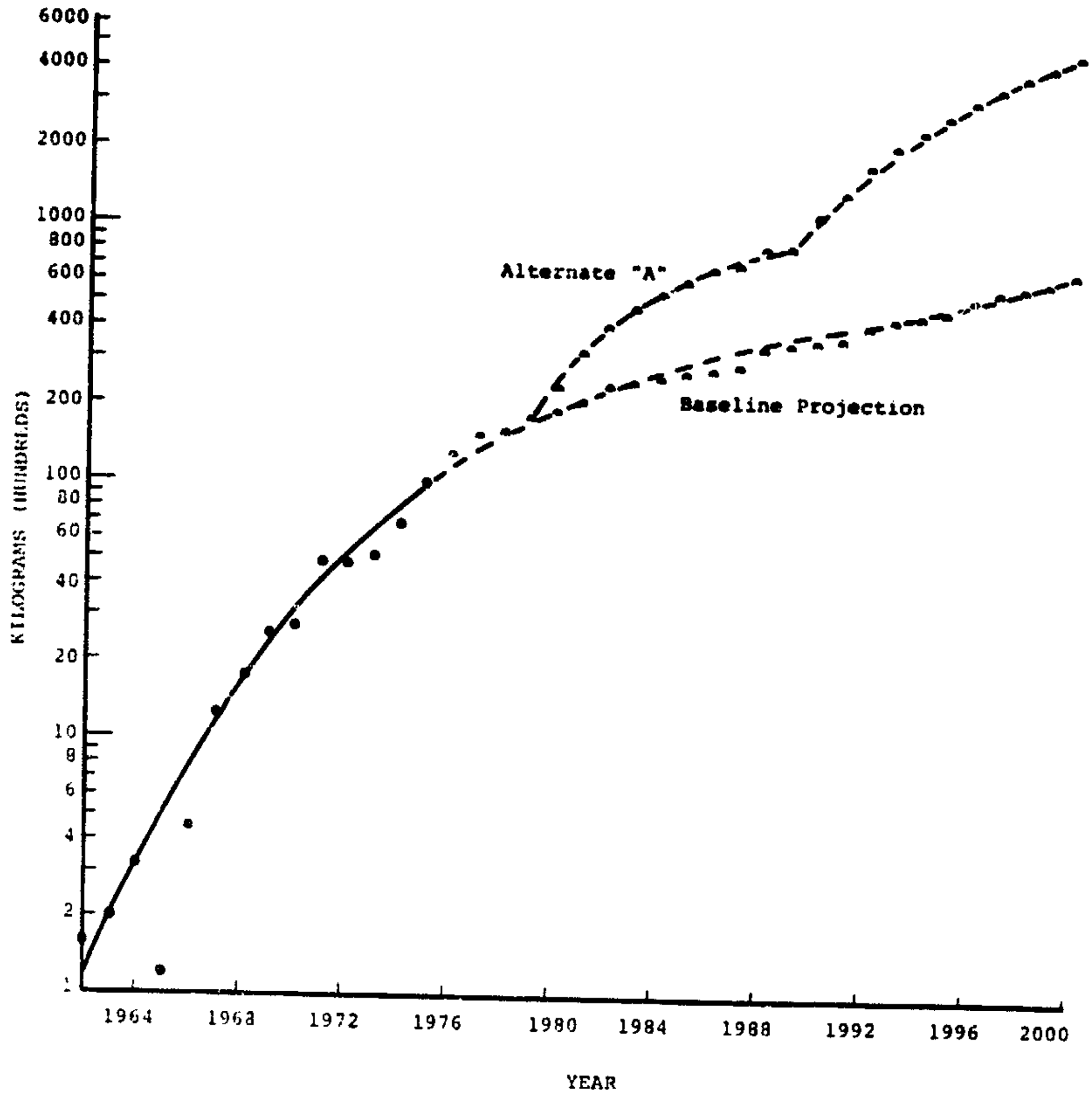

Figure 5.1. U.S. Communication Satellite Weight in Orbit and Operational (Kilograms)

The projected trend of satellite lifetime is depicted in Figure 5.2. The number of satellites in orbit and operational is included in Figure 5.3. The projected annual rate of increase is 6.8% which results in an increase from the 15 U.S. communication satellites operational in 1975 to 78 in 2000. These figures include both military and commercial satellites.

Average satellite weight in orbit and operational can be projected directly from the two preceding items (total operational weight divided by number of operational satellites). This trend projection is presented in Figure 5.4. The total weight of communication satellites placed in orbit each year may be projected by adding to the increase in total weight each year, the weight necessary to replace satellites which cease operations that year. The result of this calculation of the total weight of communication satellites to be launched each year is presented in Figure 5.5.

The number of satellite launches is shown in Figure 5.6. From an average of three communication satellite launches per year in the early 1970's. This projection indicates an average of eight by 2000, or an increase of 4% per year. Average weight of each satellite launched may now be projected as a consequential calculation, i.e., total weight added in orbit each year, divided by the number of launches in that year. The results of this calculation are given in Figure 5.7.

Summarizing these projections, two major conclusions may be reached. The first, or baseline forecast, assumes that only minor increases in communication satellite weight will occur between now and the year 2000, and that the annual number of communication satellite launches will increase to eight by 2000. The second, or Alternate "A" forecast, assumes that satellite weights will increase in two steps, first to 2,000 kg in 1980, and then to 6,000 kg in 1990, with the annual number of satellite launches increasing to eight in 2000, as in the baseline forecast.

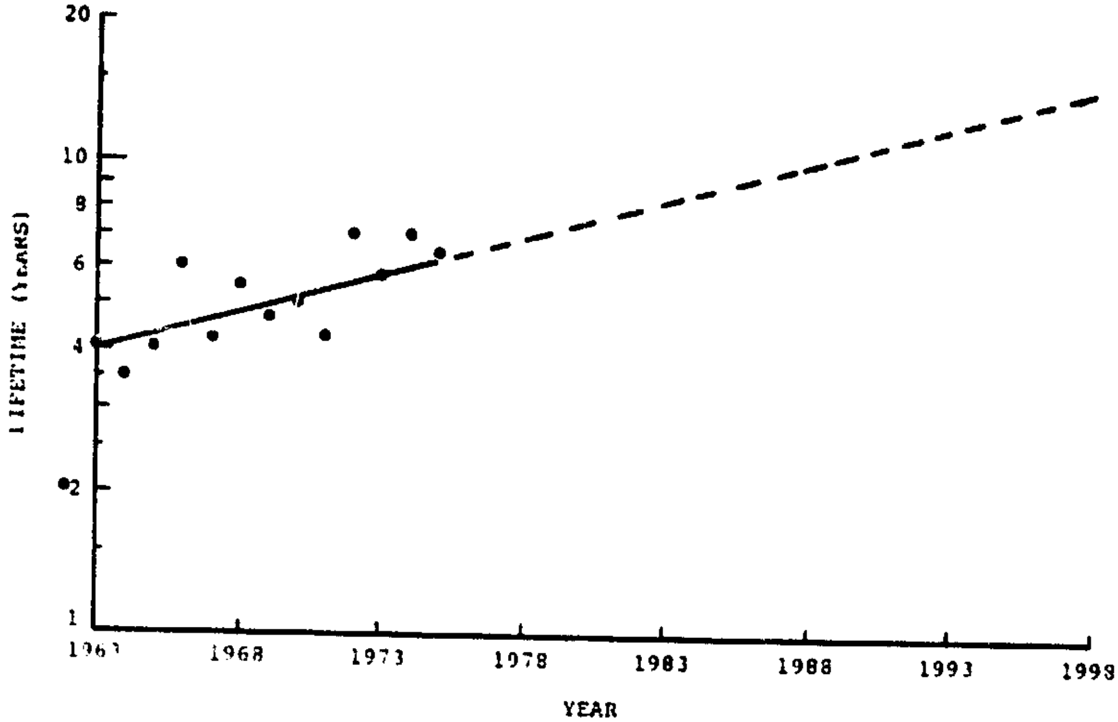

Figure 5.2. U.S. Communication Satellite Operational Lifetime (In Year of Launch)

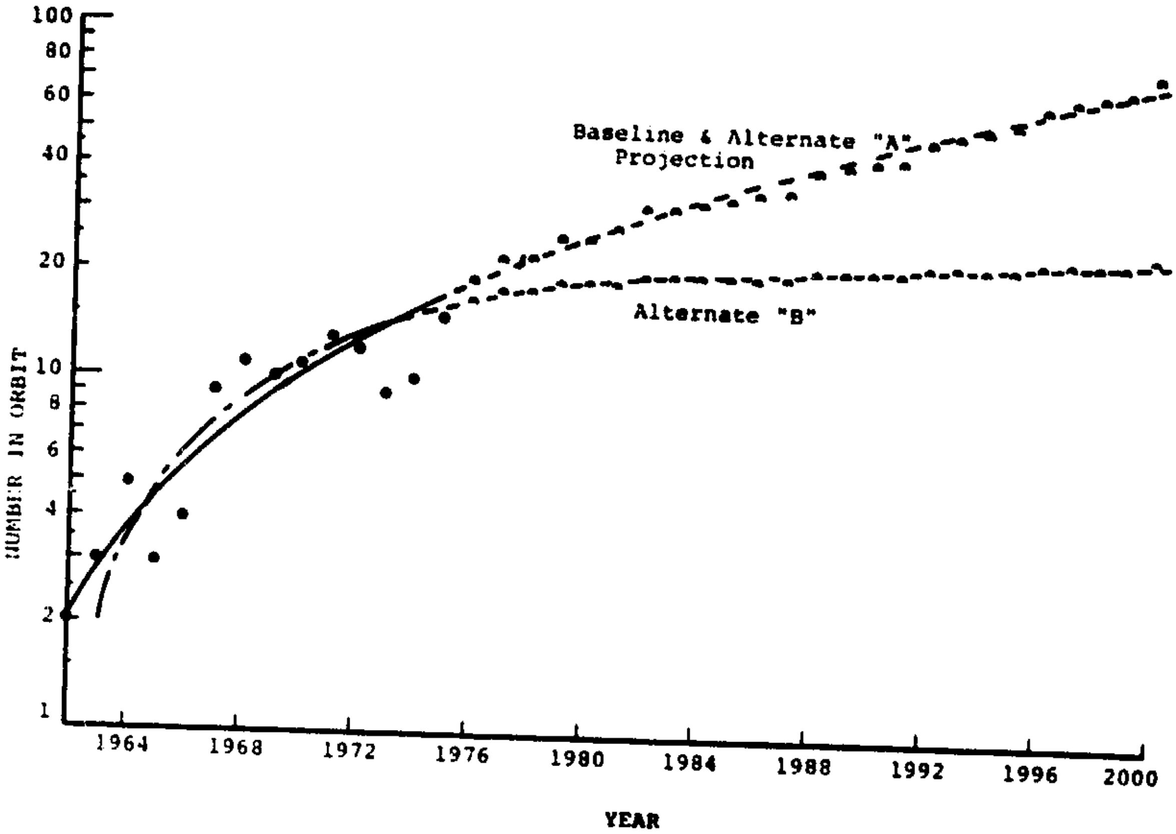

Figure 5.3. Number of U.S. Communication Satellites in Orbit and Operational at Year End

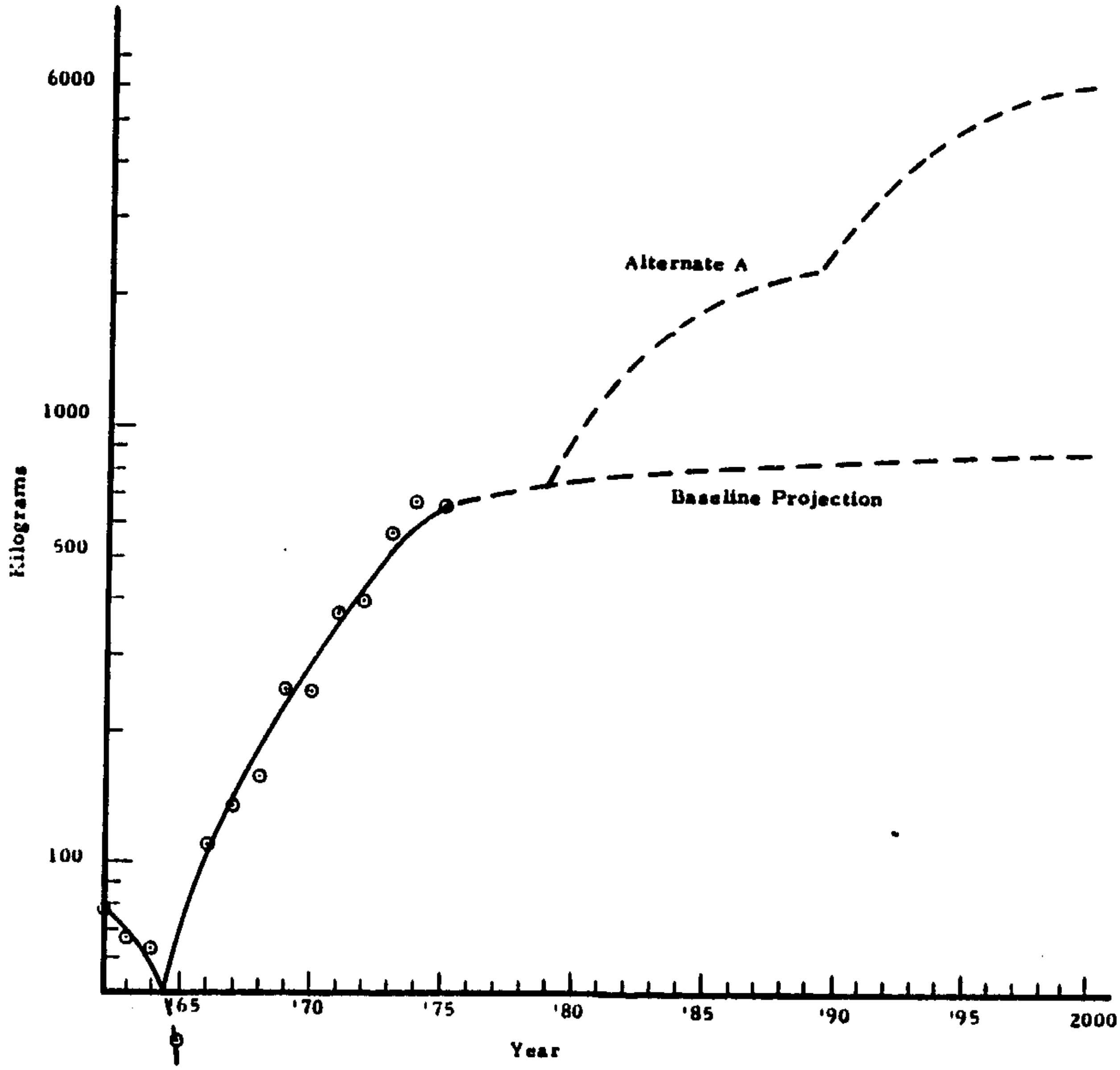

Figure 5.4. Average Weight of U.S. Communication Satellites in Orbit and Operational (Kilograms)

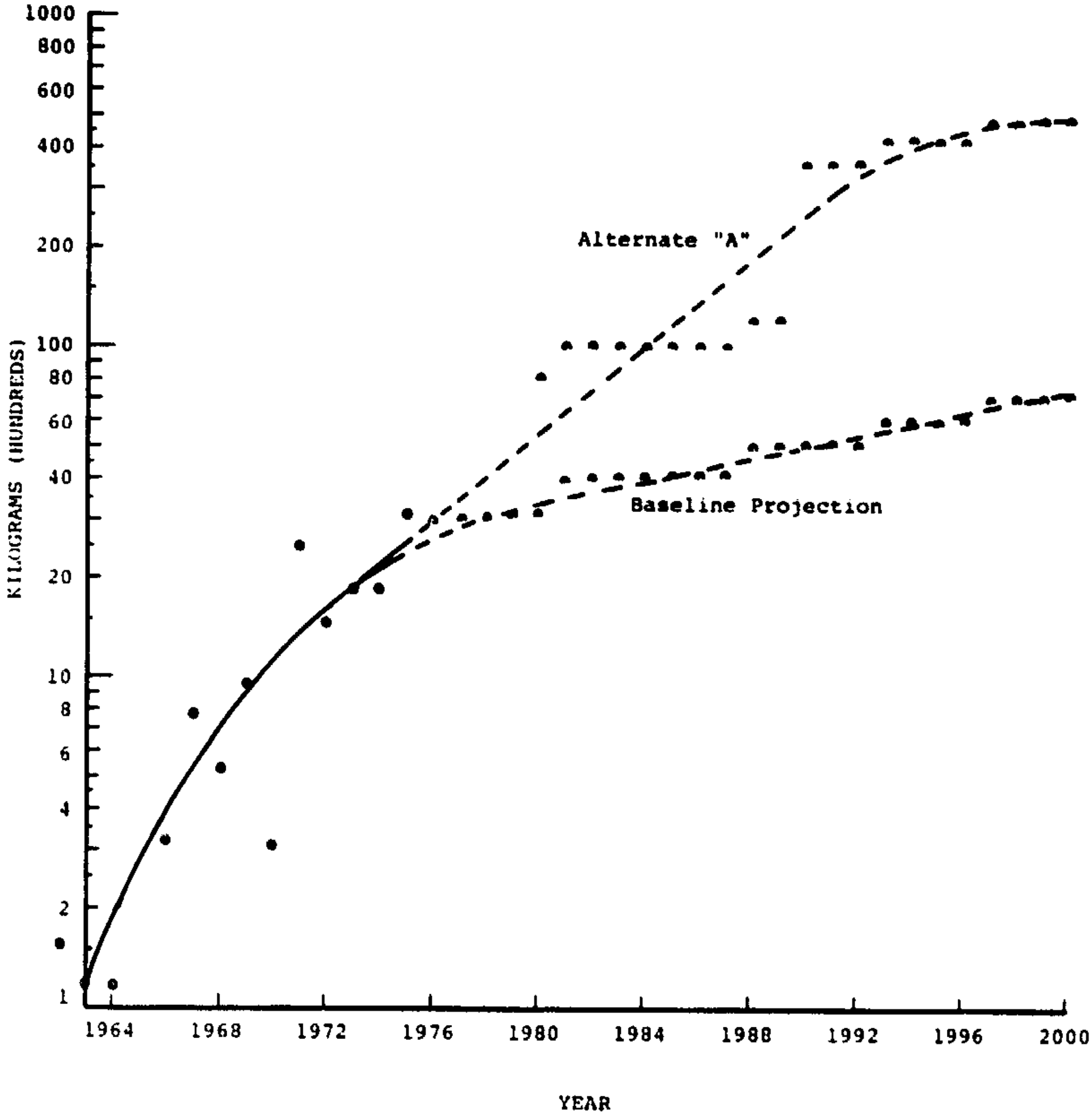

Figure 5.5. Total Weight of U.S. Communication Satellites Launched During Each Year (Kilograms)

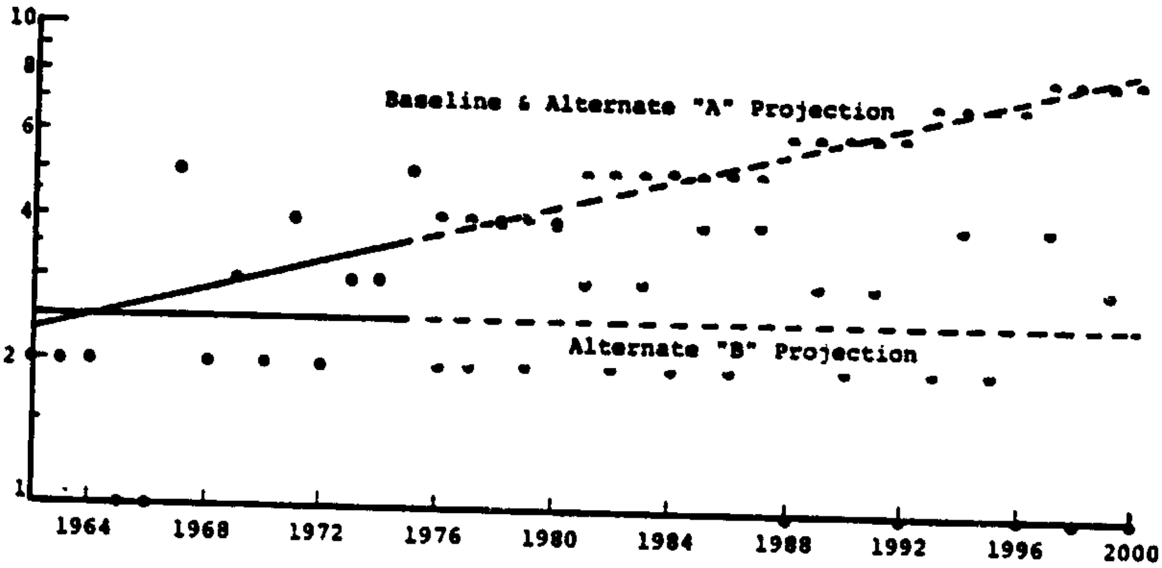

Figure 5.6. Number of Successful U.S. Communication Satellite Launches Each Year

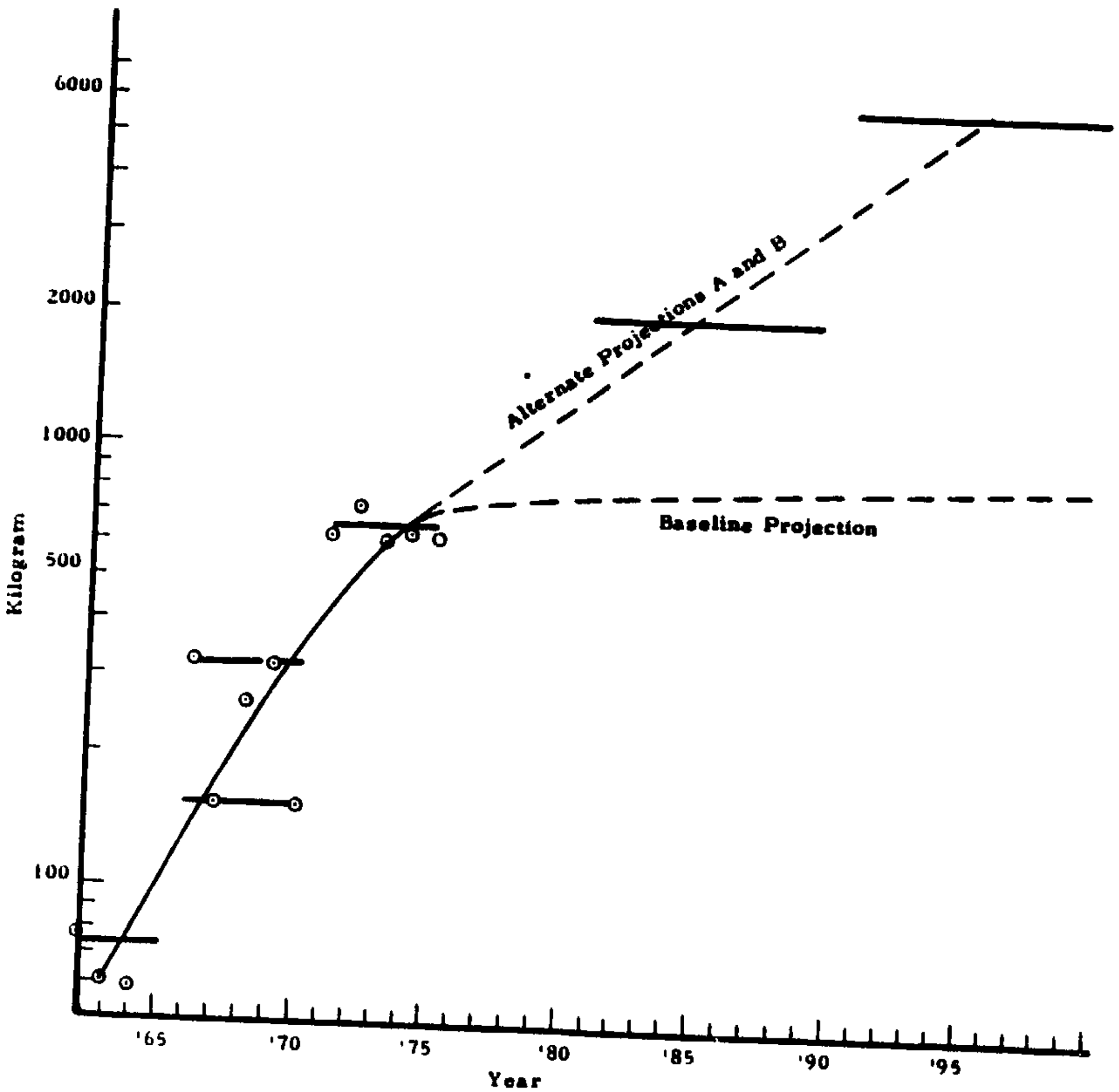

Figure 5.7. Average Weight of U.S. Communication Satellites Launched During Each Year (Kilograms)

The key factors which introduce sufficient regularity of data to fit a logical pattern of development are the trends of operational communication satellite numbers and weights. Since these two operational parameters respresent a first-order approximation of balance between technological capability and communications market demand, they provided the basis for the projections from which the forecasts of annual launch weights, satellite numbers, and average satellite weights were developed.

5.1.2 Projection of Design Trends and Technology Advances

The three forecasts of possible satellite weights and numbers may now be used as a basis in projection of design trends and technology advances for the major elements of communication satellites.

5.1.2.1 Projections of Satellite Primary Power

Available power for broadcast transmissions is the next element in this projection. The primary source of power has been an array of N-P solar cells and no change to another primary power source is projected. The most regularly behaved historical data for satellite power is the trend of total satellite power in orbit and operational. Since projections of this quantity may readily be related to the total weight of satellite systems in orbit and operational, this quantity was selected as the basis for projecting satellite power trends as shown in Figure 5.8. Calculation of the projected average power of satellites launched each year, as shown in Figure 5.9, provides the next step of the forecast.

The projection up to this point does not take into account the major change in solar array design concept, from arrays on the cylindrical surface of the satellite to deployable, flat, and continuously sun-oriented arrays. This change, already in use, increases the efficiency of the solar collector system by at least a factor of three. Therefore, assuming that the newer form of solar array will be used on all

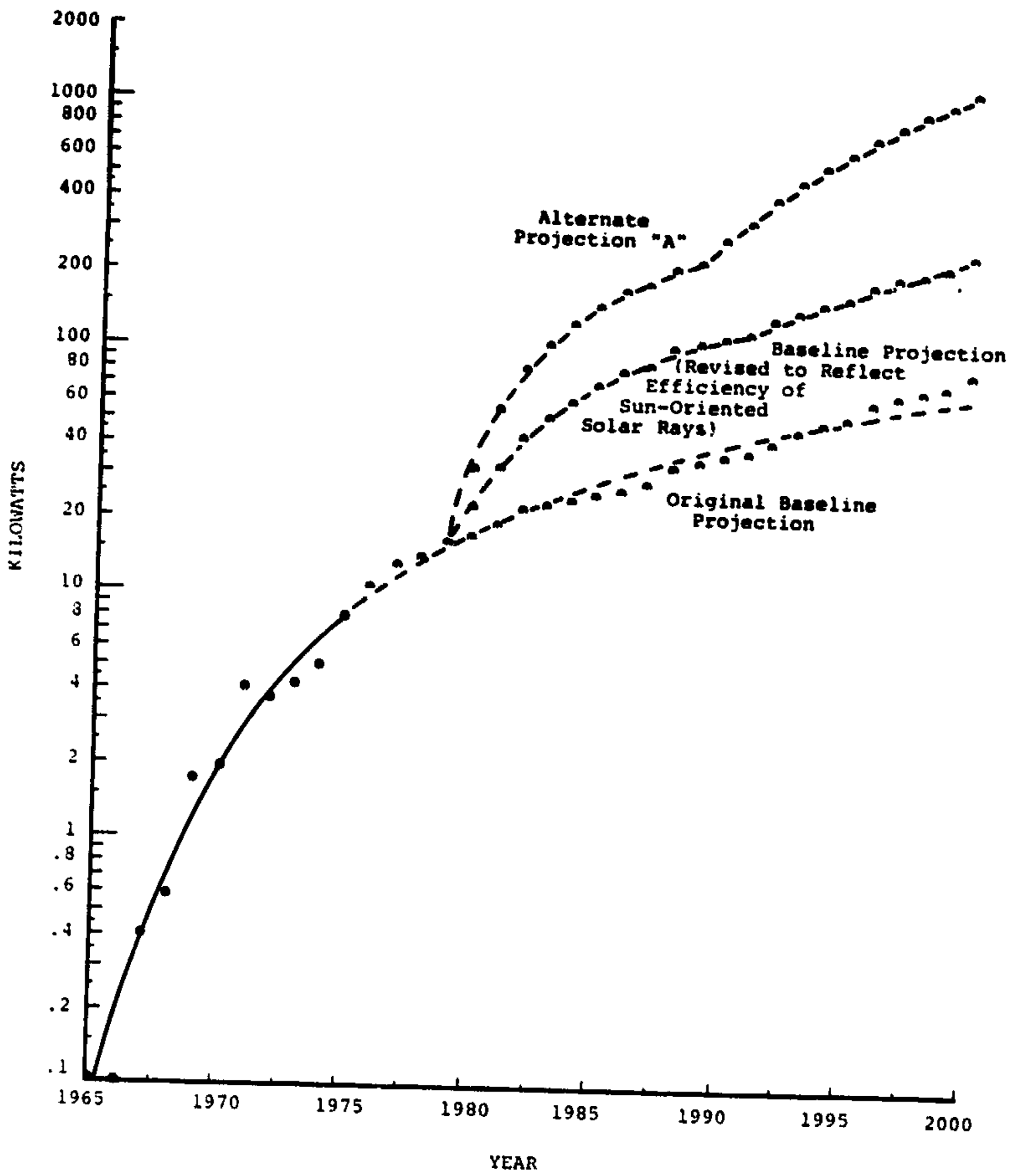

Figure 5.8. U.S. Communication Satellite Total Electric Power in Orbit and Operational

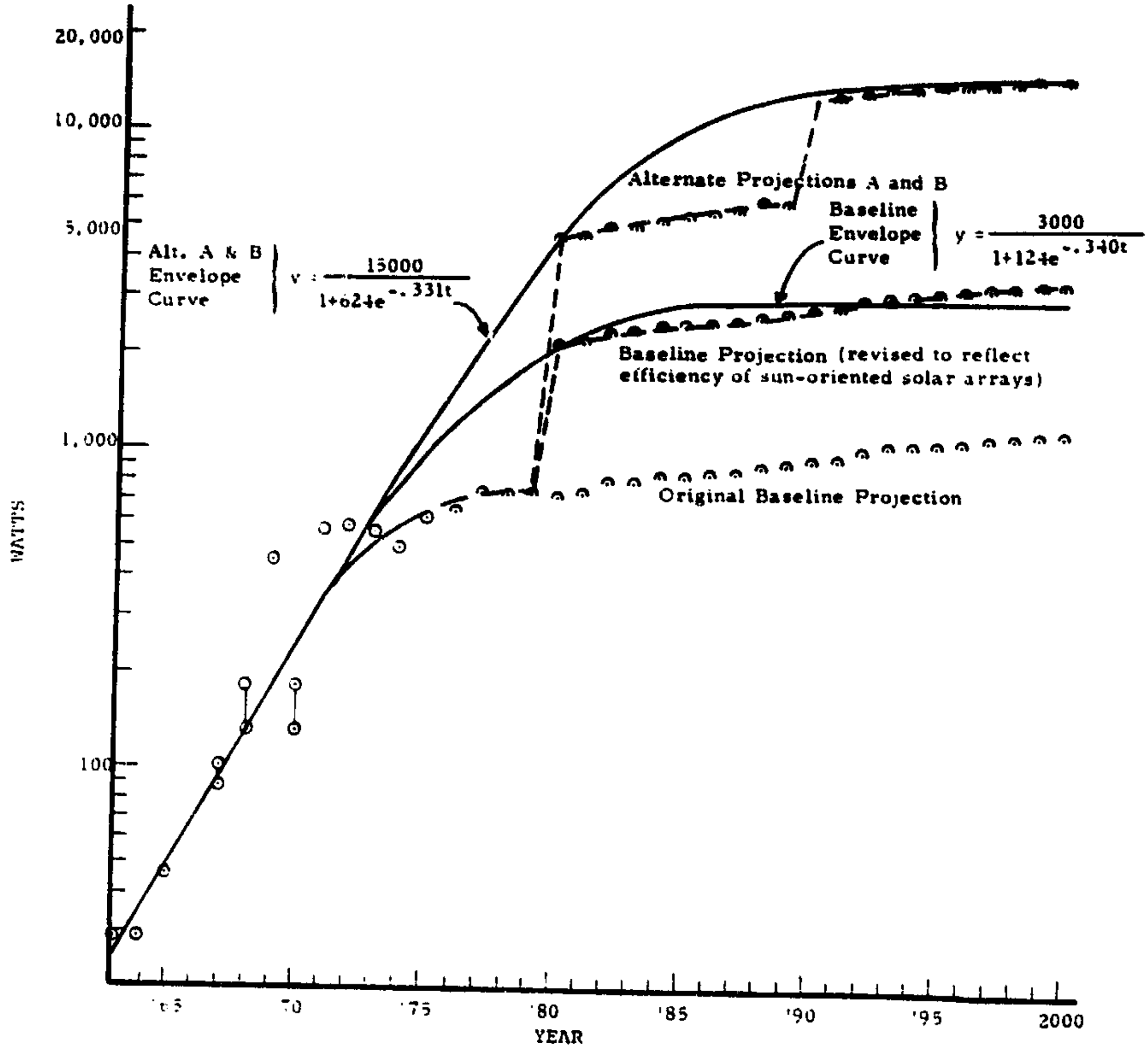

Figure 5.9. Average Power of U.S. Communication Satellites Launched Each Year

communication satellites from 1980 on, the original baseline projection is shown in Figure 5.9 and is used to recalculate total power in orbit, as plotted in Figure 5.8.

5.1.2.2 Projections of Satellite Broadcast Power

The satellite power projections may be combined with data from the power-consuming components of the satellites to provide a forecast of probable developments in those components. The sum of Total Effective Isotropic Radiated Power (EIRP) per satellite is the primary measure of broadcast power and provides the starting point in this forecast. The regression of EIRP versus total satellite power availability shown in Figure 5.10 is extrapolated and combined with the forecasts of total power to obtain projections of broadcast power.

Projection of EIRP using the Baseline and Alternative "A" and "B" forecasts of total power is shown in Figure 5.11. Baseline power is projected to provide for an EIRP of 920 dBW by 1980, and 1250 to 1530 dBW between 1990 and 2000. Power in the larger satellites of Alternates "A" and "B" would support EIRP's of 2200 dBW by 1980 and from 6800 to 8000 dBW between 1990 and 2000.

Since EIRP for wide beam (17°) channels is limited to approximately 33 dBW for C-Band by international agreements on terrestial flux density, [1] and since satellite development is in the direction of multiple spot-beam antennas to concentrate satellite transmitted power over separate small areas of the earth's surface, [2,3] the total rf power will be

[1] J.E. Keigler, et al., "Momentum Wheel Three-Axis Attidude Control for Synchronous Communication Satellites", AIAA Progress in Astronautics and Aeronautics, Communication Satellite Technology, Vol. 33, The MIT Press, Cambridge, Mass., 1974.

[2] H.J. Meyerhoff, "Power Balancing in Multibeam Satellites", AIAA Progress in Astronautics and Aeronautics, Communication Satellite Developments: Systems, Vol. 41, The MIT Press, Cambridge, Mass., 1976.

[3] W.G. Schmidt, "Satellite-Switched TDMA: Transponder Switched or Beam Switched?", AIAA Progress in Astronautics and Aeronautics, Communication Satellite Developments: Systems, Vol. 41, The MIT Press, Cambridge, Mas., 1976.

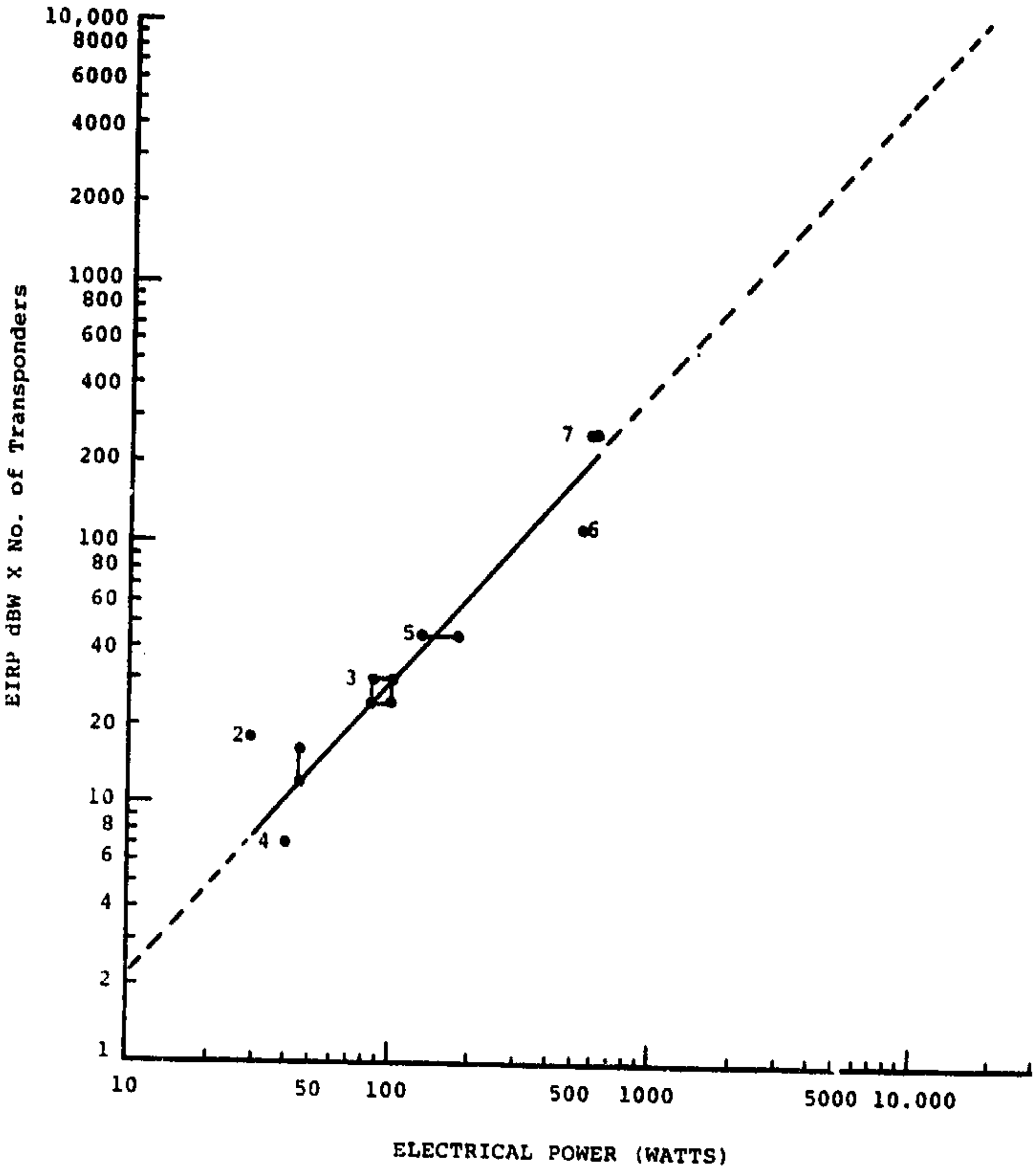

Figure 5.10. Regression of Wide-Beam EIRP Versus Satellite Power

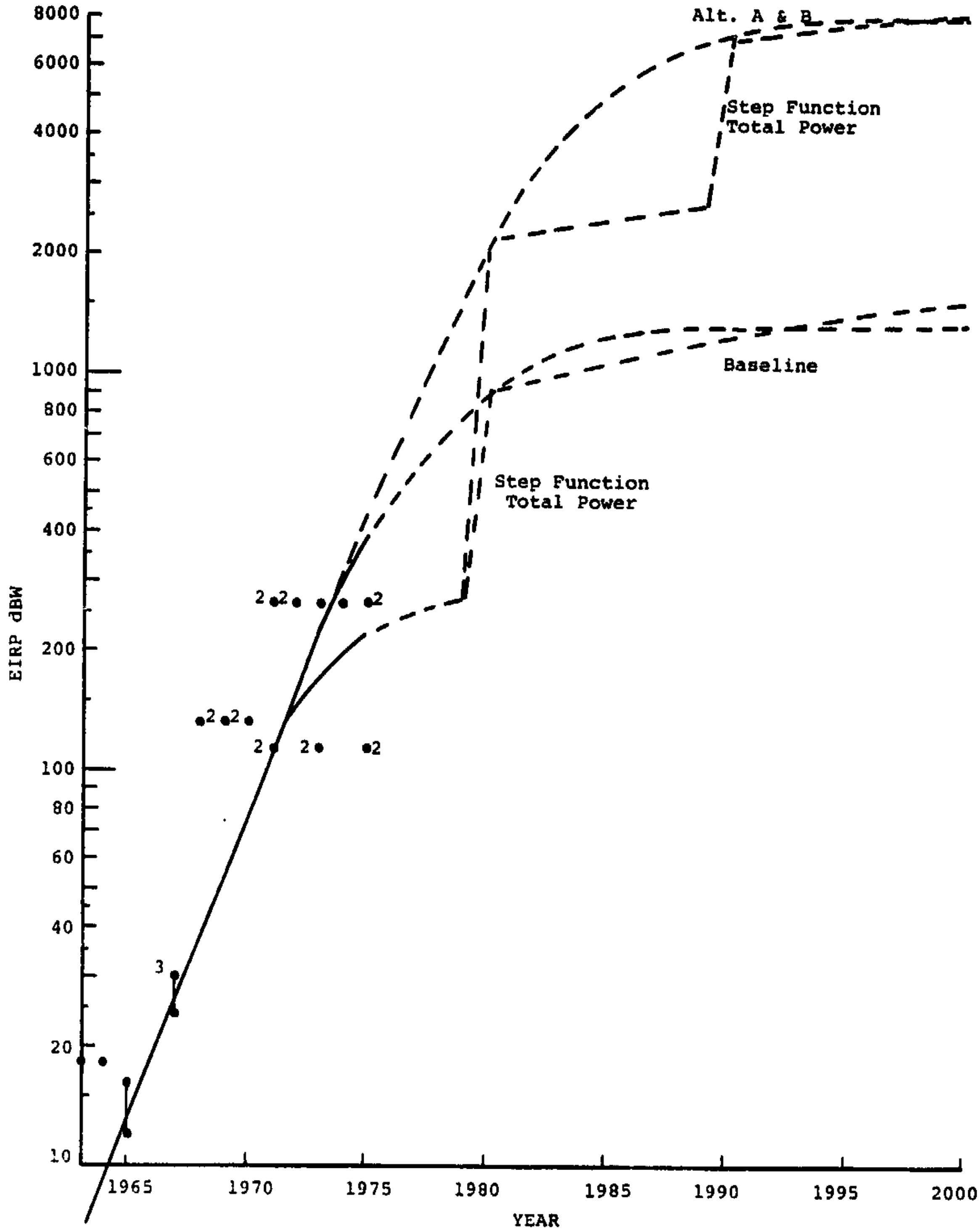

Figure 5.11. Total EIRP Per Satellite Launched (Global Beam 17°)

used primarily to increase the number of wide-band transponder channels per satellite.

The projected number of channels per satellite, derived from total EIRP and EIRP per wide-beam channel, is shown by Figure 5.12. The Baseline projection will provide 36 to 48 channels (for simultaneous operation) per satellite in the period from 1980 to 2000. The larger satellites of Alternates "A" and "B" will permit 84 to 96 channels in the period 1980 to 1990, and 240 to 288 channels from 1990 to 2000.

Transmitting antenna gain projections are shown in Figure 5.13. Since antenna gain is basically a measure of beam width, it is reasonable that wide-beam antenna gain should level off in the region of 20 dB for 11.5° beam width, which is adequate for coverage of major continental areas. The projection for spot-beam antenna gain assumes an upper limit of 70 dB. This limit is equivalent to a beam width of 0.036°, or a 22 Km spot-beam diameter at the earth's surface, which would approximate the area coverage required for most major cities. A 10-meter diameter parabolic antenna would be required to achieve this 70 dB antenna gain. This is an order-of-magnitude larger than current communication satellite antennas. Solutions to the problems associated with multibeam spacecraft antennas which are implied by such narrow beams are of great significance. Analysis of such problems is beyond the scope of this study, but include requirements for side-lobe suppression, interference protection, intermodulation interference, and cross-talk reduction.

5.1.2.3 Projection of Satellite Wide-Band Channel Capacity

Projection of the average number of transponder channels per satellite launched, together with the prior projections of satellites launched and satellites phasing out, enables projection of the number of wide-band channels expected to be operational each year. This projection is shown in Figure 5.14, for the various alternatives of satellite size and power.

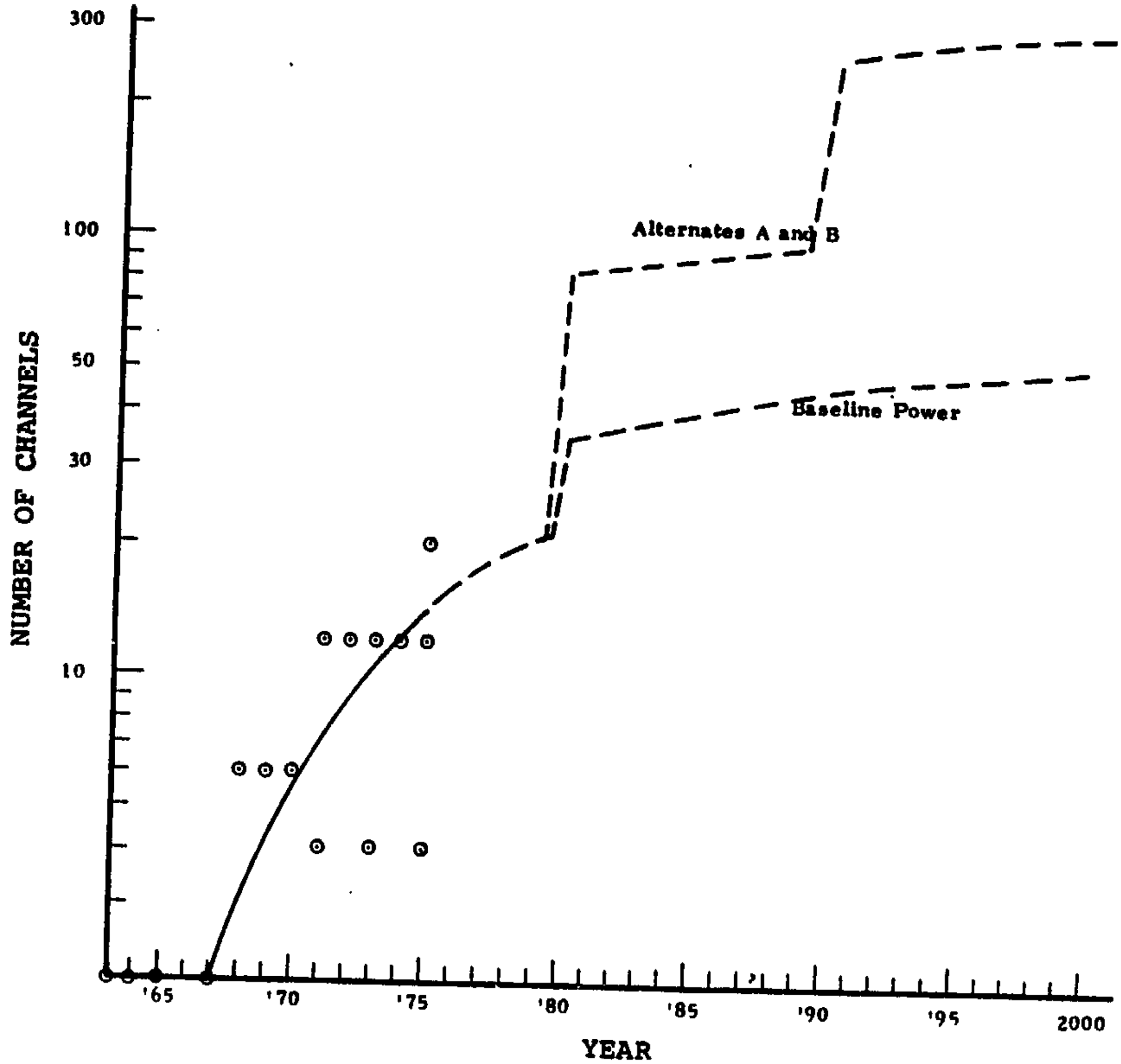

Figure 5.12. Number of Wide-Band Channels Per Satellite

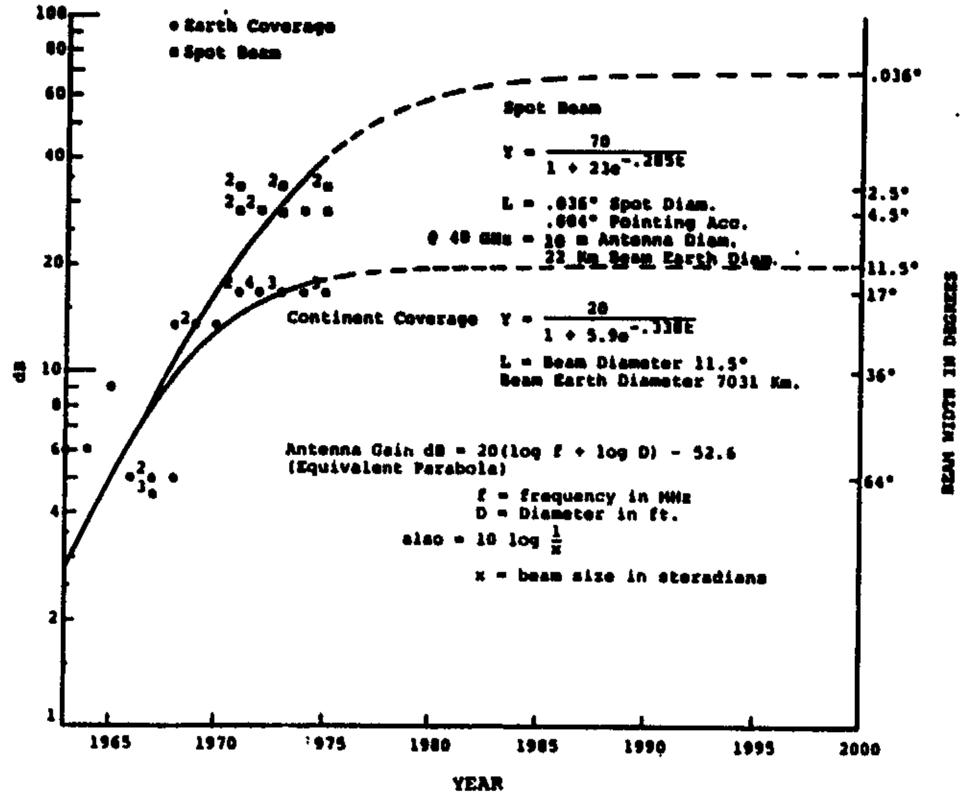

Figure 5.13. Transmitting Antenna Gain

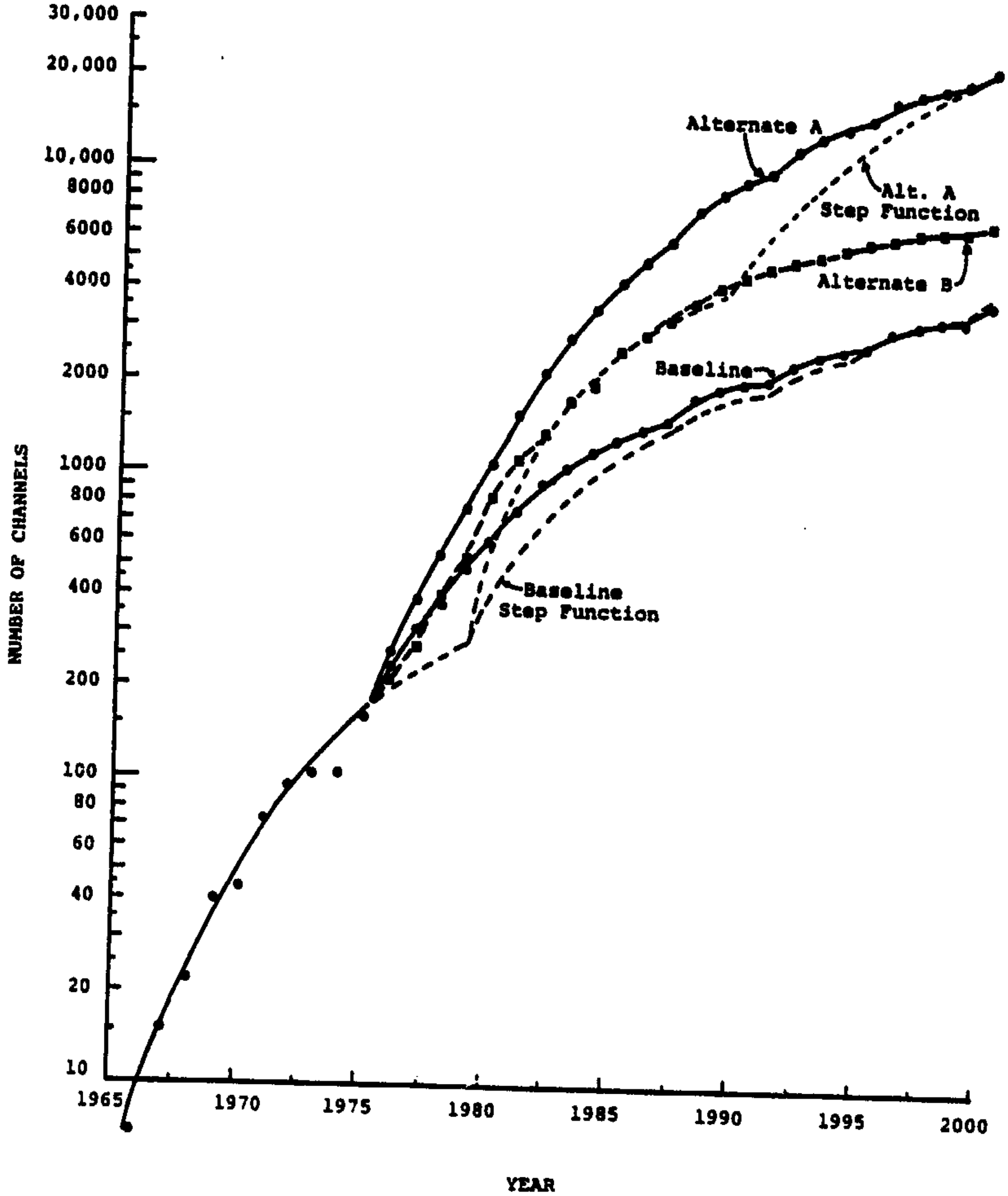

Figure 5.14. Number of Wide-Band Transponder Channels in Operation

5.1.3 Summary of Communication Satellite Trends

Three general paths for future communication satellite development emerge from these projections. The Baseline scenario represents a conservative development picture of small incremental improvements. The cumulative effect of such improvements, nevertheless, offers a substantial increase in overall satellite communication systems capabilities. This scenario should be regarded as the minimum expectation for communication satellites. In this Baseline projection, satellite size will increase only marginally, although the total number of wide-band transponder channels is projected to increase to nearly 4000 by the year 2000. Beyond the year 2000, the number of channels is projected to increase at annual rates of 5% for the years 2001 to 2010, 4% for the years 2011-2030, and 3% for the years 2031 to 2040, as follows:

Year	No. of Channel	Year	No. of Channel
2000	3822	2025	11210
2005	4877	2030	13639
2010	6224	2035	15811
2015	7573	2040	18330
2020	9214		

The second path represents a bolder projection of satellite development, but is consistent with prior developments and technical feasibility. This forecast, referred to as Alternate A, is characterized by two major increases in satellite size, coupled with the same increase in the number of satellites as in the Baseline scenario. The first increase in satellite size, to 2000 Kg in 1980, is achievable with current launch vehicle capabilities. The second increase, to 6000 Kg in 1990, is technically feasible. This scenario represents the most plausible upper limit for satellite advances. In Alternate B individual satellites are projected as being identical with those of Alternate A. However, the number of satellite launches is reduced so that the total weight placed in orbit approximates that occurring in the Baseline forecast.

These projections are summarized in Table 5.1. The larger satellites of Alternates A and B require larger launch vehicles and apogee motors,,and expand the range of technical options for increasing communication satellite capabilities. The larger satellites enhance the potential for multiple spot-beam systems, requiring advances in narrow-beam antenna technology, switching techniques, and pointing methods. The Baseline and Alternate A projections bound the likely capabilities for meeting communication market demand and total system cost, while the larger satellites forecast for Alternates A and B provide the upper limits for communication satellite R&D.

5.2 TRENDS OF SATELLITE COMMUNICATION EARTH STATIONS

The directions of change in earth station technology have been toward smaller antennas, reduced costs, and reduction in the land-line interconnection system. The history of this technology is insufficient to provide a basis for extrapolation of trends. However, the data which is available provides a basis for determination of probable antenna sizes and a starting point for cost projections.

TABLE 5.1

SUMMARY TABULATION OF PROJECTED BROADCAST SATELLITE CHARACTERISTICS

Year	Aver. Wt. Kg	Aver. Power Kw	Aver. Total TWTA Power Watts	No. of Wide-Band Channels	No. of Satellite	Total Wt. Metric Tons	Total Power Kw	Total No. of Wide-Band Channels*	Equiv. Voice-Grade Channel Capacity
1975	622	0.6	220	15	15	10	8	160	120K
				BASELINE PROJECTION					
1980	785	2.1	570	35	25	19	23	600	450K
1985	815	2.5	800	46	33	26	71	1300	975K
1990	840	2.9	870	49	43	35	111	2000	1.9M
2000	890	3.4	870	49	78	68	248	3800	2.9M
2040								18300	14M
				ALTERNATE A					
1980	2000	4.7	1520	83	25	23	33	1100	825K
1985	2000	5.2	4000	193	33	61	148	4300	3.2M
1990	6000	12	5800	267	43	110	275	9400	7.0M
2000	6000	15	6400	296	78	468	1116	22500	17M
				ALTERNATE B					
1980	2000	4.7	1520	83	19	19	--	800	600K
1985	2000	5.2	4000	193	20	38	--	2600	2.0K
1990	6000	12	5800	267	21	50	--	4400	3.3M
2000	6000	15	6000	296	24	144	--	6900	5.2M

* Rounded to Nearest 100

5.2.1 Earth Terminal Costs Versus Antenna Size

Earth terminal costs tend to be associated with antenna size, not only in terms of the antenna itself, but also in terms of transmitter and receiver costs. It is axiomatic that total terminal costs will be optimized in actual systems, so that it may be inferred that terminal costs will follow established patterns in the absence of major advances in technology. Following this assumption, earth terminal costs for the antenna areas are plotted in Figure 5.15. These data support a formula for approximate earth terminal cost as follows:

Earth Terminal Cost, E_c (in dollars) - 3600 x antenna area (in sq m).

A curve for antenna systems costs is also shown in Figure 5.15. The formula for antenna systems costs in accordance with this curve is as follows:

Antenna System Cost, A_c (in dollars) =

$$10^3 \times \left\{ 0.14 \times \text{antenna area} + [\text{antenna area}]^{0.8} \right\}$$

with antenna area given in square meters.

5.2.2 Earth Terminal Cost Projections

The economies of quantity production may reasonably be expected to lower earth terminal costs. A projection of expectations for lowered costs may be made using the conventional "learning curve" approach.* For this projection, a 90% learning curve was selected, which is quite conservative in comparison with the 80% learning curves usually associated with production of electronic equipment.

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* Learning curve percentages indicate the percentage of initial cost associated with each doubling of the initial quantity, i.e., a 90% curve indicates a 10% cost reduction each time the production quantity is doubled.

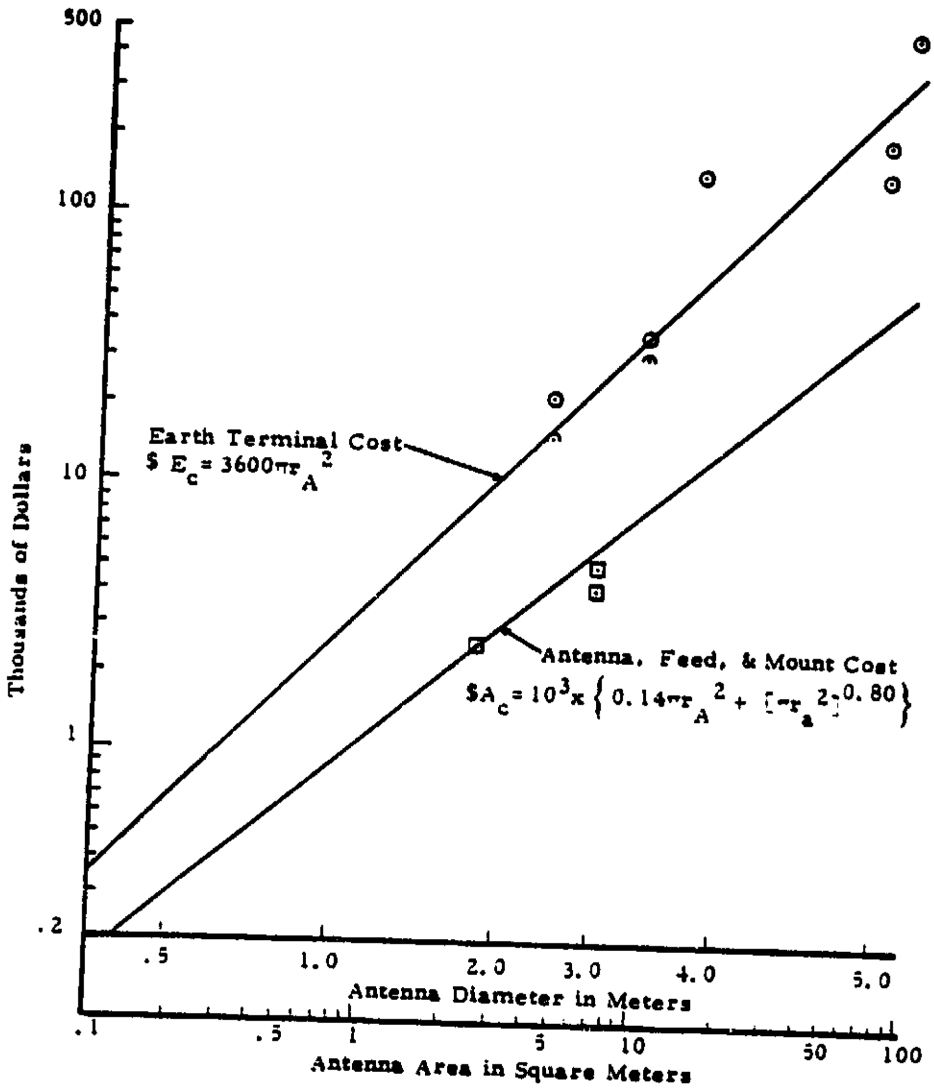


Figure 5.15. Earth Terminal Costs Versus Antenna Size

Figure 5.16 portrays earth terminal costs for a typical TV receive, two-way voice, terminal, and for a typical two-way voice terminal under various conditions. The initial cost basis for one-channel** TV receive terminals, taken from Figure 5.15, is assumed to be $30,000 for a production quantity of 100 units. A cumulative production quantity of 10,000 units on a 90% learning curve should lower this cost to $15,000 for the 10,000th unit. Since this cost would still exceed a reasonable outlay for a single-family installation, the alternate possibility of a terminal for large apartment complexes may be considered. Such a terminal, whose costs are also shown on Figure 5.16, would be an 11-channel TV receiver, capable of receiving 11 channels simultaneously and distributing the channel signals to individual TV sets for channel selection at the set, in a manner similar to current cable TV. Initial costs for this added capability are conservatively assumed to be $2000 for each added channel at the terminal, giving an initial cost of $50,000 for such a terminal. With cumulative production of 10,000 units, the 10,000th unit would cost approximately $25,000. Assuming a market of 10,000 apartment complexes each with 80 or more apartment units, this price would permit an acceptable rate of return-on-investment at revenue rates competitive with cable TV.

A tunable, one-channel-at-a-time, TV receiver, plus two-way voice, for individual installations, would require production of one-million units on an 80% learning curve to lower the cost of such a unit to $1600. This quantity and cost is a reasonably close match for that portion of the farm market with annual sales of $20,000 or more per year.

Two-way voice communication using 0.6-meter antenna earth stations at an initial cost of $1000 (as indicated by Figure 5.15 and accompanying discussion) would reach unit costs

** "One-channel" refers to a terminal which is capable of receiving only one channel at a time, although various channel frequencies may be selected.

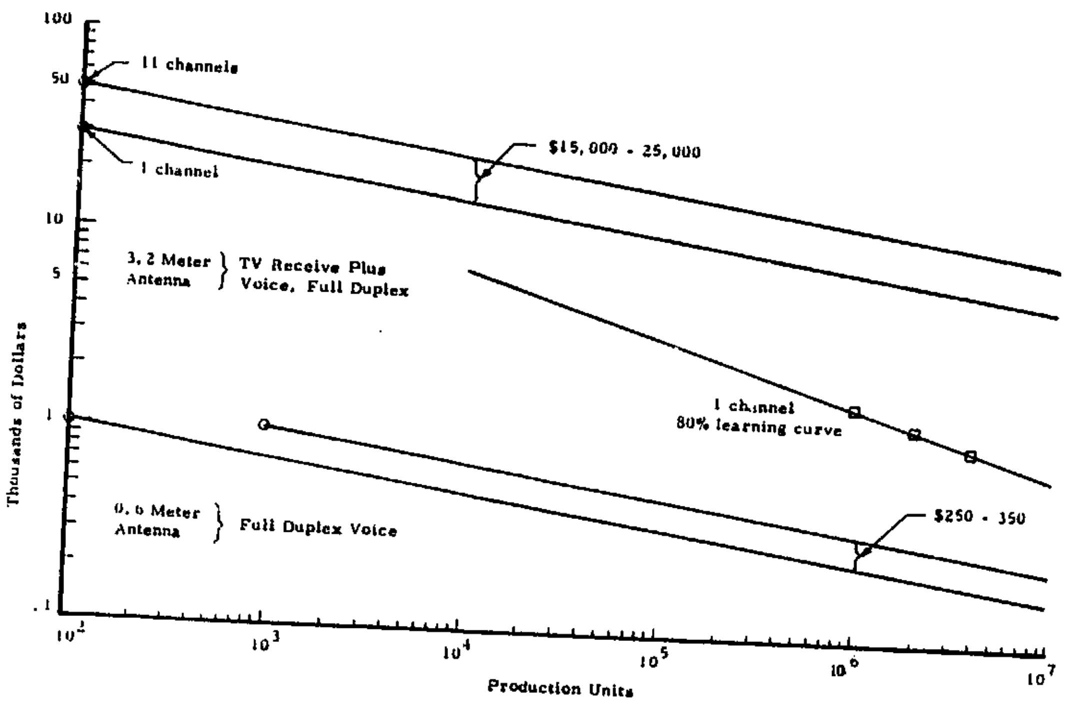


Figure 5.16. Earth Terminal Production Costs With 90% Learning Curves

of $250 to $350 at the one-millionth unit on a 90% learning curve, as shown on Figure 5.16.

5.3 PROJECTION OF COST TRENDS IN SATELLITE COMMUNICATION

In addition to the earth station cost trends presented in Subsection 5.2, cost trends for other major elements of satellite communication systems have been developed. These projections are presented in the following paragraphs.

5.3.1 Projection of Leasing Costs for Wide-Band Transponder Channels

The first of these projections is a learning curve projection of leasing costs for wide-band transponder channels, as shown in Figure 5.17. The data for Intelsat leasing costs offers strong support for a 77% learning curve. This learning curve projection may be combined with the projections of total numbers of wide-band channels to give cost projections versus time, as shown in Figure 5.18.

Most long-range projections of leasing costs have inherently assumed continuing exponential rates of decrease until some point at which the forecaster felt a leveling off would occur. Such forecasts have also tended to ignore the usual relationship between quantitative increase in capacity (with time) and cost reductions, i.e., the learning curve experience factor. As may be noted from Figure 5.18, the current scatter of leasing cost data would make the selection of an accurate exponential rate for leasing cost reduction very problematical. However, by combining the learning curve from Figure 5.17 with the Baseline and Alternate A projections of numbers of wide-band transponder channels, projections of leasing costs can be obtained which appear reasonably consistent with current data and intuitive expectations. These curves, as given in Figure 5.18 indicate a drop in leasing costs per transponder (with associated earth systems) to $1.3 million by the year 2000 with the marginal increases in satellite size

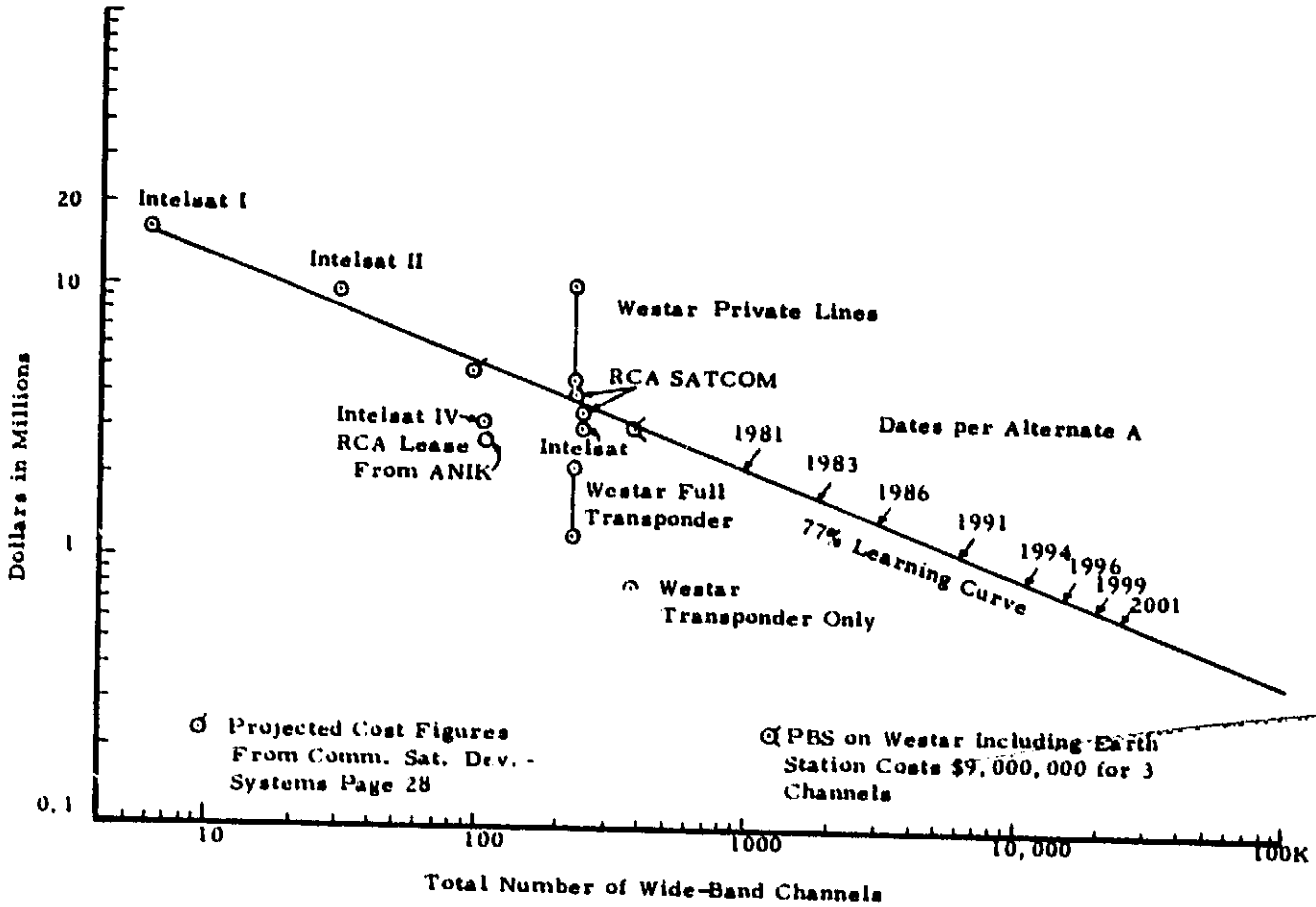


Figure 5.17. Learning Curve Projection of Leasing Cost Per Wide-Band Transponder Channel Versus Number of Operational Channels

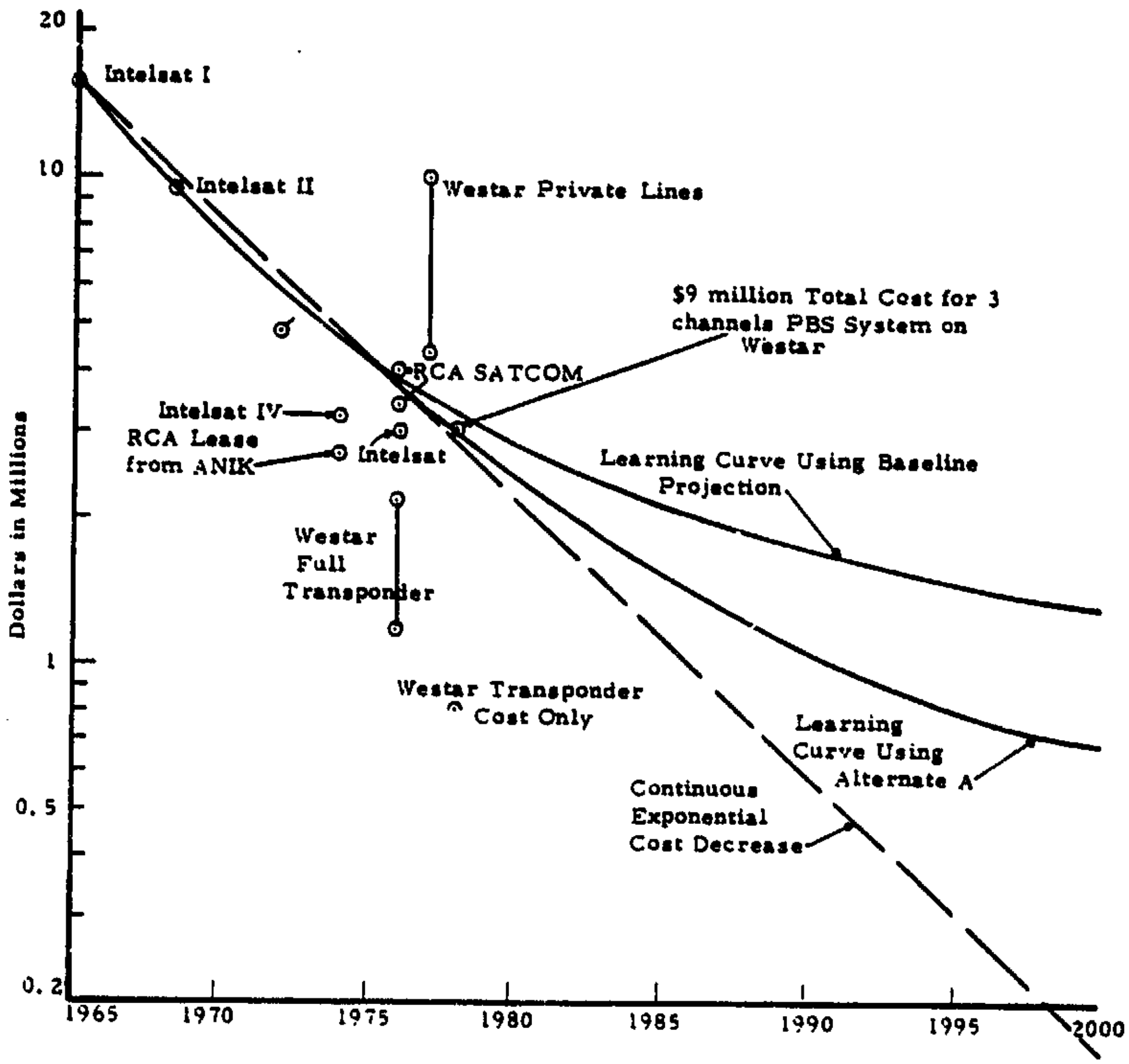


Figure 5.18. Cost Per Wide-Band Transponder Channel - Including Associated Earth Systems

assumed for the Baseline projection. The larger satellites of Alternate A would result in annual leasing costs decreasing to about $700,000 per complete wide-band transponder channel by 2000.

Combining the projections of leasing costs per wide-band channel with the projections for numbers of channels, projections of total revenues may be obtained, both for the total system and for the satellite portion of the system. These projections are given in Figure 5.19. For comparison purposes, it may be noted that projected total system revenues for the year 2000 of $5.27 billion (Baseline) and $14.5 billion (Alternate A) are 20% and 57%, respectively, of the 1973 revenues of the U.S. domestic telephone system ($25.5 billion).

5.4 PROJECTION OF SPECIAL TELECOMMUNICATIONS SERVICE

Radio telecommunications services for aviation, marine operations, public safety activities, and industrial use have each followed a common pattern of increase in the amount of service provided, measured in terms of numbers of operating stations. Based on the assumption that satellite services can capture portions of these markets, it is projected that growth in satellite usage for these services will follow the characteristic pattern of the growth in radio services.

5.4.1 Marine Operations

Fixed stations will transmit video information and data on weather, marine traffic, navigation hazards, harbor conditions, shipping documentation, and possibly personal contact exchange (e.g., family information to sailors), to ships at sea. Distances involved make satellite communication the only possible means for providing such services. Because of the value of such services, it is projected that the number of fixed stations offering such services using satellite transmission will eventually be as large as the current number of fixed marine radio stations. Estimates of satellite channel capacity required

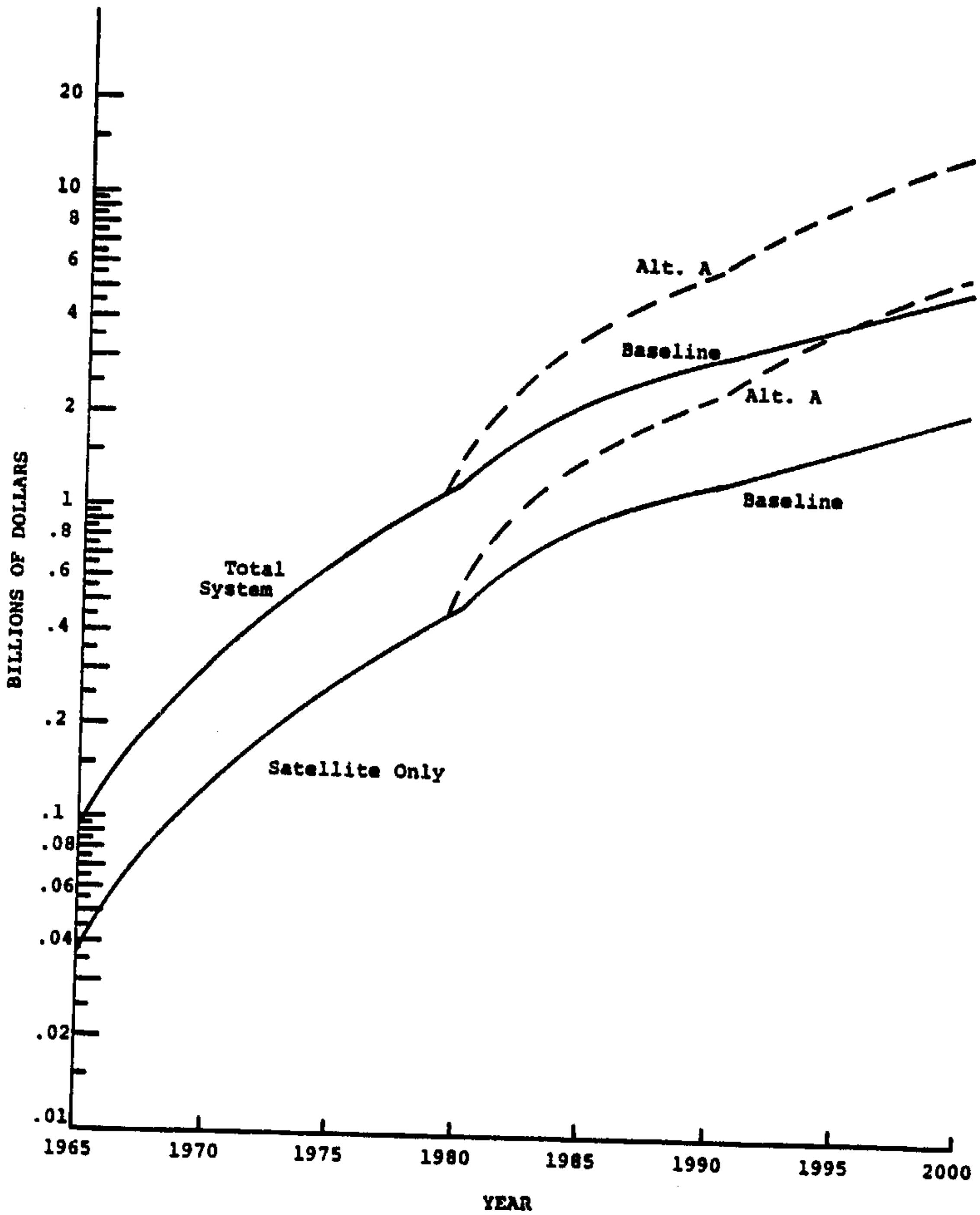


Figure 5.19. Total Annual Revenue From Satellite Communication Systems

for any given number of fixed stations are dependent on the amount of real-time video-transmission required versus intermittent transmissions, and on the number of separate transmissions to individual ships versus broadcast services. These estimates are included in that portion of this report which projects satellite channel demand. Mobile marine stations using satellite transmission are estimated to increase to a number which is equal to 20% of the current number of mobile marine radio units. This is equal to the merchant vessel proportion of current marine units, and assumes that the number of merchant marine vessels will remain approximately constant, and that most pleasure boats will not utilize satellite communication. These mobile stations will have TV receive-only and voice/data transmit and receive capability.

5.4.2 Aviation Operations

Fixed stations will transmit video information on weather, air traffic, airport conditions, and traffic control instructions. It is projected that the number of fixed stations offering such video services through satellite transmission will eventually reach 40% of the current number of aviation radio stations, on the basis that such a number will be adequate to meet the needs of airlines and the business sector of general aviation. Airborne stations using satellite communications are projected to increase to 20% of the current number of aviation radio units, equivalent to 30% of all aircraft. These airborne units will be TV receive-only, with voice/data transmit and receive capability.

5.4.3 Public Safety Activities

This category includes police activities fire-fighting, emergency ambulance service, and disaster-related activities. It is postulated that ultimate growth in the number of public safety stations having TV and voice/data transmit capabilities using satellites will reach 10% of the current number of public service radio stations. This estimate is based on expansion of centralized services in metropolitan areas beyond the limits of fully effective line-of-sight service plus equivalent service to large nonmetropolitan areas, and on recognition of the additional utility provided by several types of video service. Receive-only TV plus voice/data transceiver capability is projected to reach 5% of the current number of mobile radio stations of this type, i.e., most units will continue to have radio voice communications only.

5.4.4 Industrial Use

Fixed industrial stations with TV plus voice/data transmission are expected to reach a number equal to 5% of the current number of industrial radio stations. This usage is expected to come from such installations as off-shore oil, platforms, other remote operations, and centralized control of wide-spread industrial activities. Mobile industrial stations with TV receive only plus voice/data transceivers are estimated to number ultimately 2% of the current number of mobile industrial radio units. In addition to these mobile stations, it is projected that 8% of the land transport units (10,000 trains plus 7% of the motor freight trucks) will have this capability.

5.4.5 Projections of Special Telecommunication Services

These projections of upper limits of numbers of stations in the future, based on current levels of radio stations, are predicted on the basis that the pattern of radio usage has reached, or is approaching saturation in each market, and that a similar pattern will prevail in usage of the satellite capability postulated.

The growth patterns for special services radio stations are shown in Figures 5.20 and 5.21. This data also forms the basis for projection of the numbers of special services stations estimated to use satellite transmissions for communication, in accordance with the postulates noted above.

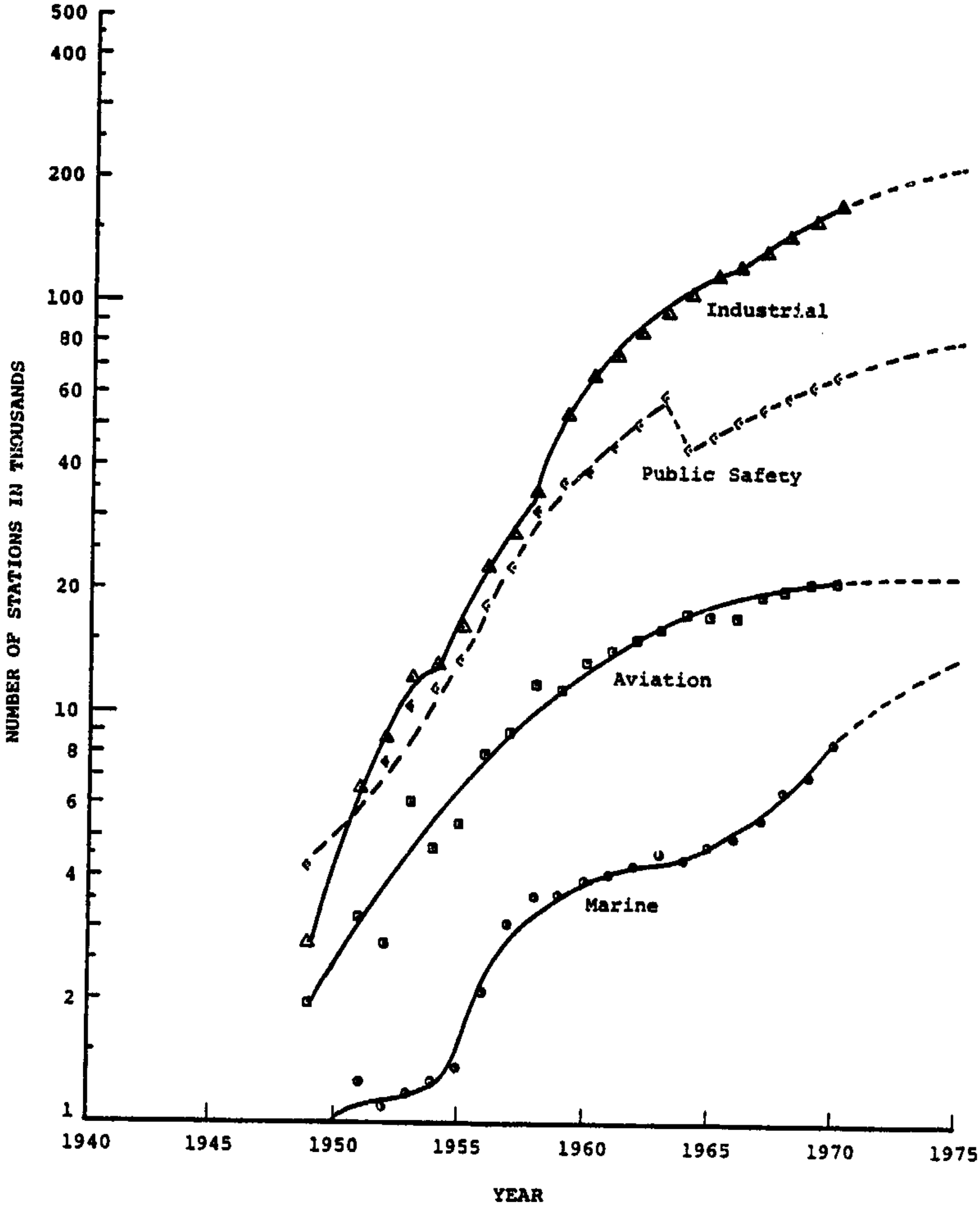


Figure 5.20. Fixed Radio Stations for Special Communication Services (Source: "Historical Statistics of the United States")

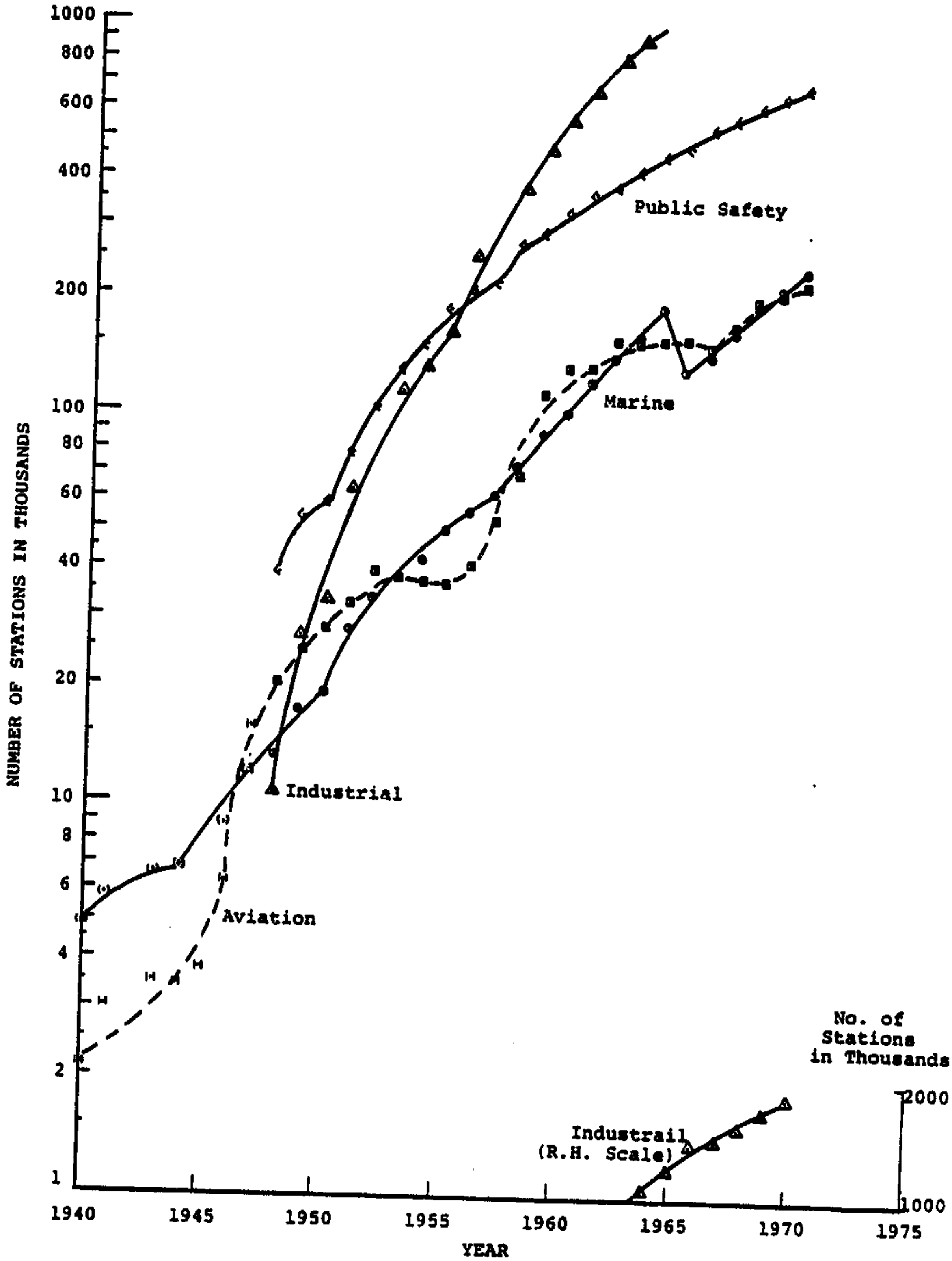


Figure 5.21. Mobile Radio Stations for Special Communications Services (Source: "Historical Statistics of the United States")

For the purposes of the projection, three assumptions apply: (a) that the patterns for increase in numbers of radio stations for special services will be repeated when satellite communications begin to provide service in the same markets; (b) that the year 1981, for satellite services, will be equivalent to the year 1951 for radio stations, and that the pattern of increase will follow year-by-year, e.g., satellite year 1990 will be equivalent to radio year 1960; and (c) that summation of the numbers of stations projected for each service in each year will give a reasonable indication of the total numbers of stations involved with satellite communications, with the principle of compensating errors operating to smooth the pattern of increase and minimize the effect of errors in the separate projections for each service.

The ratios of projected stations using satellite transmissions to radio stations for each service, as noted in preceding paragraphs, result in approximately equal numbers of fixed stations for each service. To calculate the satellite channel capability which the special service fixed station TV transmissions will require, the following approximations were used:

Service	Transmission Rate	No. of Channels Per Station
Marine	2 frames per second around-the-clock operation	.067
Aviation	10 frames per second around-the-clock operation	.333
Public Safety	0.1 channel per day health 0.9 channel per day police	1.0
Industrial	2 frames per second, peak-to-average load ratio = 3	0.20
Average for all	(assumes each service has approximately 1/4 of the total number of stations)	0.4

Multiplication of the projected total number of special service stations by 0.4 will provide the forecast of satellite channel demand for special service TV broadcasts in these markets, as shown by Figure 5.22.

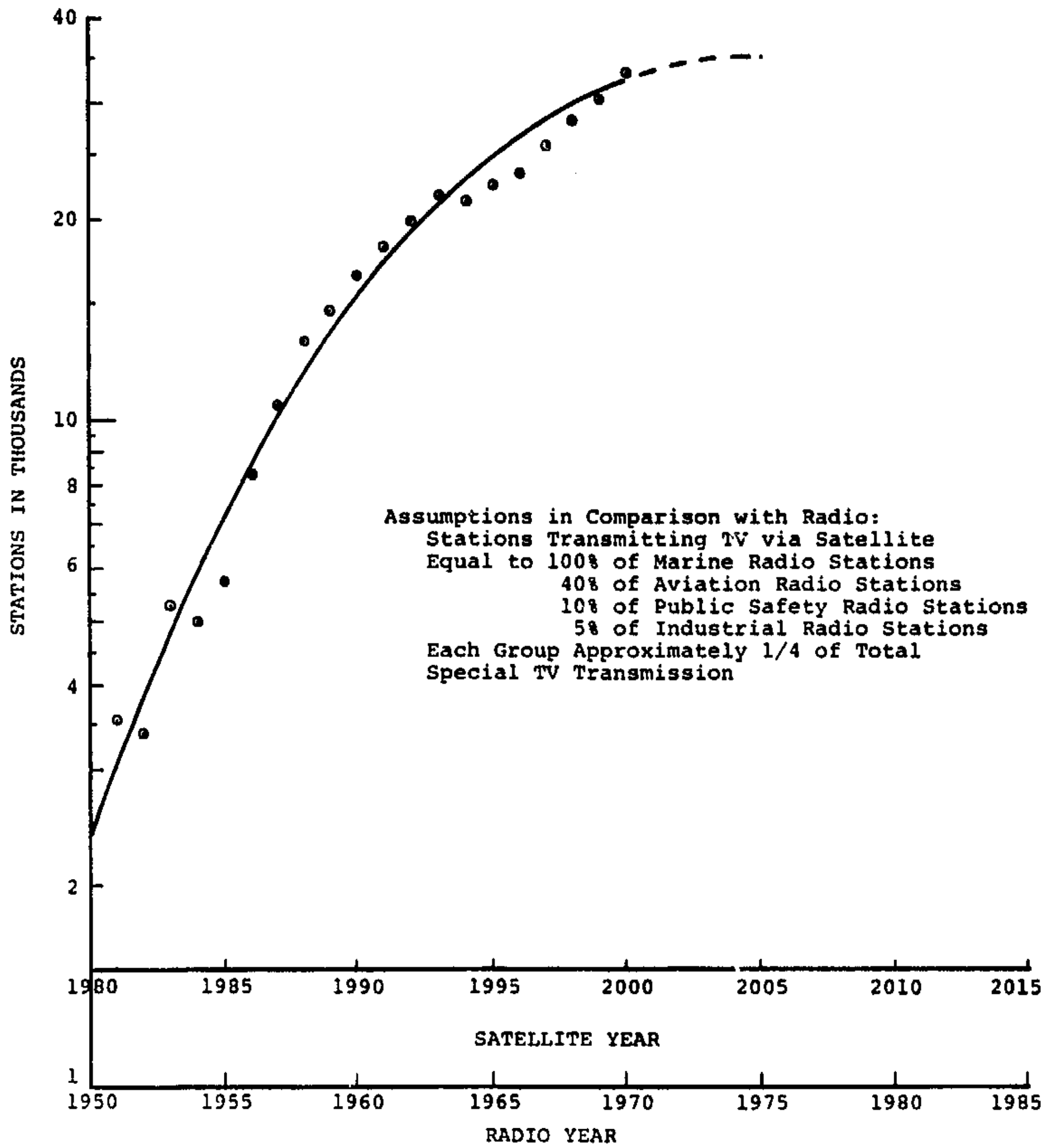


Figure 5.22. Composite Special Land Stations Projection--Based on Historical Pattern of Special Radio Services Growth

The ratios of stations using satellite transmissions to radio stations, for each service, as previously noted, result in approximately equal number of mobile stations for each service. Calculation of the channel capacity required to support the voice/data transmission of the mobile stations (in addition to the TV receive-only requirement) is based on the following approximation:

> Each mobile unit will be transmitting 10% of the time (six minutes per hour), with a peak-to-average ratio of three, and each voice/data channel will require 0.00133 of wide-band channel capacity, so that 3/10 x 0.00133, or 0.0004, times the number of mobile stations will give the number of wide-band channels required.

The number of channels required for this voice/data service is small in comparison with the TV requirement, so that the more significant element of this projection is the number of mobile receivers projected. Graphical indication of the projected pattern of increase in numbers of mobile special services stations is presented in Figure 5.23.

In summary, the total number of special services fixed stations using satellite transmission is projected to equal 12% of the number of fixed radio stations for these services, reaching 33,000 stations in the year 2000. The total number of mobile stations using satellite transmissions is expected to equal 7% of the number of mobile radio stations, reaching 208,000 in the year 2000. Television transmissions are projected to require 13,200 wide-band channels by the year 2000, with voice/data transmissions requiring an additional 83 wide-band channels, for special services for marine, aviation, public safety, and industrial operations.

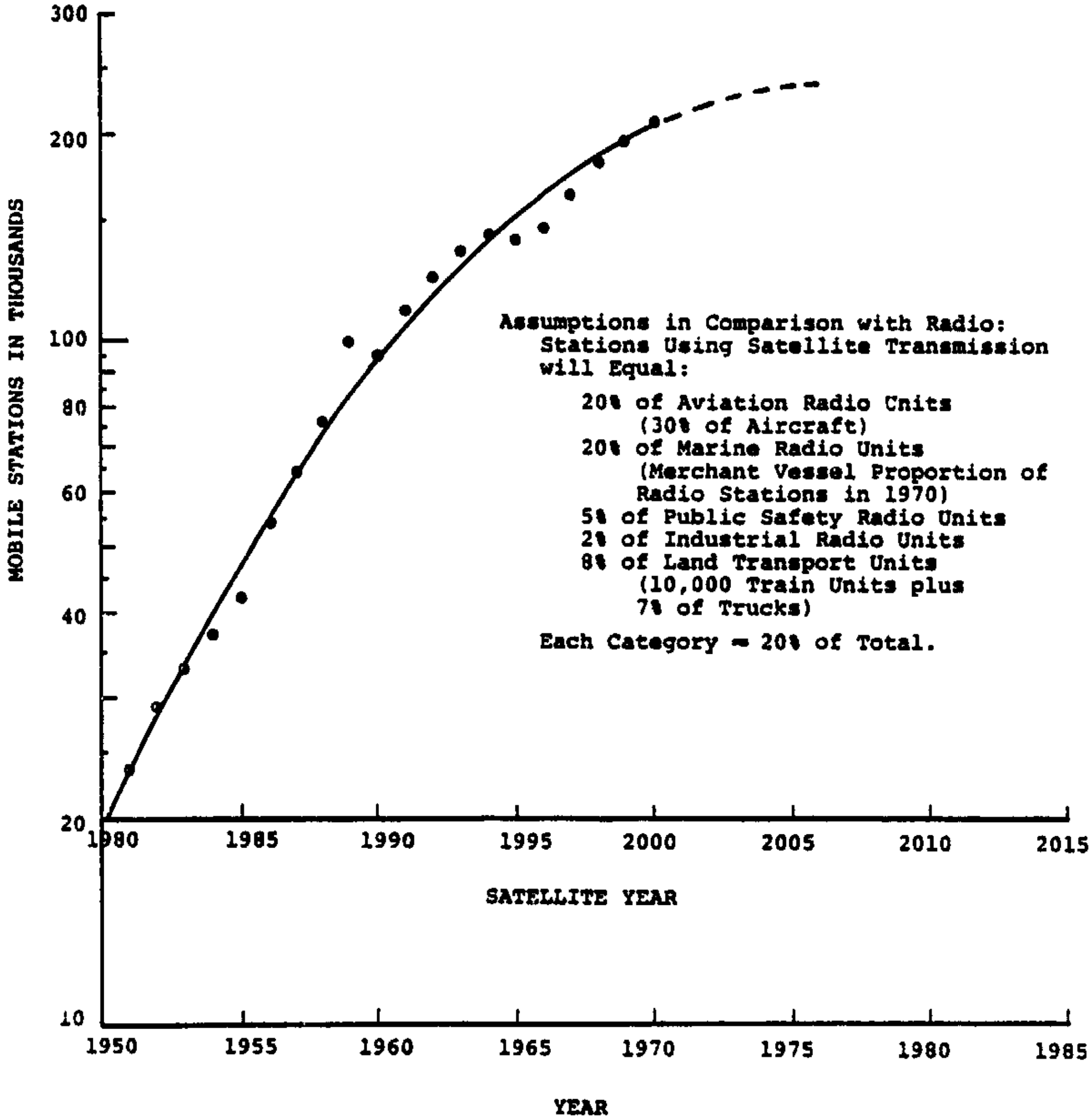


Figure 5.23. Composite Special Mobile Stations Projection--Based on Historical Pattern of Special Radio Services Growth for Voice and Data

5.5 PROJECTIONS OF BROADCAST SERVICES

The increases in various broadcast services may be examined to discern patterns which might be repeated in the growth of similar satellite services. Such patterns are presented and discussed in the following paragraphs.

The patterns of increase in commercial AM broadcast services are shown in Figure 5.24. It may be noted that the very rapid initial growth slowed markedly and then fell below the trend line ultimately established from 1947 to 1974.

The commercial FM broadcast services shown in Figure 5.25 is a close replica of the AM growth pattern, following 22 years later. The characteristic of dynamic overshoot is evidenced even more markedly.

Commercial TV broadcasting evidenced two dynamic overshoots, the first from 1946 to 1950, and the second from 1953 to 1961, as shown in Figure 5.26. From 1953 to 1974, the number of TV stations matches almost exactly the pattern of increase in number of AM radio stations during the period from 1923 to 1944. If TV continues to follow the pattern of increase in numbers of AM stations, then an upward jump in number of TV stations should occur during 1979, increasing from the current number of 700 stations to between 1400 to 2000 stations. Two elements appear necessary if this increase is to take place. First, the expansion must take place in the UHF band which is not now heavily used. Second, additional programming must be provided at costs compatible with advertising revenues available. The additional programs may come either from new networks or from local programming.

The growth of cable TV also evidences dynamic overshoot, although to a lesser extent than the previous examples, as shown in Figure 5.27. It appears that this service will continue to increase to saturation of the market of urban places larger than 2500 population near the end of this century.

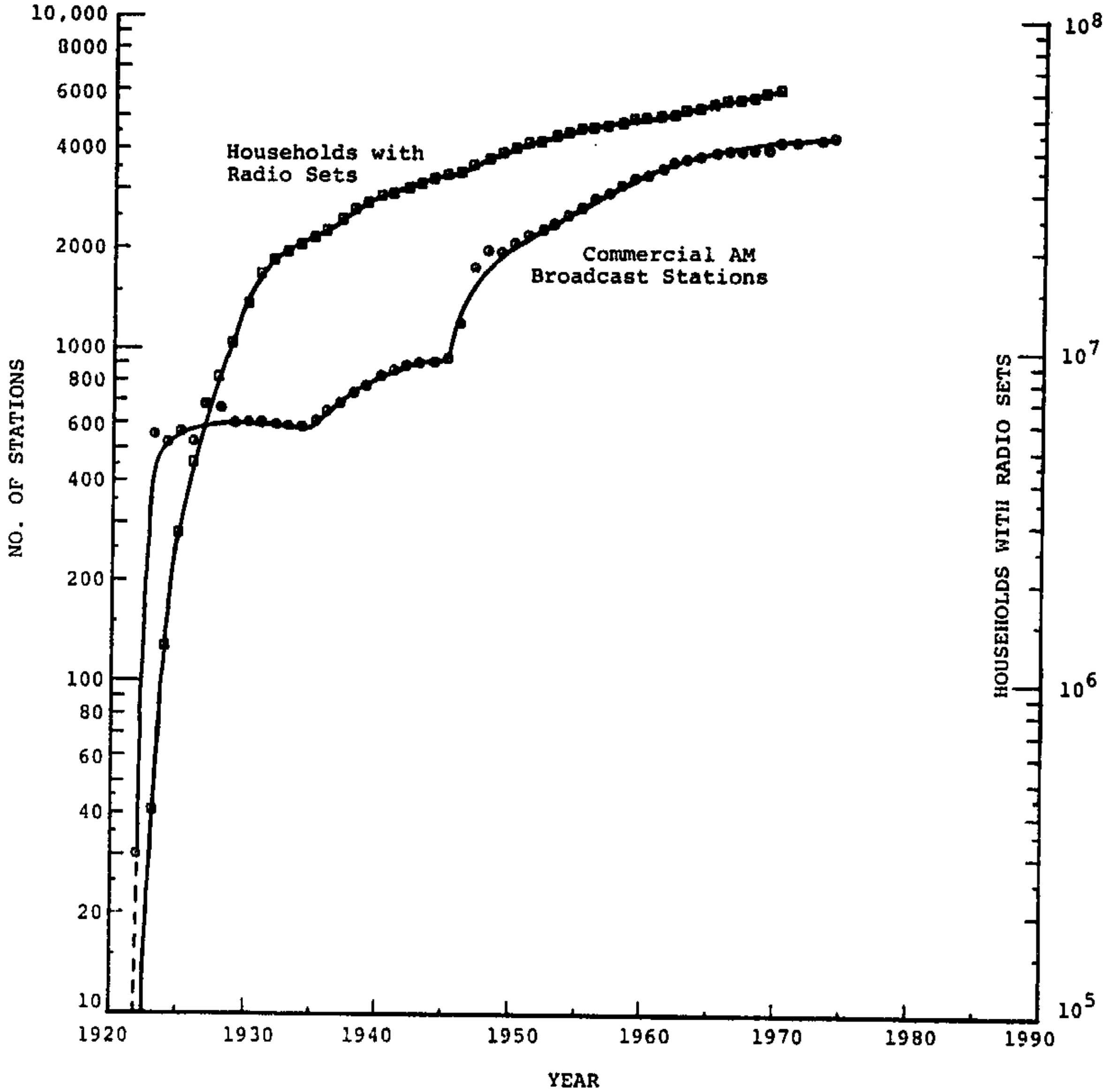


Figure 5.24. Commercial AM Broadcast Services

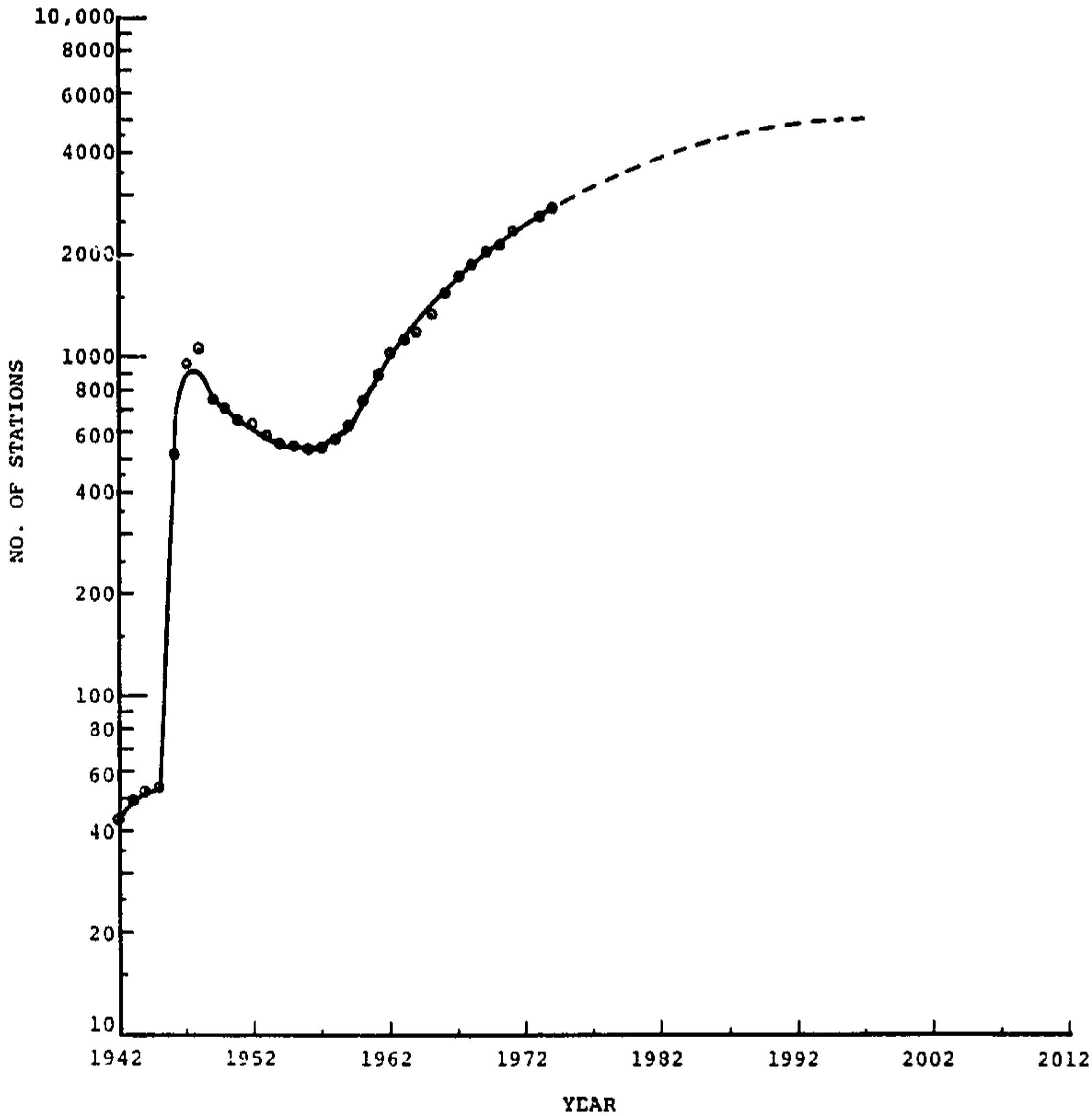


Figure 5.25. Commercial FM Broadcast Stations

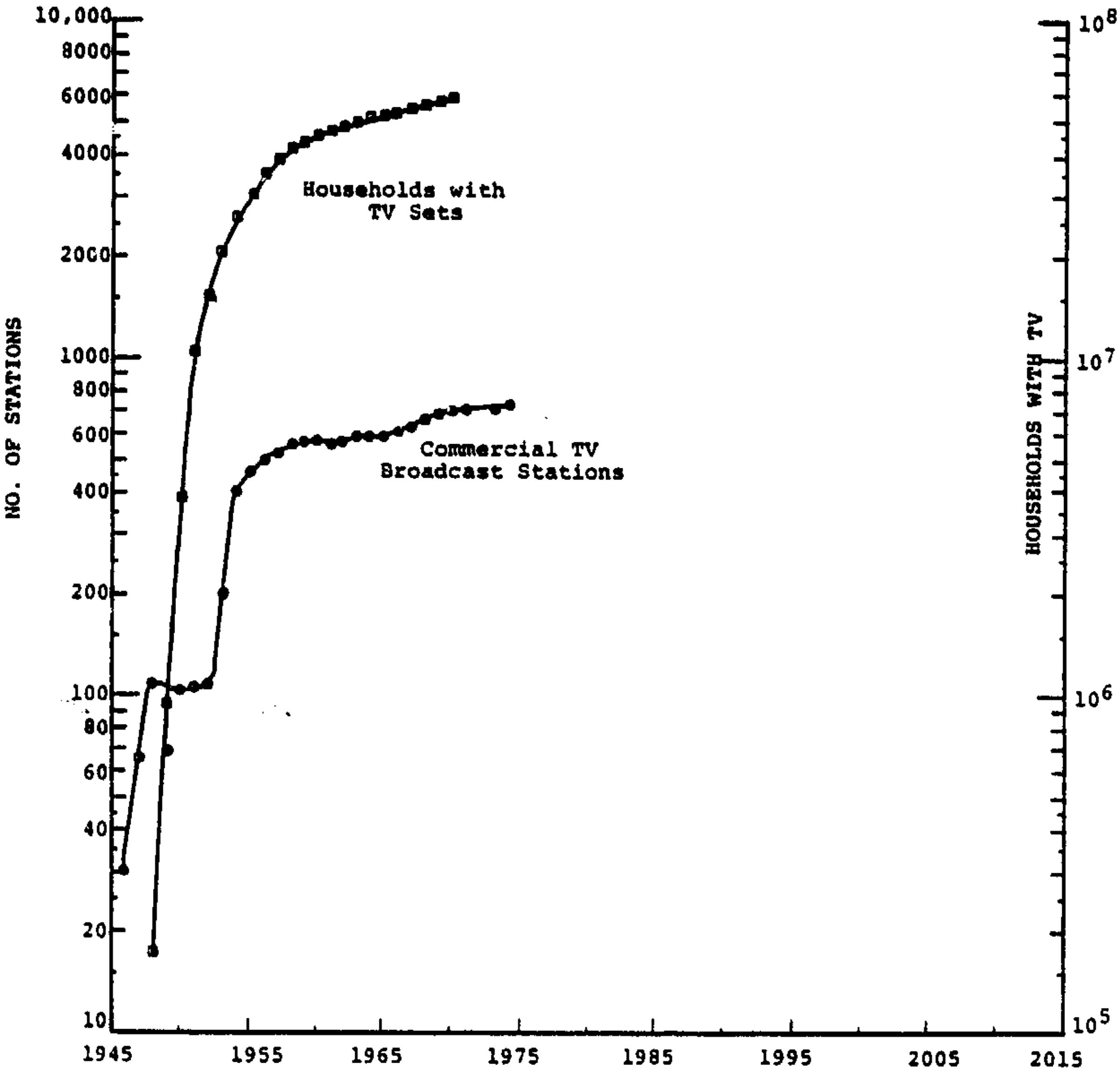


Figure 5.26. Commercial TV Broadcast Services

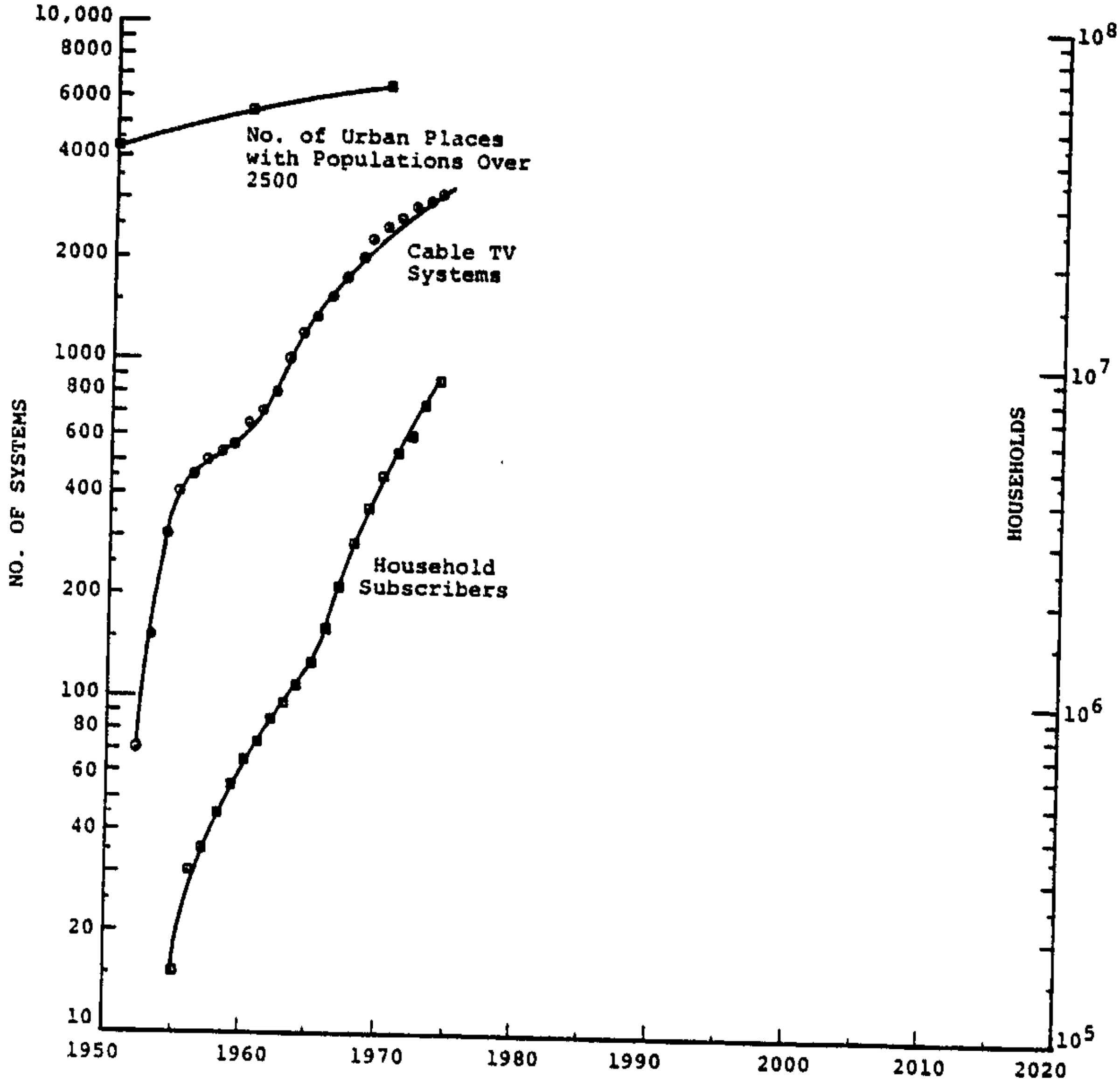


Figure 5.27. Cable TV Systems

Data for educational TV stations is shown in Figure 5.28. If the number of institutions of higher learning is taken as a surrogate for potential market size, further expansion may be projected to follow the curve shown on the figure, reaching a fivefold increase in the current number of stations in the 1990's, i.e., about 1200 stations.

The characteristics of the dynamic overshoot for commercial AM, FM, TV, and cable TV are markedly similar. For AM and FM, the time from initial rise to a pronounced first minimum was 12 years, for commercial TV with two successive overshoots, the combined time to the second minimum was 13 years, and for cable TV with a weak overshoot, the comparable period was 7 years. The time required for the pattern to damp to steady growth was nearly 20 years in all four of these situations.

Comparison of these growth patterns with the projected increases in number of wide-band transponder channels, as previously given in Figure 5.14, is shown in Figure 5.29. In this figure, the growth in total number of earth-based TV systems from 1946 to 1974 is compared with the increase in numbers of satellite wide-band channels for an equivalent 28-year period from 1969 to 1997. (The earth-based TV systems are defined herein to include the numbers of commercial TV stations, plus educational TV stations, and the numbers of cable TV systems). If it were to be assumed that satellite use would be restricted solely to broadcast functions, then the Baseline projection given in Figure 5.14 and repeated in Figure 5.29 is conservative in comparison with the actual increase in numbers of earth-based TV systems.

This comparison, of course, does not address the issue of the size of the total market for broadcast services, nor the degree to which satellites might substitute for the earth-based broadcast systems. Except for the fact that growth in cable TV was coincident with a slow-down in growth of commercial TV stations, there is little evidence that any of the broadcast

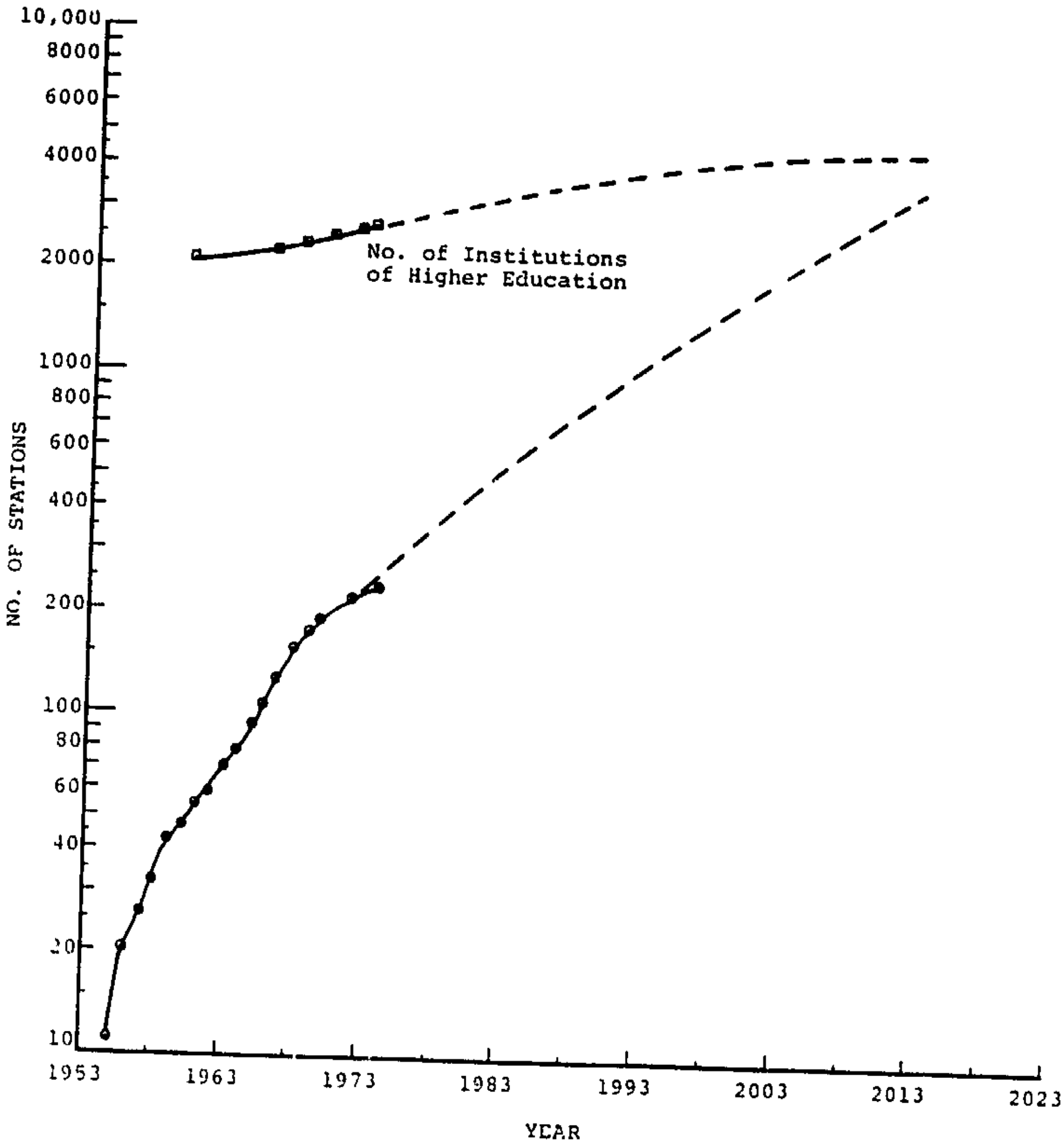


Figure 5.28. Educational TV Stations

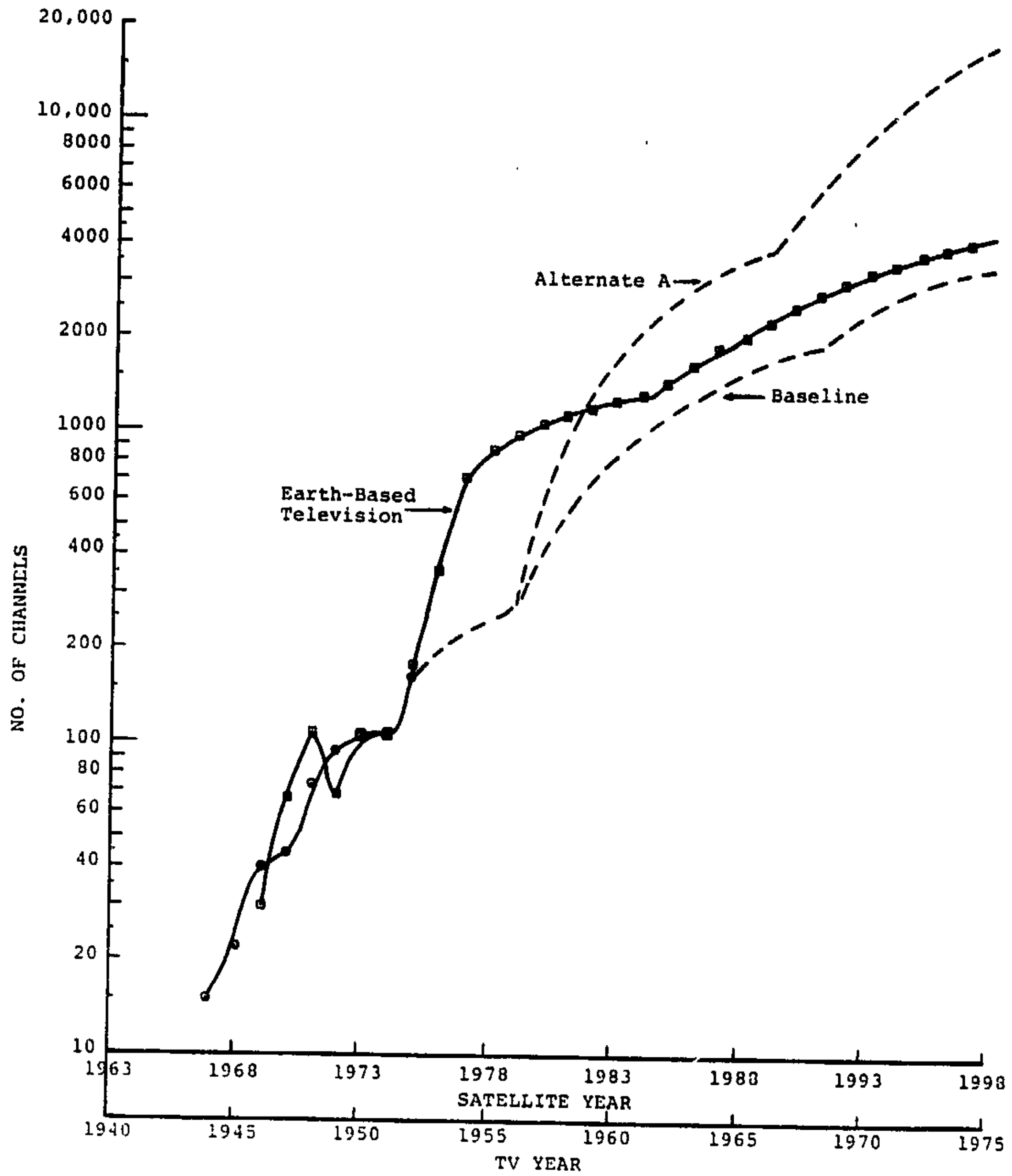


Figure 5.29. Comparison of Projections of Numbers of Satellite Wide-Band Channels Versus Historical Increase in Numbers of TV Systems (Cable Plus Broadcast)

systems depressed growth in the other systems. Therefore, it might be argued that growth in satellite broadcasting will proceed in accordance with the trends projected, regardless of the degree of substitution for other services and Independently of tht total market sum of such services.

The Alternate A projection, also repeated in Figure 5.29, exceeds the growth pattern of earth-based television at approximately the halfway point in the period, i.e., in 1982 on the satellite time scale. Therefore, it may be postulated that the additional increases in capacity projected in Alternate A will be associated with services other than commercial and general educational broadcast activites. Since this projected additional capacity is nearly three times larger than the general broadcast segment, it is apparent that fulfillment of the Alternate A projection will depend heavily upon the generation of such additional services, such as, telephone communications, data transfer, and special communication service.

5.6 SUBSTITUTION OF ELECTRONICS FOR PAPER AND INK IN COMMUNICATIONS

One way of providing a bench-mark against which various projections in the communications market may be tested is the construction of an overall estimate of the total communications market, and the relative shares of this market which will be satisfied by various technologies.

Except for face-to-face communication, it may be stated categorically that two technologies constitute the total communications market, i.e., communication is effected either through hard-copy, principally paper-and-ink, or through electronic devices. The hard-copy, or paper-and-ink, market is defined herein to include expenditures for postal service (less parcel post), the total receipts of the newspaper, book, and periodical publishing industry, and expenditures for motion picture entertainment (does not include television payments to motion picture industry). The electronic market is defined to include total domestic telegraph, telephone, and broadcast revenues, plus consumer expenditures for radio and television receivers and phonographs.

Figure 5.30 presents the trends of U.S. expenditures for communications. It is of interest that, even before the advent of the telephone, the telegraph had captured a significant portion of the communications market in terms of dollar volume, although the comparative "bit" volumes of information transmitted were grossly weighted in favor of paper-based communication. Viewing electronic communications as a substitute for paper-based communications, the technique of substitution analysis may be used to forecast future market proportions for each of the two media. If the current, well-established substitution trend is continued, the electron-based media should capture 75% of the market by the year 2000, as indicated in Figure 5.31.

Further insight into the development of the total communications market may be gained from the data plotted in Figure 5.32. In this figure, tht total expenditures for communication are plotted in terms of percentages of GNP, Personal Income, and Personal Consumption Expenditures. These percentages show a steady increase in communications expenditures from 0.44% of GNP to 5% of GNP in 1930, with similar increases of the percentages referenced to Personal Income and Personal Consumption Expenditures. Apparently the 5% is close to the maximum that the public desires to spend on communication, since this figure has held reasonably constant during the past 45 years. This 5% figure, used in conjunction with a projection of GNP growth to $6,700 billion by the year 2000, provides communication expenditures of $335 billion in the year 2000, as shown in Figure 5.33.

Using the market share projection indicated in Figure 5.31, the electron-based communications market should reach $250 billion in the year 2000. Paper-based communications, even though losing another 14% of the market (down to 25% of the total) will still expand from $25 billion to $84 billion by 2000.

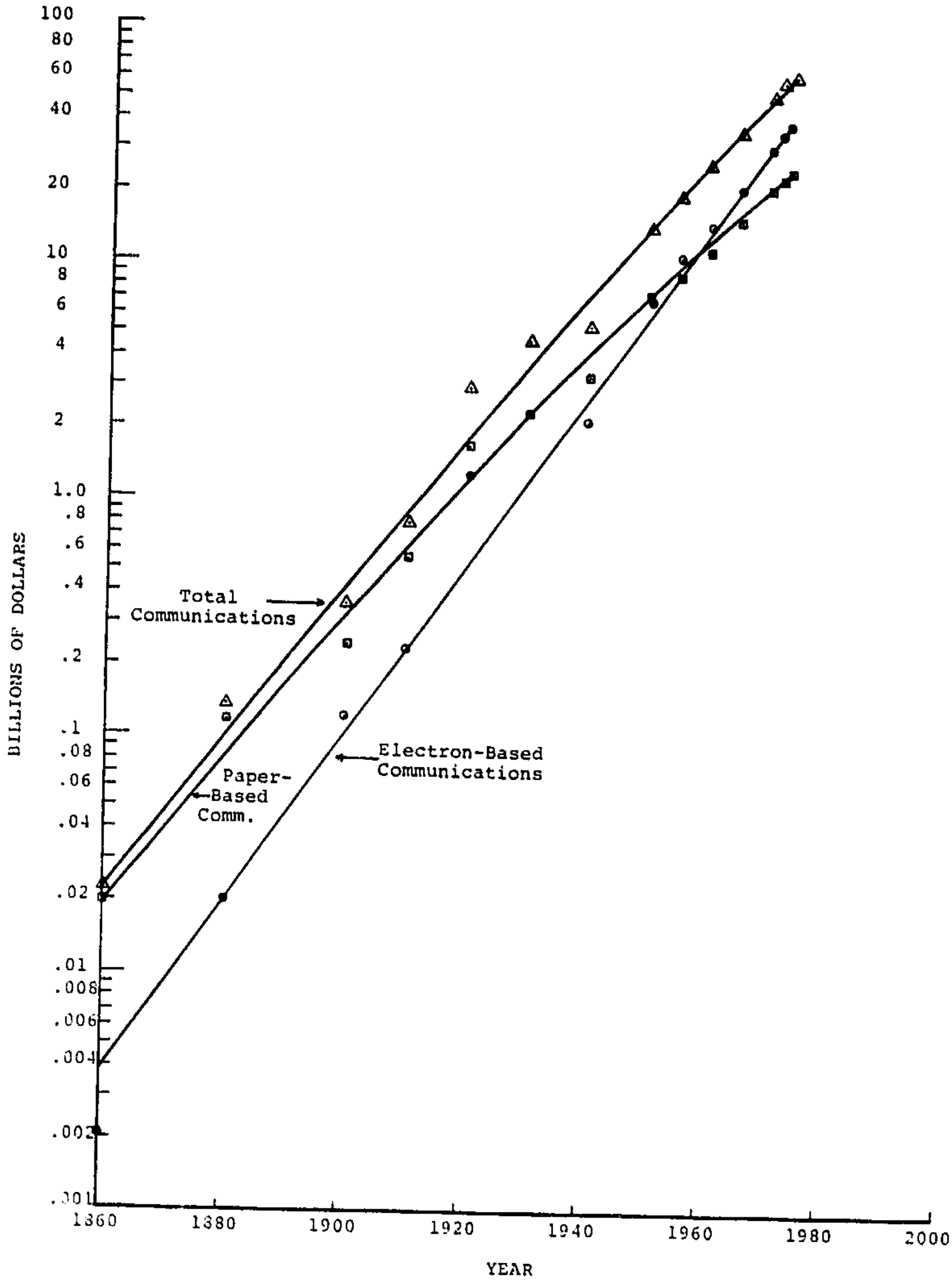


Figure 5.30. Communications Expenditures

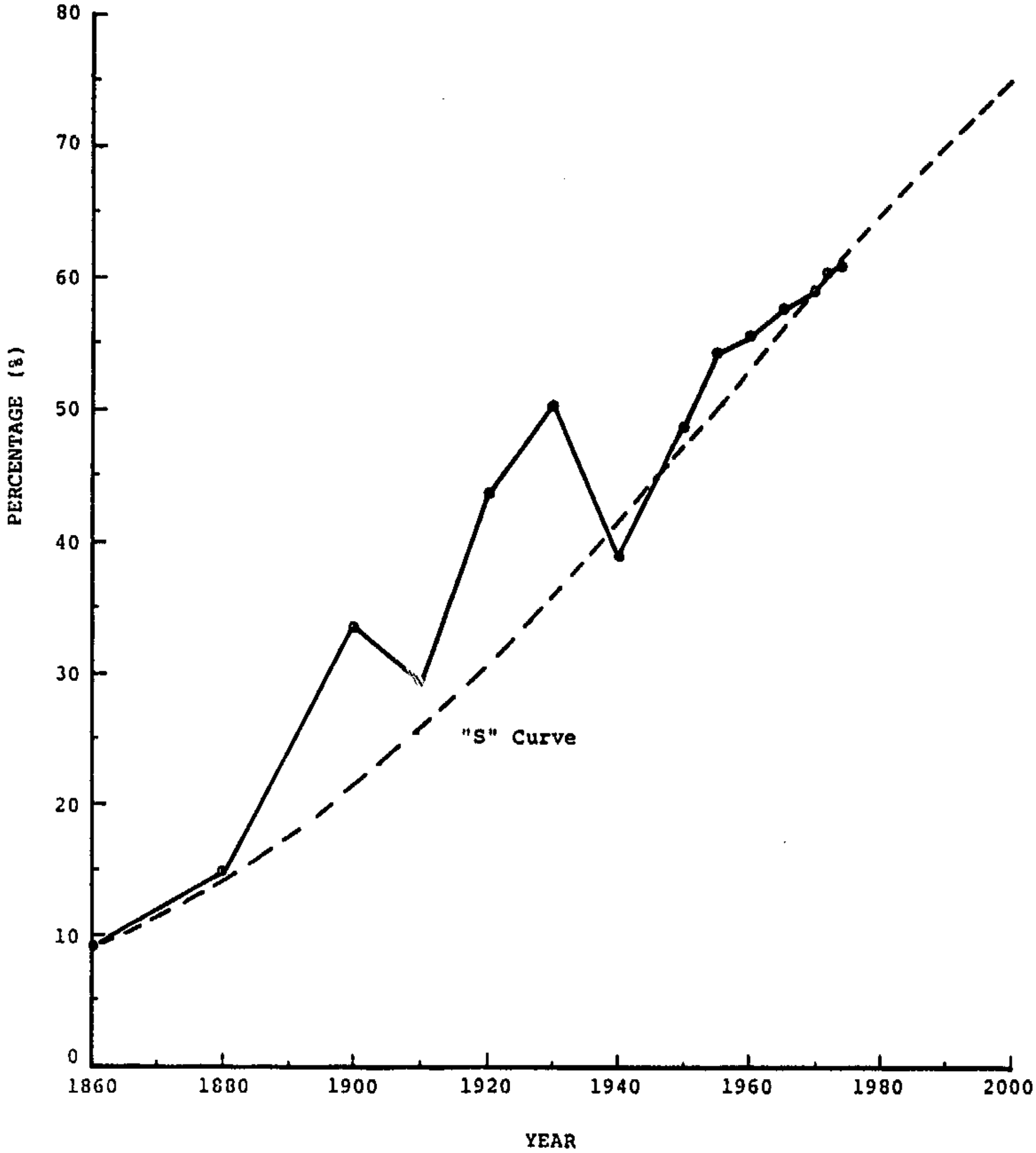


Figure 5.31. Market Shares for Electron-Based Communication Versus "Paper-Based", or "Hard-Copy" Communication

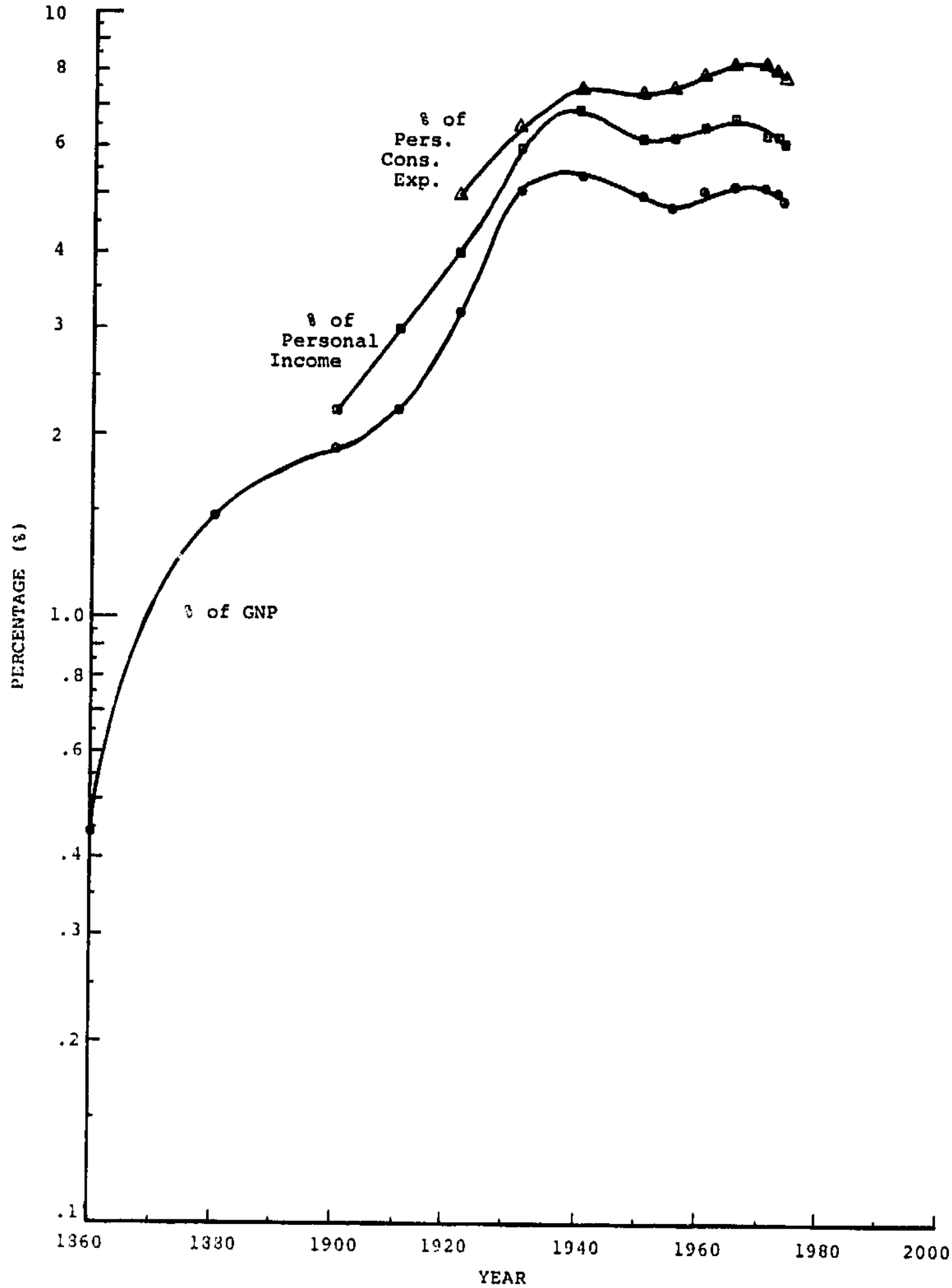


Figure 5.32. Communications Percentages

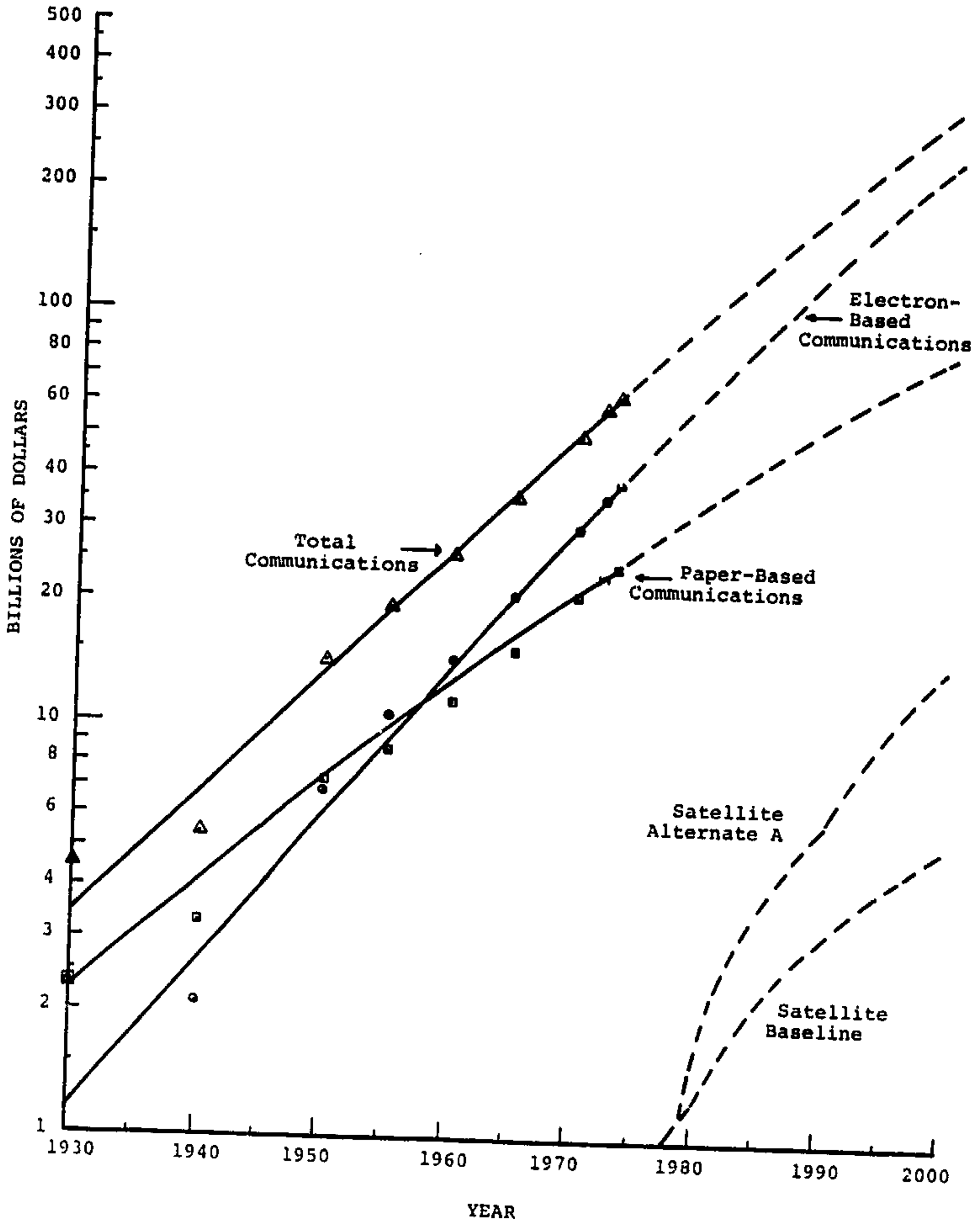


Figure 5.33. Projection of Communications Expenditures

The projections of satellite annual revenue trends may now be compared with the projections of the total electron-based communications market. The data from Figure 5.19 is repeated on Figure 5.33 for this comparison. The Baseline projection of $5.3 billion in 2000 for satellite revenues is only 2.1% of the projection for electron-based communication expenditures, and thus indicates extreme conservatism in this estimate. The Alternate A projection of $14 billion is less than 6% of the total electron-based communication projection and is thus also a conservative estimate. At $14 billion, this projection is only 35% of the current $40 billion level of expenditures for electron-based communications, so that the substitution of satellites in lieu of other transmission media should occur in a reasonably orderly manner.

In summary, the projections of annual satellite revenues developed in the preceding portions of this report meet the test of reasonableness in comparison with projections of total communications market expenditures. Even rather large errors in underestimating satellite costs and overestimating market size would not invalidate the projections of numbers of satellite channels supportable by the market. None of the above discussion should be taken as an indication that satellite operations will actually penetrate the market to the extent shown, since many other factors will govern the extent of market capture. This analysis is solely for the purpose of indicating that the projections of numbers of operational satellite channels and the costs thereof, are within the bounds of reasonable expectation from the standpoint of probable national expenditures for communications.

SECTION 6

THE MARKET PENETRATION MODEL

In order to project the penetration of various telecommunications innovations in different markets, it is necessary to develop models for market penetration. The specific models for each major market are given in Appendix 4. This section discusses the general form of the market penetration model used in this study.

The penetration of a product into some market, when plotted against time, generally has the shape of a "lazy S". This form is known as a growth curve, and there are numerous mathematical expressions which define one or another growth curve. In practice, it is found that the different mathematical expressions often given equivalent results. Therefore, the choice of growth curves to describe market penetration is usually made on the basis of mathematical convenience.

One of the most commonly used growth curves is the Logistic or Pearl-Reed curve. This curve is given by the formula

$$f = \frac{1}{1 + Ae^{-Bt}} \quad . \qquad (6\text{-}1)$$

Here, f is the fractional market share, A and B are parameters which control the location of the midpoint of the curve and the steepness of slope at the midpoint, and t is time. In this study, an alternative but equivalent form of the logistic curve will be used. This alternative form provides a degree of mathematical convenience which is lacking in the more common form given above. This alternative form is

$$f = \frac{1}{1 + 10^{A - Bt}} \quad . \qquad (6\text{-}2)$$

Here, the symbols in the formula have the same meaning as above, although the values for A and B will be different in the two equations when they are used to describe the same growth curve.

Fisher and Pry [1] showed that when the logistic curve is described by the second formula, the following convenient transformation can be made

$$\log[f/(1 - f)] = -A + Bt \quad . \tag{6-3}$$

That is, the market share of the new or growing technology, divided by the market share of the old or shrinking technology, can be expressed simply in terms of the two parameters of the logistic curve. In particular, when this ratio is plotted on semi-log paper, it appears as a straight line. This property is very useful when it is desired to project a future market share on the basis of a plot of historical market shares.

From the above expression, it can be seen that the parameter A controls the location of the growth curve, while the slope of the curve is determined by the parameter B. That is, information about the rapidity of market penetration is completely characterized by B, while information about the starting time of market penetration is completely characterized by A. Moreover, it can be seen that, when time increases by an amount equal to (1/B), the ratio f/(1 - f) increases by a factor of 10. Therefore, a specific growth curve can be characterized by a "ten-folding time" equal to 1/B, which, in this report, is referred to as a "T-time". Thus, when the logistic curve is used as the market penetration model for some technology to be introduced in the future, the rapidity of penetration can be described in a single number, the T-time for the growth curve. Note that it takes one T-time for penetration to growth from about 1% of the market to about 9%, a second T-time to reach 50%, a third T-time to reach 91% of the market, and a fourth T-time to reach 99% of the market. Thus, the time from introduction

[1] Fisher, J.C. and R.H. Pry, "A Simple Substitution Model of Technological Change", TECHNOLOGICAL FORECASTING AND SOCIAL CHANGE, Vol. 3, 1971, pp. 75 - 88.

of some new service or product until market saturation is reached is about four T-times, or 4/B years.

In this study, all market penetration forecasts are made on the basis of a Fisher-Pry model using the logistic curve given above. The T-times are developed from historical studies of analogous products or services in the same markets. Thus, the penetration of a product in the market represented by financial institutions would be forecast on the basis of T-times exhibited by past innovations of a similar type in the same market. The details of the various markets, innovations, and historical T-times are given in Appendix 4.

SECTION 7

SCORING MODEL

7.1 INTRODUCTION

The purpose of the scoring model is to assist in determining the appropriateness of government involvement in subsidizing technological development. It is presupposed that the technology in question has been shown to provide net benefits. The question being raised is whether or not government should intervene to modify the decisions of the private economy. The model deals with the appropriateness of government financing, not government production. Whether a good should be produced publicly or privately depends on the relative efficiency of different producers.

Every economic system is a mechanism for permitting society to deal efficiently with the problem of scarcity. This scarcity, which is the natural result of limited resources, compels us to make choices as summarized in the following questions:

- What goods and services shall be produced?
- How are goods and services to be produced?
- For whom are goods and services to be produced?
- How much output shall be produced?

The U.S. economy is essentially a market system where most of the answers to these questions are generated privately, through the interaction of individual supply and demand. Nevertheless, the government has certain distinct economic functions to perform in such a system. Government intervention is viewed as the exception, although the areas where government activity is accepted have grown during the past 50 years.

Government economic functions are categorized as follows.

1. Allocation - this refers to government involvement in answering the first two questions--What? and How? Government activity can be through the means of taxation, expenditures, regulation, production, or direct controls.

2. Distribution - this conerns the For Whom? question and essentially pertains to the distribution of income and wealth. Although all government activities can affect distribution, taxes and transfer payments are the primary means of government policy.

3. Stabilization - government activity influences the size of total output and employment in the economy. Both monetary and fiscal policy, as well as some direct controls, are used to influence the aggregate economy.

This scoring model is concerned with the appropriateness of subsidies by a specific agency. Therefore, it deals primarily with the allocation function of government. However, it should be noted that there are cross impacts between the functions and the four questions cannot be decided in isolation.

Government involvement in the allocation question arises in two situations:

First, there are malallocations of resources by the market. These inefficiencies in the market system result in a nonoptimal allocation of resources such that the output and/or price of an item are not efficient.

Second, there are instances where the market is completely incapable of deciding on resource allocation.

Each of these situations will be discussed.

7.2 MALALLOCATION BY THE MARKET

Economic efficiency is achieved when the production of a good or service is carried to the point of equality between marginal cost and price. At this point, the cost of resources used to produce the last unit of the item (marginal cost) is just equal to the money value of the satisfaction received from consuming the last unit (price). Failure of the market to achieve this optimal level of output can result from two situations: (a) lack of perfect competition and (b) costs and/or price do not reflect social costs and benefits.

7.2.1 Lack of Perfect Competition

7.2.1.1 Perfectly Competitive Equilibrium

Businessmen are motivated by a desire to maximize profit and, therefore, tend to produce at the level of output where the additional cost of producing (marginal cost) is just equal to the additional revenue from the sale of the last unit (marginal revenue).

A perfectly competitive market is one characterized by a large number of sellers of identical products. The individual firms can sell as much or as little as they wish. Due to their small size, variations in output leave the product's price unchanged.

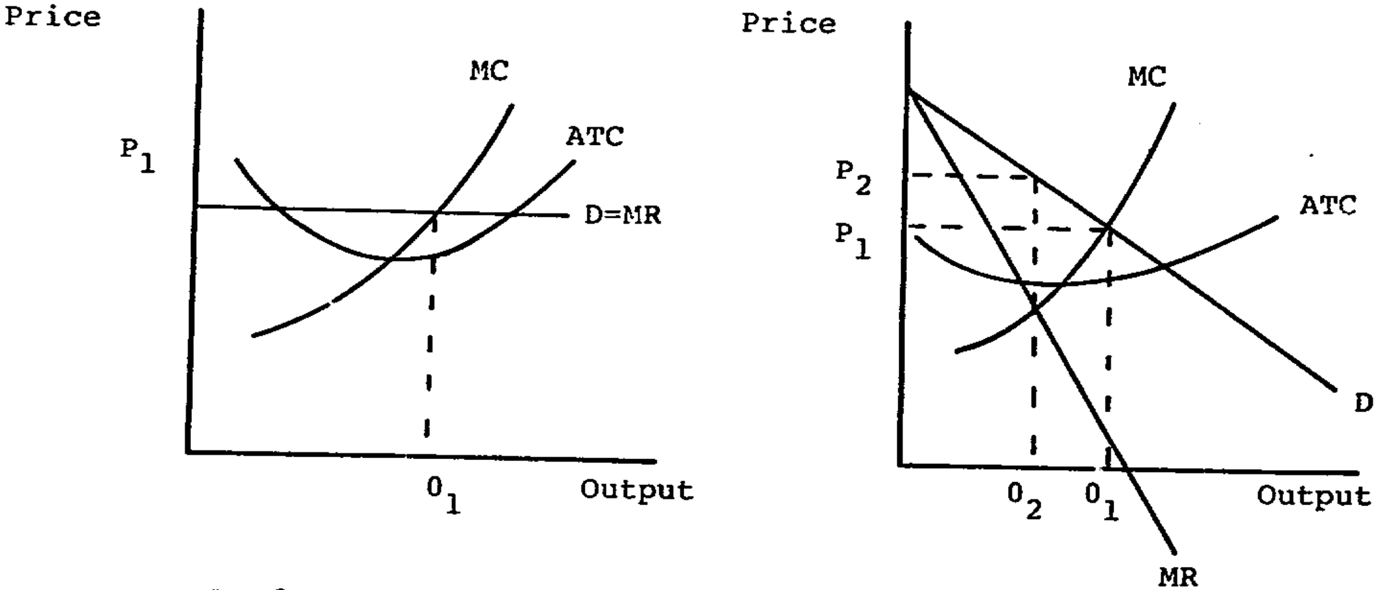
Each additional sale adds an amount to revenue (marginal revenue) which is equal to the price. Therefore, price and marginal revenue are equal, and there is a coincidence between the profit maximizing condition (MC = MR) and the welfare maximizing condition (MC = P).

7.2.1.2 Imperfect Competition

Actual market structures can depart from the competitive ideal due to either product differentiation or limits in the number of firms. Firms in these less competitive markets influence the price of their products (e.g., a decision to put more on the market lowers the price and vice versa). Therefore, marginal revenue and price are not identical. The profit maximizing output (MC = MR) does not coincide with society's optimum output (MC = P).

The distinction is shown in Figure 7.1. The perfectly competitive firm is shown on the left. Its inability to affect price is illustrated by the horizontal demand and marginal revenue curve. Profit maximization occurs at P_1 and 0_1. (ATC illustrates average total cost.)

Imperfect competition is shown on the right. Due to the inverse relationship between price and output, demand



Perfect Competition — Imperfect Competition

Figure 7.1 Price-output Relations With Perfect and Imperfect Competition.

and marginal revenue do not coincide. Profit maximization occurs at P_2, 0_2 instead of the socially optimal levels of P_1 and 0_1.

Efficiency would be increased if output rose from 0_2 to 0_1. In many cases, the discrepancy is less than would justify government activity. In others, antitrust activity or government regulation are the most likely policies. There is one situation, however, in which government subsidy is appropriate--a decreasing cost industry.

7.2.1.3 Decreasing Cost Industry

A decreasing cost situation is said to exist when there are significant efficiencies to be gained by large-scale production. These efficiencies or economies of scale result in declining average cost as the firm expands the size of its operation. Such industries are likely to be characterized by a smaller number of firms. In extreme cases, there may be only one producer.

As indicated in Figure 7.2, production at the socially optimum level (P_1, 0_1) is impossible. The firm would suffer a loss at that point.

The government may attempt to deal with this problem in either of two ways, both of which make government subsidization appropriate.

A. The government could regulate the firm, insisting on production at 0_1. A subsidy would be paid to the firm equal to the average total cost of 0_1 minus P_1 times output 0_1.

B. The government could regulate the firm, setting the price at P_2 and output at 0_2. This results in less than an optimal solution and is the approach used in most public utility regulation.

The value of a subsidy arises when considering the adoption of technological changes. Because the firm is guaranteed a price which covers average cost, there is no incentive

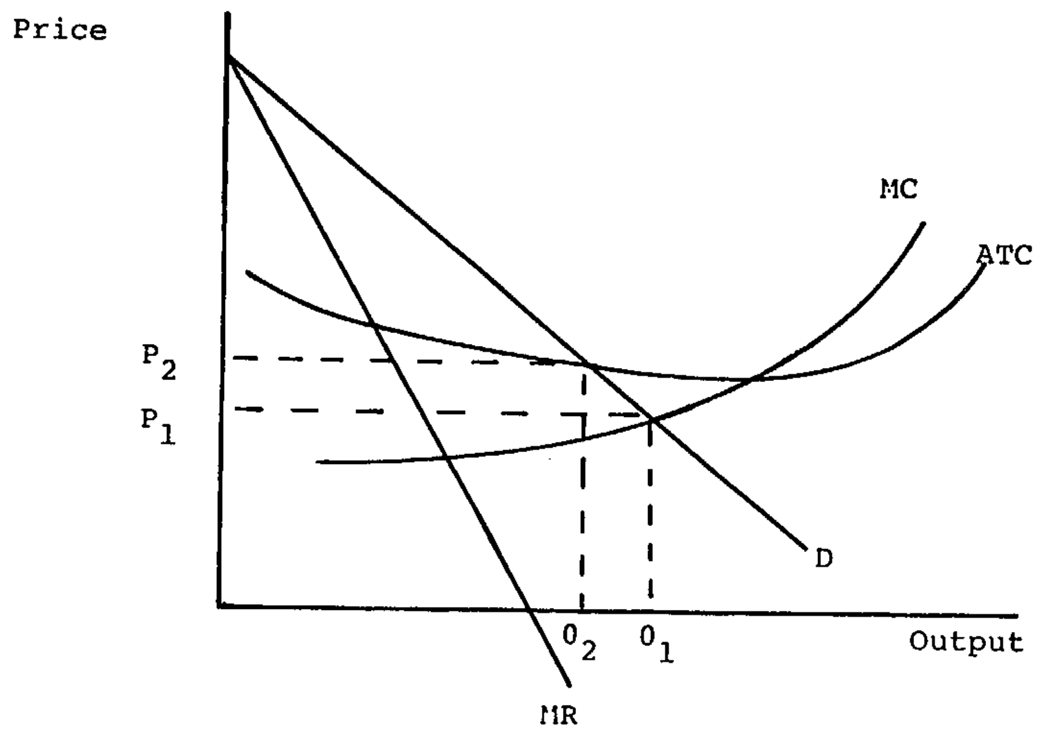


Figure 7.2 Price-output Relations in an Industry with Declining Costs.

to reduce costs through technological improvements. The adoption of technological changes would appear to be dependent on government subsidy.

7.2.2 Externalities

Externalities exist when the production or consumption of goods provide benefits or costs to persons other than the buyer and seller. In such situations, the private costs and demand are not an accurate indication of society's costs and benefits. Therefore, the market allocation of resources is inefficient and government intervention is in order.

7.2.2.1 External Benefits

External benefits are benefits which accrue to third parties, people who are neither buyers nor sellers in a transaction. Such benefits arise, for example, when a person contracts with a lawn service to spray and care for his yard. There are obviously individual benefits to the buyer in the form of more attractive property. However, there are also benefits to others in the neighborhood--a more pleasant environment, some reduction in weeds in their own yard, enhanced property values, etc. These benefits to others are external benefits.

In the presence of external benefits, the market will tend to underproduce the good in question. In Figure 7.3, D_1 represents the demand for lawn service by buyers. D_2 is based on the social benefits; benefits to buyers plus the external benefits.

Because external benefits are not considered by the market, output will be 0_1 and price at P_1. The socially optimal position is at P_2 and 0_2.

The appropriate government action in this case is to provide a subsidy. Buyers should be charged a price equal to A and the government should subsidize each unit by an amount equal to P_2 - A to cover the external benefits.

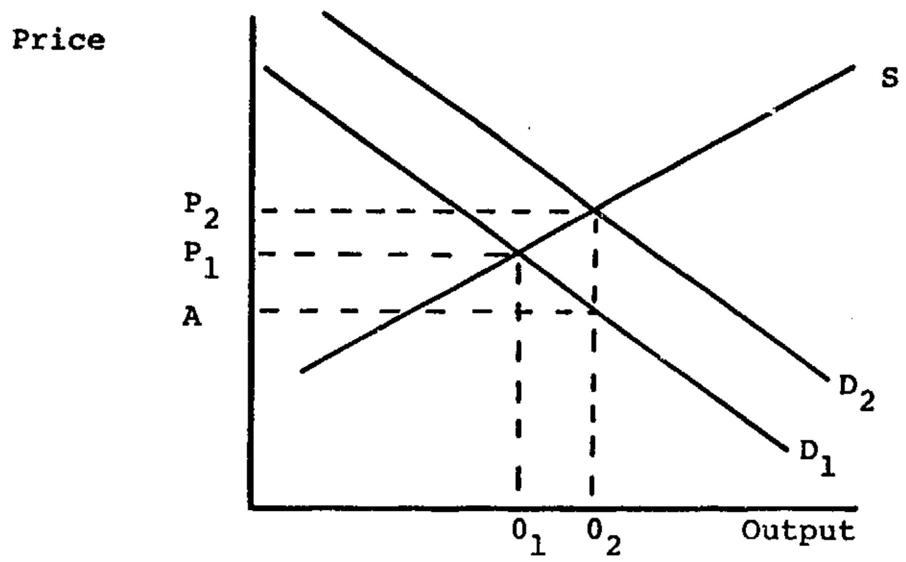


Figure 7.3 Price-output Relations in the Presence of External Benefits.

7.2.2.2 External Costs

In this situation, the production or consumption of a product levies costs on persons who are neither buyers nor sellers. Air pollution exemplifies such an external cost. People living in the vicinity of a polluting plant suffer costs in terms of a depreciated environment, medical expenses, reduced property values, etc. However, the market will not take these external costs into account.

In Figure 7.4, S_1 represents the actual production costs faced by the firm. S_2 represents the social costs, production costs plus the external costs.

Because external costs are not considered by the market, output will be at 0_1 and price at P_1. The socially optimal point is 0_2, P_2.

The most efficient way to deal with this problem is to internalize the external costs. Through fines or effluent fees, the production costs are made to coincide with the social costs, reducing output to 0_2 and raising the price to P_2. However, there may be situations where this procedure in output will result in unemployment in this industry and the unemployed resources may not be readily absorbed in other sectors. If the pollution costs are not internalized for all producers, (they might not be for foreign producers) an increase in price to P_2 places these firms at a competitive disadvantage.

In such situations, the government might provide a subsidy to offset the external costs (reduce pollution). Although not the optimal solution, this second best solution might be the most practical alternative.

7.2.2.3 External Economies

In this situation, the private costs of the business firm are greater than the social costs. The result is similar to the case of external benefits--the product will be under-produced when only the private costs are considered. In Figure 7.5,

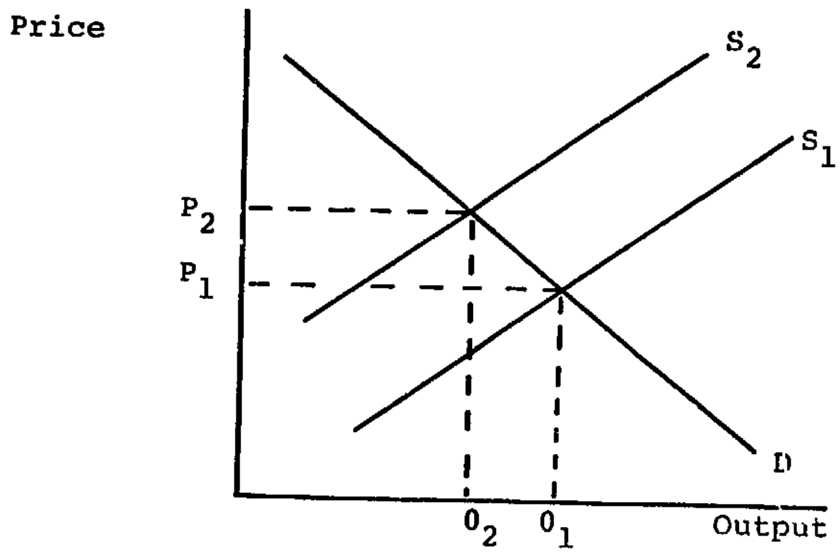


Figure 7.4 Price-output Relations in the Presence of External Costs.

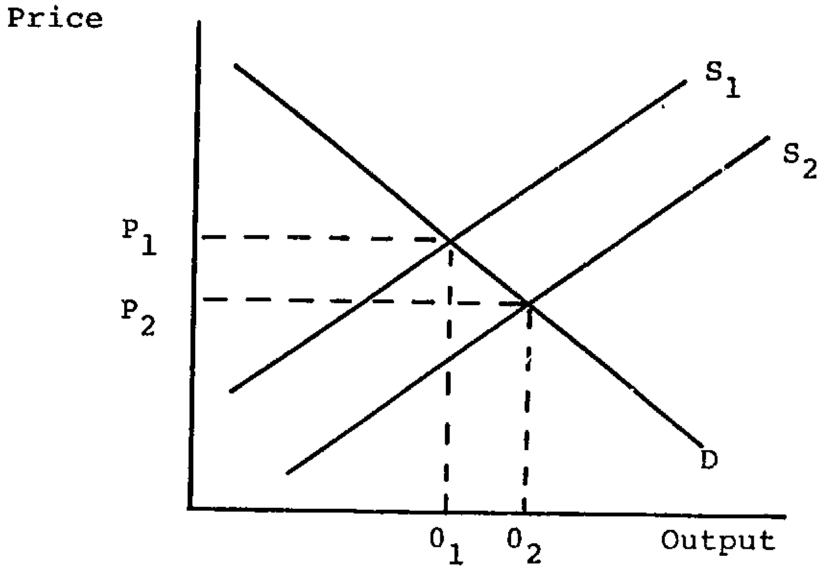


Figure 7.5 Price-output Relations in the Presence of External Economies.

S_1 represents private costs and S_2 is based on social costs. Resource allocation would be improved by an increase in output from 0_1 to 0_2.

External economies can arise in a variety of situations:

A. Technological Externalities--activities associated with the production of one product reduce the costs of producing other things. For example, the technology developed by one firm may be applicable to other products, thereby reducing their costs of production. The development of a transportation or communication system for one sector of the economy might reduce production costs in another sector.

B. Differences Between Public and Private Risk--the risk involved in a commitment of resources may be higher for the individual than for society. For example, the individual firm may suffer the risk of losing some of the gains from an innovation to his competitors. Society will benefit regardless of the division of profit among individual firms.

C. Intertemporal Externalities--in this situation, the future consequences of a decision may fall to someone other than the decision maker. This may cause the private decision maker to overestimate present costs, failing to consider certain long-run benefits.

Once again, the appropriate government intervention is in the form of a subsidy which equalizes private and social costs.

7.3 ALLOCATION NOT POSSIBLE BY THE MARKET

There are two instances in which the market mechanism is incapable of allocating resources: public goods and merit wants.

7.3.1 Public Goods

A public good is one which confers benefits on the economy at large, rather than on individuals. Such a good is consumed nonexclusively, i.e., its use by one person does not reduce the ability of the good to provide satisfaction to someone else. Moreover, the satisfaction received by an individual is independent of his contribution.

A lighthouse is an example of a public good. Its warning can be received by large numbers of people simultaneously. When the light is functioning, it is not possible to exclude someone from receiving the warning, whether they have contributed to the support of the lighthouse or not.

This inability to exclude people from receiving the benefits is the characteristic which necessitates government activity. A private business firm cannot compel people to pay for such a service, nor are they likely to survive on voluntary contributions. Public goods must be collectively financed. Government taxation and subsidies are the most likely vehicle.

7.3.2 Merit Wants

These goods and services can be provided through the market mechanism. However, they are considered to be so meritorious that they are funded publicly. Examples would include such services as school lunch programs, free education, and toll-free highways.

Merit wants involve a deliberate decision to alter the allocation which would result in the market in the interest of increasing the amount of the good or service available and/or altering the distribution of the benefits.

Government subsidies are necessary if merit wants are to be financed.

7.4 SCORING MODEL

The appropriateness of government activity has been shown to depend on the presence of any of a variety of conditions. The scoring model provides for the summary of these conditions into a single number which facilitates the evaluation of projects.

The number which results from the scoring model has little meaning except in comparison to similar numbers for alternative endeavors.

The scoring model is an additive one where the composite score is the sum of four factors:

$$S = X_1 + X_2 + X_3 + X_4 ,$$

where

X_1 = decreasing cost considerations. The value may vary from 0 to 1. A value of zero represents the absence of decreasing cost. A positive value would represent the percentage of optimal output by which actual output would fall short in the absence of government intervention. For example, a value of .4 indicates that actual output is 60% of optimal output.

X_2 = externalities. The value may vary from 0 to 1 on the same basis as above (the shortfall of actual output from optimal output, expressed as a percentage of optimal). It should be noted that subsidies for external costs do not change output to the optimum. However, the same weighting system can be employed.

X_3 = public goods. The value is 0 or 1. One is the appropriate weight in the case of public goods because they would not be offered in the absence of government intervention.

X_4 = merit wants. The value is 0 or 1. The existence of merit want consideration requires the subversion of market decision making

A composite score of zero indicates that government activity is inappropriate. The higher the score, the more appropriate government activity would be.

SECTION 8

THE TELECOMMUNICATIONS MODEL

8.1 INTRODUCTION

Forecasts of satellite communications growth and of special broadcast services using satellites were presented in Section 5 of this report. Forecasts of other major elements of the U.S. telecommunications system were given in Section 4. For each element of the telecommunications system, the forecast were generated on the basis of certain assumptions, e.g., that a specific historical pattern would continue, or that market penetration would be similar to the market penetration historically exhibited by an analogous product or service. However, none of the projections for the individual elements took into account the projections of the other elements.

The elements of the U.S. telecommunications system do not exist in isolation, however. Changes in one element affect the other elements, in greater or lesser degree. The occurrence of a forecasted change in one element of the system may affect the occurrence of some change forecasted for a different element of the system. Hence, the model of the U.S. telecommunications system is developed as a cross impact model, in which the forecasts for the individual elements of the system are tied together by their interactions with one another. Thus, the model is an internally consistent picture of the future U.S. telecommunications system, in which the various elements are allowed to interact, and in which changes in one element are reflected in impacts on other elements.

The remainder of this section of the report will discuss the interactions among the elements of the telecommunications system. This discussion will be in terms of how the forecasts for each element are altered by developments in other elements of the system.

8.2 TELEVISION

As described in Section 4, the television element of the system is driven by revenues. Total revenues are related to GNP, which is projected independently of the remainder of the model. The advance of CABLE TV, CABLE TV games, video disc purchase, and TV games will decrease the revenues for TV stations and hinder the growth of TV station by delaying the date of occurrence. The growth of TV station between 1985 and 2000 could provide more programs for viewers and thus hinder the market of video disc. But the growth of TV station could enhance the probability of occurrence for the video tape recording market. The slow or non-growth of TV station will be expected to reduce the probability of occurrence for the video tape recording market on one hand, and improve the chance for video disc market on the other hand.

8.3 DIRECT BROADCAST TV

Direct broadcast of TV programs from satellites, in the KU band, is a possibility included in the model. Existing satellites are not adequate for this service, but the projected 2000 kilogram and 6000 kilogram satellites are adequate. If these larger satellites are introduced, then direct broadcast can occur with 10% probability.

The usage of special broadcasting TV could provide experiences in operating facilities for broadcasting TV and enthusiam for doing so. Therefore, we can expect favorable impact from special broadcasting TV to direct braodcasting on the timing and probability for occurrence. The application of computer-aided instruction in schools through direct broadcasting will also enhance the chance of occurrence for direct broadcasting at the lowest level (i.e. 10 channels) for similar reasons.

Direct broadcasting at higher levels (i.e. 30 and 60 channels) could provide significant competition with CABLE TV market. Thus, direct broadcasting could have unfavorable impacts on CABLE TV market at 90% and 99% penetration levels.

8.4 CABLE TELEVISION

As explained in Section 4, CATV is projected to continue to grow either with its historical T-time, or twice its historical T-time. The choice between the two growth rates is made at the outset of each simulation run, and the historical T-time (high growth rate) occurs with probability .80. Once the growth rate is determined, the year of achievement of specific levels of penetration is automatically specified. Probability of achievement of various levels of penetration is not affected by growth rate, however. Penetration of 50%, 90% and 99% of the market is assigned probabilities of .90, .80 and .70, respectively, regardless of date of achievement. The number of CATV systems is in turn determined by the degree of market penetration of CATV, as described in Section 4. Growth of CATV is hindered by the advent of direct satellite TV broadcasting.

CATV distribution systems will switch from coaxial cable to fiber optics. Use of fiber optics in 10% of CATV systems will be achieved not later than 1986. This date will be advanced if CATV follows the high growth rate curve. Utilization of fiber optics in CATV is accelerated by successful use of fiber optics in the telephone system, both local loop and long-distance trunks. Fiber optics in CATV is also possible through the existing fiber optics local loops installed by telephone companies.

Addition of a return channel (from subscriber to the head end of the cable system) occurs following achievement of 10% market penetration by TV games. The return channel may be incorporated into conventional coax systems by 1983 (probability of .40), or may occur after CATV begins to incorporate optical fibers (probability of .60 without earlier coax return channel; probability of 1.0 if coax return channel already in use).

8.5 TELEPHONE

In the model, growth of number of telephones and number of telephone calls is deterministic, as described in Section 4. However, conversion of the analog, electrical telephone system to digital transmission, and/or to optical fibers, is affected by other elements of the model, both in timing and probability.

Conversion of the local loop to digital transmission is enhanced and advanced by conversion of the long-distance trunks to digital transmission, by conversion of the local loop to optical fibers, and by adoption of Point-of Sale Electronic Funds Transfer, which requires digital transmission from local stores to banks or other central processing locations.

Conversion of long-distance trunks to digital transmission is enhanced and advanced by adoption of Electronic Check Clearing and the Electronic Stock Market, which require digital data transmission between cities.

Conversion of the local loop to fiber optics may be advanced from the schedule shown in Section 4, to a more rapid growth curve with a T-time of 5 years. This switch to a more rapid schedule occurs with probability .30.

Conversion of long-distance trunks to fiber optics is advanced and enhanced by utilization of fiber optics for the telephone local loop, and by conversion of the long-distance trunks to digital transmission.

The magnitude of the long-distance trunk system is expressed in the model in terms of equivalent wide-band channels. The number of equivalent channels is computed on the basis of the projected number of long-distance calls, given in Section 4. It is assumed that each call takes 10 minutes, that the telephone system bandwidth is 4 kHz, and that the historical peak-to-average load factor of 5 for long-distance trunks will continue to apply in the future. The schedule for availability of a given number of wide-band channels is, therefore, linked to the projection of number of telephone calls. However, this schedule may be advanced by selection of a strategy of utilizing long-distance telephone trunks to distribute TV programs to TV stations and to CATV systems.

8.6 SATELLITE CHANNELS

The growth of the satellite element of the telecommunications system, as projected in Section 5, is represented in the model solely in terms of wide-band channels available.

Thus, numbers of satellites, power levels, etc., are not directly included. However, the introduction of 2000 kg and 6000 kg satellites are included as specific events, which may occur respectively in the 1980's and the 1990's. The introduction of the 2000 kg satellite has probability .80 and may occur with probability of 0.03 from 1980 to 1984 and with proba ility of 0.17 from 1985 to 1989. The introduction of the 6000 kg satellite has probability .60 and may occur with equal likelihood in any year from 1990 to 1999. The growth projection for satellite channel capacity, as input to the model, follows the Baseline projection, and occurs with probability 1.0.

If the world's satellite communication channel is allocated on the basis of the nation's population, the share for the United States would be equivalent to about 6065 wide-band channels. Thus, allocation of satellite orbit slot will become a limiting factor in the year 2010 if the growth of satellite communication channel follows the Baseline projection. However, the progress of satellite communication technologies could increase the U.S. satellite communication capacity by a factor of 4. These advanced satellite communication technologies include digital coding methods with 2,3, or 4 times increase in capacity, polarization technique, spot beam method, and combinations of digital coding and polarization techniques which provide about the same capacity increase as spot beam or digital coding method with 4 times capacity improvement does. The development of 6000 kg satellite or space geostationary platform are necessary for the spot beam technology.

The occurrence of specific events which create substantial demand for satellite channels will enhance the growth of satellite communication capacity. These impacts are discussed below.

The advent of computer aided instruction, utilizing a direct data link from student to the central computer, via satellite, can add a significant demand for channels. At a maximum, this might reach 29,539 wide-band channels.

Special broadcast services, providing capabilities similar to equivalent terrestrial services, are described in Section 5. If these services grow as projected, demand might reach 13,000 wide-band satellite channels.

8.7 SPECIAL BROADCAST SERVICES

Special broadcast services, as described in Section 5, are expected to follow growth patterns similar to those of equivalent terrestrial services. In the model, two alternate growth patterns are utilized, one based on the historical growth of terrestrial equivalent services, and the second on a slower growth rate. Under the high growth rate schedule, special broadcast services reach a level of 13,000 wide-band channels in the year 2000; under the low growth rate schedule, this level is not reached until 2020. Special broadcast services are not impacted by any other elements of the model.

One of advanced satellite communication technologies with lower level of capacity improvement such as digital coding technologies with 2 or 3 times channel capacity increase, or polarization method is required for the special broadcast services at 2000 or 6000 wide-band channels. Advanced satellite communication technologies with higher capacity improvement as spot beam technology, digital coding with 4 times channel capacity increase, or combinations of digital coding with 2 or 3 times channel capacity increase and polarization technique could make the special broadcast services at 9000 or 13000 wide-band channels feasible. Without the availability of advanced satellite communication technologies, special broadcast services could not be a reality.

8.8 TV GAMES

Market penetration of TV games is given in Section 4. The rate of market penetration is not affected by other elements of the model.

8.9 CATV GAMES

CATV games are introduced following the installation of CATV return channels by two years. The advent of CATV return channels raises the probability of CATV games to .30. The market of video disc competes with CATV games and it could delay the growth of CATV games.

8.10 VIDEODISC

The basic forecast for video recording is based on a home market penetration model. The growth of TV stations has impact on the video recording market. If the growth of TV stations progresses as projected, it will have more programs on the air as candidate for video recording. Consequently, the growth of TV stations is expected to enhance the video recording market. On the contrary, the slow growth of TV stations could generate adverse effects on the video recording market.

Video disc purchase is another element in the cross impact model. The basic forecast for video disc purchase is based on a T-time of 8 years in market penetration. Video disc purchase is assumed to achieve 10% market penetration in 1990. The growth of TV stations could discourage the purchase of video disc. However, the failure of growth in TV stations could increase consumers' purchase of video disc for providing more choice in programs. Gains in TV games and CATV games market would persuade consumers to delay purchasing of video discs. Experiences on video recording could encourage consumers to purchase video discs.

8.11 ELECTRONIC CHECK CLEARING

Electronic check clearing is introduced in the period 1980 - 1983, with equal probability in each year of the period. It is not affected by any other elements of the system. Probability of introduction is .85.

8.12 ELECTRONIC STOCK MARKET

Replacement of the existing stock market system with an electronic stock market, in which all offers to buy or sell stock are mediated through a computer, with matches of buy-sell offers being directed to the brokers who transmitted the offers, occurs during the period 1985 - 1988. Probability of occurrence is equally distributed over all years in this period. Overall probability of occurrence is .85. Introduction of the electronic stock market is not affected by any other elements of the system.

8.13 POINT-OF-SALE ELECTRONIC FUNDS TRANSFER

Point-of-sale electronic funds transfer reaches 10% of the market in 1983, 50% in 1989, and 90% in 1995 (T-time of 6 years). Probabilities associated with these levels of penetration are .95, .90, and .85, respectively. This development is not affected by any other elements of the model.

8.14 COMPUTER AIDED INSTRUCTION

Computer aided instruction, involving a direct link from users to computer and return, is projected to achieve penetration of 10% of the market in 1995, 50% in 2002, and 90% in 2010 under a late market penetration schedule. Probabilities associated with these levels of market penetration are .30. We consider computer aided instruction in schools and in households separately in the cross impact model. All computer aided instruction may go through either direct broadcast from satellites with a probability of .10 or centralized computers with a probability of .90. The high probability is assigned to the route through centralized computer because, at the high levels of usage projected, it will probably be more economical to utilize a local computer rather than pay the transmission costs to a centralized computer. A centralized computer for computer aided instruction makes economic sense only when the number of users is sufficient to saturate the central computer, but not sufficient to keep several local computers busy.

We believe that if computer aided instruction ever does capture any significant fraction of the school market, this automatically implies that usage levels will be sufficient to saturate computers in individual school districts. The selection of routes for computer aided instruction is made at the start of simulation of each scenario by the cross impact model. In addition, three sets of market penetration schedule are available for computer aided instruction in schools. A specific market penetration schedule is selected at the beginning of each scenario by the cross impact model.

Advanced satellite communication technologies such as spot beam, digital coding method with 4 times increase in channel capacity, or combinations of digital coding method with 2 or 3 times increase in channel capacity and polarization technique is required to make computer aided instructions possible. Video disc purchase is the only element in the cross impact model that has impact on computer aided instruction. Purchase of video discs by schools tends to substitute for computer aided instruction. Thus, purchase of video discs will decrease the probability of occurrence and delay the progress of computer aided instructions.

The route taken by computer aided instructions in schools will dominate the selection of route by computer aided instructions in households. They tend to take the same route.

The cross impact model consists of a set of events, representing discrete forecasts, and the interactions among those events. The events themselves have been described in Section 4 and 5. This description of the interactions among the events completes the description of the cross impact model.

The cross impact model contains 181 events and about 500 interactions. A condensed version of the model is shown in Table 8.1

TABLE 8.1
SUMMARY OF INTERACTIONS

FROM \ TO	TV Stations	Direct Broadcasting	CATV:	Homes	Return channels	Fiber optics	Fiber optics return channel	Fiber optics local loop	Satellites:	Weight	Channels	New technologies	Local Phones:	Digital	Fiber optics	Long Distance Calls:	Digital	Fiber optics	Calls	Special Applications:	POS-EFT	Elect. ch. clear	Spe. brod. TV	Transportation	Radio for prod.	Elect. lib. for prof.	Elect. lib. for schools	CAI in schools	Public service	Bus. community	Video conference	Home:	TV Games	CATV Games	Video disc	Video record.	Computer	CAI
TV Stations																																						
Direct Broadcasting				-																															(+,-)	(+,-)		
CATV:																																						
Homes	-	-			(0,-)	(0,-)																																
Return chan.		-					+	-																														
Fiber optics								(-,+)						+	+																			+				
Fiber opt. R.C.				+				-																														
Fiber opt. local loop						-	+																															
Satellites:																																						
Weight											+	(+,-)																										
Channels																																						
New technologies											+												+		+	+	+	+			+						+	+
Local phones:																																						
Digital															+	(0,-)																						
Fiber optics						+		(0,-)						+	+																							
Long dist. calls:																																						
Digital														+				+																				
Fiber optics						+								+	+																							
Calls																																						
Special appl:																																						
POS-EFT														+																								
Elect. ch. clea.																+																						
Special brod. TV		+								+																												
Transportation																			-																			
Radio for prof.																																						
Ele. Lib. for Prof.																																						
Ele. Lib. for sch																																						
CAI in sch.		+																																				
Public services																																						
Bus. community																																						
Video conf.		+								+									-												+							
Home:																																						
TV Games	-	-					+																															
CATV Games	-																																	-				
Video disc	-																																	-				
Video recording																												-					-					
Computer																																		+				
CAI		+		+		+																																

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(1) + indicates the occurrence of row events has favorable impact (such as increase the probablity of occurrence or advance the timing of occurrence) on column events.

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(3) 0 or blank indicates no impact from row events on column events.

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SECTION 9
SAMPLE ASSESSMENT

The purpose of the overall project, as stated previously, was to develop a methodology for assessing the consequences of technological change in different elements of the U.S. telecommunications system. The specific approach chosen was to employ a methodology, the cross impact model, which allowed the user to assess the consequences of change in any portion of the system, in the context of all the other changes which were also taking place in the system. That is, the consequences of a specific technological innovation were to be assessed, not under the assumption that the remainder of the system remained static, but with full account taken of changes which were already forecast to take place in the remainder of the system, or which took place in the remainder of the system in response to the specific innovation.

The final task of the project was to demonstrate the use of the methodology on a problem of practical interest to NASA. The specific issue selected was the impact of optical fiber applications on the overall U.S. domestic telecommunications system, particularly the satellite communications segment.

9.1 ASSESSMENT OF FIBER OPTICS APPLICATION

Fiber optics technology has progressed significantly in recent years and it is expected to play a major role in the future United States telecommunications system. Three deployments of fiber optics application in the cross impact model analysis were considered. These are referred to as high, low, and normal deployment of fiber optics. Further descriptions of these fiber optics application cases are presented in section 9.1.1. The main focus is on the interactions and complementary actions between satellite communications applications and optical fiber applications and their relationship to the remainder of the telecommunications systems. Market penetration of optical fiber applications and demands for satellite communication channels and their distributions over time are examined. The cross impact model generates the market penetration forecasts by considering the impacts on fiber optic penetration by other elements of the U.S. telecommunication system.

9.1.1 Sensitivity Analysis of Fiber Optics Applications

Fiber optics technologies are undergoing rapid development and there is a substantial amount of uncertainty involved in the projection of their applications and their influences in the future U.S. telecommunications system. Sensitivity analysis on the cross impact model provides a more complete picture of the future telecommunications system. Thus, sensitivity analysis is a very useful decision making tool.

High, low, and normal deployments of fiber optics application will be analyzed in this section. In the case of high deployment of fiber optics, the most favorable condition, a probability of occurrence of 1.0 was given to fiber optics applications at the start of the cross impact simulation. On the contrary, a zero probability of occurrence was assigned initially for fiber optics application events in the case of low deployment of fiber optics. However, potential interactions between elements in the cross impact model could still enhance the progress of fiber optics applications. In addition, probabilities for selecting fast or slow market penetration in fiber optics applications remained the same for all three deployment cases.

9.1.2 A Cross Impact Model For Sample Assessment

A general cross impact model for the U.S. telecommunications system has been described in Section 4. In the sample assessment, a cross impact model with emphasis on fiber optics applications and the satellite communications application has been tailored from the general model and is presented in Table 9.1.

Table 9.1 The Cross Impact Matrix of the Sample Assessment

FROM / TO	TV Stations	Direct Broadcasting	CATV:	Homes	Return channels	Fiber optics	Fiber optics return channel	Fiber optics local loop	Satellites:	Weight	Channels	New technologies	Local Phones:	Digital	Fiber optics	Long Distance Calls:	Digital	Fiber optics	Calls	Special Applications:	POS-EFT	Elect. ch. clear	Sp. brod. TV	Transportation	Radio for prof.	Elect. lib. for prof.	Elect. lib. for schools	CAI in schools	Public service	Bus. community	Video conference	Home:	TV Games	CATV Games	Video disc	Video record.	Computer	CAI
TV Stations																																						
Direct Broadcasting				-																															(+,-)	(+,-)		
CATV:																																						
Homes	-	-			(0,-)	(0,-)																																
Return chan.		-					+	-																														
Fiber optics								(-,+)						+	+																			+				
Fiber opt. R.C.				+				-																													-	
Fiber opt. local loop						-	+																															
Satellites:																																						
Weight											+	(+,-)																										
Channels																																						
New technologies											+												+		+	+	+	+			+						+	+
Local phone:																																						
Digital															+	(0,-)																						
Fiber optics						+		(0,-)						+	+																							
Long dist. call:																																						
Digital														+				+																				
Fiber optics						+								+	+																							
Calls																																						
Special appl:																																						
POS-EFT														+																								
Elect. ch. clea.																+																						
Special brod. TV		+								+																												
Transportation																			-																			
Radio for prof.																																						
Ele. Lib. for Prof.																																						
Ele. Lib. for sch																																						
CAI in sch.		+																																				
Public services																																						
Bus. community																			-																			
Video conf.		+								+																					+							
Home:																																						
TV Games	-	-					+																															
CATV Games	-																																	-				
Video disc	-																																	-				
Video recording																											-						-				-	
Computer																																		+				
CAI		+		+		+																																

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9.1.2.1 Fiber Optics Application Events

Optical fiber application events examined in this sample assessment include fiber optics in local loops at 10, 50 and 90% level of market penetration (FIBOP LL10, FIBOP LL50, FIBOP LL90), fiber optics in long distance calls at 10, 50 and 90% level of market penetration (FIBOP LD10, FIBOP LD50, FIBOP LD90), fiber optics in Cable TV at 10, 50 and 90% level of market penetration (FIBOPCAB10, FIBOPCAB50, FIBOPCAB90), fiber optics in Cable TV return channels at 10, 50 and 90% level of market penetration (FBOPRTCH10, FBOPRTCH50, FBOPRTCH90), fiber optics in Cable TV through telephone company's local loops at 10, 50 and 90% level of market penetration (CATVFBLL10, CATVFBLL50, CATVFBLL90), and fast fiber optics penetration option on most of the above events (HIFIBOPLL, HIFIBOPLD, HIFIBOPCAB, HIFBOPRTCH).

Initial probabilities and dates of occurrence of fiber optics application events in the cross impact model are summarized in Table 9.2. Fast and slow market penetration schedules for each optical fiber application are built into the cross impact model and will be selected appropriately through events such as fast fiber optics penetration in local loops (HIFIBOPLL), fast fiber optics peneration in long distance calls (HIFIBOPLD), fast fiber optics penetration in Cable TV (HIFIBOPCAB), and fast fiber optics penetration in Cable TV return channel (HIFBOPRTCH). Table 9.3 lists these schedules.

The structure of cross impact models for high, low and normal deployments of optical fiber activities in the U.S. telecommunications system are about the same except for the differences in probilities of occurrence for fiber optics application events and one option for selecting the transmission medium for long distance telephones. In the normal deployment case, long distance calls could be transmitted either over satellites or through optical fiber cables. The decision on route selection for long distance calls will be made in 1989. Both routes have the same probability for occurrence.

Table 9.2 Initial states of fiber optics application events

Application Event	Year of Occurance	Probability of Occurrence Low Case	Normal Case	High Case
FIBOP LL10	1981	0.0	1.0	1.0
FIBOP LL50	1988	0.0	1.0	1.0
FIBOP LL90	1997	0.0	1.0	1.0
HIFIBOPLL	1980	0.3	0.3	0.3
FIBOP LD10	1986	0.0	0.9	1.0
FIBOP LD50	1990	0.0	0.8	1.0
FIBOP LD90	1999	0.0	0.7	1.0
HIFIBOPLD	1985	0.5	0.5	0.5
FIBOPCAB10	1986	0.0	0.9	1.0
FIBOPCAB50	1990	0.0	0.8	1.0
FIBOPCAB90	2000	0.0	0.7	1.0
HIFIBOPCAB	1985	0.5	0.5	0.5
FBOPRTCH10	1987	0.0	0.9	1.0
FBOPRTCH50	2001	0.0	0.8	1.0
FBOPRTCH90	2016	0.0	0.7	1.0
HIFBOPRTCH	1987	0.3	0.3	0.3
CATVFBLL10	1985	0.00	0.15	1.00
CATVFBLL50	1995	0.00	0.10	1.00
CATVFBLL90	2004	0.00	0.05	1.00

Table 9.3 Market penetration schedules of fiber optics applications

Application Event	Fast Schedule	Slow Schedule
FIBOP LL10	1980	1981
FIBOP LL50	1984	1988
FIBOP LL90	1988	1997
FIBOP LD10	1985	1986
FIBOP LD50	1988	1990
FIBOP LD90	1992	1999
FIBOPCAB10	1985	1986
FIBOPCAB50	1988	1990
FIBOPCAB90	1992	2000
FBOPRTCH10	1987	1987
FBOPRTCH50	1995	2001
FBOPRTCH90	2002	2016
CATVFBLL10	--	1985
CATVFBLL50	--	1995
CATVFBLL90	--	2004

Furthermore, an event for testing the capability of the United States telecommunications system to meet the projected traffic load generated from long distance calls is incorporated in the cross impact model. If advanced satellite communications technologies are not available to meet the demand, then optical fiber cables would be the only alternative left for telephone companies in their efforts to meet customers' demand for long distance calls. The route selection in cases of high and low deployment is "pre-determined" and there is no need to test the capability of the telecommunication system for meeting the demand generated by long distance calls.

9.1.2.2 Satellite Communications Application Events

Satellite communications application events have been combined into 13 groups. Namely, transportation (TRANSPRT10, TRANSPRT50, TRANSPRT90), two-way radio communication for professionals (RADIPROF10, RADIPROF50, RADIPROF90), electronic library services for professionals (ELELIBPR10, ELELIBPR50, ELELIBPR90), computer conferences in households (HOUSEHLD10, HOUSEHLD50, HOUSEHLD90), electronic library services in schools (ELELIBSH10, ELELIBSH50, ELELIBSH90), computer-aided instruction in schools through direct broadcasts (CAISDBRD10, CAISDBRD50, CAISDBRD90), computer-aided instruction for home viewers through direct broadcasts (CAIHDBRD10, CAIHDBRD50, CAIHDBRD90), public services communication (PUBSER10, PUBSER50, PUBSER90), business communication (BUSCOM10, BUSCOM50, BUSCOM90), special broadcast TV (2KCHSBTV, 6KCHSBTV, 9KCHSBTV, 13KCHSBTV), direct broadcast of TV from satellite to viewer (DBRDCST10C, DBRDCST30C, DBRDCST60C), electronic mail (ELECMAIL10, ELECMAIL50, ELECMAIL90), and Video conferences (VIDEOCON10, VIDEOCON50, VIDEOCON90). These applications are classified into three categories: those needing no new technology; those requiring doubling of channel availability; and those requiring at least quadrupling of channel availability. Projections of traffic loads for certain application events are adjusted to reflect a more appropriate picture of the U.S. telecommunications systems in the early part of next century.

The transportation application concerns pipeline network status, truck location, audio to/from trucks, taxicab location, and audio to/from cabs. Public services communications contain data transfer, telemodicine, educational broadcasting, public safety, disaster management, remote testimony, instrumented hospital bed, and continuing education. Data base search, computer conferences, and telecommuting by employees are the main elements in the business communication group. Contents of other satellite communications application groups have been defined previously in Section 3.

Traffic loads of satellite communications applications presented in Section 3 are mainly estimated for contemporary years (1970s). But, the cross impact model investigates the future extended to the year 2040. Therefore, projections made for the year 2010 would reflect a more suitable situation. A revised projection of major satellite communications application events are presented in Table 9.4. Growth rates are assumed to be 1% per year from 1977 to 2010 in making this revised projection. The difference between two projections in Tables 9.4 and 3.1 would be a growth compound factor based on assumed yearly growth rate.

Total number of channel required for a satellite communication application group is the sum of channel demands for each individual application element in the group. The only exception is the public service communication group. Aggregate projections for the public service communication group under slow, fast and mid-market penetration schedules were obtained through preliminary simulation runs. These aggregate projections took into consideration the interactions within the public service segment and among other segments in the cross impact model.

The possibility of picture phone services has been discussed in Section 3. A great deal of uncertainty associated with the application makes it fruitless to attempt to select a credible set of assumptions at the present time. The inclusion of picture phone application under certain assumptions could easily swamp the entire U.S. telecommunications system.

Table 9.4 Market potential of satellite communication applications (projections for the year 2010)

Application Event	Number of Wide-Band Channels
TRANSPRT10	22
TRANSPRT50	110
TRANSPRT90	200
RADIPROF10	99
RADIPROF50	493
RADIPROF90	887
ELELIBPR10	38
ELELIBPR50	190
ELELIBPR90	342
HOUSEHLD10	36
HOUSEHLD50	181
HOUSEHLD90	326
ELELIBSH10	1015
ELELIBSH50	5074
ELELIBSH90	9132
CAISCH10	4097
CAISCH50	20485
CAISCH90	36873
PUBSER10	90
PUBSER50	450
PUBSER90	810
BUSCOM10	7
BUSCOM50	38
BUSCOM90	68
2KCHSBTV	2000
6KCHSBTV	6000
9KCHSBTV	9000
13KCHSBTV	13000
DRBDCST10C	10
DRBDCST30C	30
DRBDCST60C	60
ELECMAIL10	9
ELECMAIL50	43
ELECMAIL90	77
VIDEOCON10	3000
VIDEOCON50	15000
VIDEOCON90	27000

Under another set of assumptions with tremendous technology breakthroughs, different requirements in the system design, modification of users' habits, and the possibility of using optical fiber as the primary medium for transmitting picture phone calls, the demand of satellite communication channels could drop by a factor of 100 or 1000. It is evident that assumptions on picture phone application will determine the kind of output from the cross impact model. Therefore, the picture phone application is not included in the cross impact model for this sample assessment.

Details concerning the probability of occurrence and market penetration schedules for satellite communications application events are given in Table 9.5.

9.1.2.3 Advanced Satellite Telecommunications Technologies

Advanced technologies in satellite telecommunications considered in the sample assessment are spot beam, digital coding with a compression factor of 2, 3 or 4, polarization, combinations of polarization and digital coding with a compression factor of 2 or 3. These technologies provide two levels of capacity improvement. A high level of increase could come from spot beams, digital coding techniques with a compression factor of 4, or combinations of polarization techniques and digital coding methods. A low level of capacity improvement could be achieved by any of these advanced technologies. The development of either the 6000 kg satellite or the geostationary space platform is the prerequisite for utilizing the spot beam technology.

The 2000 kg satellite is expected to be in orbit in the 1980s with a 0.80 probability of occurrence. Date for occurrence of this event is distributed over a 10-year time span (1980 to 1989). A low probability (.03) was assigned to each of the first five years, and a high probability (.17) was for each of the last five years in the time span. The development of 6000 kg satellite is considered to be feasible in the 1990s with a probability of .60 for occurrence. Equal chances are assumed for the occurrence of 6000 kg satellite in a 10-year period from 1990 to 1999. The occurrence of the 6000 kg satellite enhances the probability of occurrence for the spot beam technology to .85.

Table 9.5 Probabilities of Occurrence and Market Penetration Schedules of Satellite Communication Applications

Application	Probability	Early Sched	Mid Sched	Late Sched
TRANSPRT10	1.0	1980	1985	1990
50	1.0	1988	1993	1998
90	1.0	1995	2000	2005
RADIPROF10	0.8	1982	1987	1992
50	0.8	1987	1992	1997
90	0.8	1992	1997	2002
ELELIBPR10	0.6	1985	1990	2000
50	0.6	1995	1999	2010
90	0.6	2004	2009	2019
HOUSEHLD10	0.4	1985	1990	1995
50	0.4	1995	1999	2005
90	0.4	2005	2009	2014
ELELIBSH10	0.6	1985	1990	1995
50	0.6	1993	1998	2002
90	0.6	2001	2005	2010
CAISDBRD10	0.3	1985	1990	1995
50	0.3	1993	1998	2002
90	0.3	2001	2005	2010
CAIHDBRD10	0.1	1995	----	----
50	0.1	2005	----	----
90	0.1	2014	----	----
PUBSER10	0.6	1996	2001	2006
50	0.6	2006	2010	2016
90	0.6	2015	2020	2025
BUSCOM10	0.8	1983	1988	1993
50	0.8	1990	1995	2000
90	0.8	1997	2002	2007
ELECMAIL10	0.7	1985	----	----
50	0.6	1995	----	----
90	0.5	2004	----	----
VIDEOCON10	0.1	1990	----	2005
50	0.1	1995	----	2010
90	0.1	2000	----	2015
DRBDCST10C	0.1	1995	----	----
30C	0.1	2005	----	----
60C	0.1	2015	----	----

Table 9.5 (Continued)

Application	Probability	Early Sched	Mid Sched	Late Sched
2KCHSBTV	0.90	1988	----	1988
6KCHSBTV	0.85	1992	----	2000
9KCHSBTV	0.80	1997	----	2010
13KCHSBTV	0.75	2002	----	2020

Geostationary space platforms are projected to be operational in the late 1980's with a probability of .15. Distribution of the timing of space platforms is equally spread over a 5-year period from 1986 to 1990. The advent of geostationary space platforms makes the spot beam technology feasible with a probability of .95.

The polarization technology could be available at all frequencies as early as 1985 with a probability of .25 for occurrence. The timing for the technology may be equally possible over a 10-year span from 1985 to 1994.

We treat the digital coding technology with different compression factors as mutually exclusive events in the cross impact model. The digital coding technology itself has a probability of .50 for occurrence. Equal chances are assumed for any of three compression factors in the digital coding technology, which is projected to be available as early as 1985. The timing of this technology is evenly distributed over a period of 10 years from 1985 to 1994.

Combinations of the polarization technology and lower levels of the digital coding technology could provide the same level of satellite communications capacity achieved by the spot beam technology or the digital coding technology with a compression factor of 4. Different orders of occurrence for the spot beam technology and the digital coding technology in combinations of these two technologies are possible in the cross impact model.

9.1.2.4 Satellite Communications Application Categories

All satellite communications application groups discussed in Section 9.1.2.2 could be further classified into three categories. Application Category 1 requires any of those technologies that could provide a high level of increase in the satellite communications channel capacity as described in the previous section. Those advanced satellite communications technologies with a low level of capacity improvement are sufficient for satellite communications application groups in Application Category 2. The last category of applications, Application Category 3, does not need any advanced satellite communications technology. Table 9.6 lists elements of satellite communications applications by categories.

9.1.3 Major Elements of the Cross Impact Model in the Sample Assessment

The cross impact model used in the sample assessment consists of major segments of the U.S. telecommunications system such as TV stations, CABLE TV, local and long distance telephones, special business telecommunications, fiber optics applications, and satellite communications applications. These segments have been discussed in Sections 3, 4, 8 and earlier parts of Section 9. The cross impact model is succinctly described by the matrix shown in Table 9.1. In addition, a complete list of major events and cross impacts in the U.S. telecommunications system is presented in Appendices 2 and 3.

9.2 MODEL OUTPUT

A cross impact model generates information on relative frequency of occurrence for individual events, aggregate scenarios, distribution of timing and probability of occurrence of events, etc. We focus our attention on events that are most related to optical fiber and satellite communications such as optical fiber in telephones, televisions, Cable TV return channels, and all those satellite communications applications. Refined forecasts obtained from cross impact models will be presented and analyzed in subsequent sections.

Optical Fibers and satellites compete with each other for some telecommunications applications; for other applications they are complementary. Each in turn competes with other technologies, and exists in a complementary relationship with yet other technologies. A forecast of the use of optical fibers cannot be made without taking into account the entire

Table 9.6 Categories of Satellite Communications Application

Category 1	Category 2	Category 3
ELELIBSH50	ELELIBSH10	TRANSPRT10
ELELIBSH90	HOUSEHLD10	TRANSPRT50
CAISDBRD10	HOUSEHLD50	TRANSPRT90
CAISDBRD50	HOUSEHLD90	RADIPROF10
CAISDBRD90	2KCHSBTV	PUBSER10
CAIHDBRD10	6KCHSBTV	PUBSER50
CAIHDBRD50	RADIPROF90	BUSCOM10
VIDEOCON10		BUSCOM50
VIDEOCON50		BUSCOM90
VIDEOCON90		DBRDCST10C
9KCHSBTV		DBRDCST30C
13KCHSBTV		DBRDCST60C
		ELECMAIL10
		ELECMAIL50
		ELECMAIL90
		ELELIBPR10
		ELELIBPR50
		ELELIBPR90

context of the telecommunications system. Issues examined include growth of use of satellites, incorporation of optical fibers in the telephone network, use of optical fibers in CATV and other "captive" applications, and the interaction of fiber optics with CATV return channel, digital telephone, and data transmission.

9.2.1 Forecasts of Optical Fiber Applications

Figure 9.1 shows a projection of the number of telephones which will have fiber optics for the connection in the local loop. Two projections are shown, both with a 1979 starting point. The projection in schedule A is based on a ten-year schedule for conversion of existing plant to fiber optics; the projection in schedule B is based on a twenty-year conversion schedule. The second portion of the telephone system which can utilize fiber optics is the long distance trunks. Figure 9.2 shows the number of calls per year projected to be transmitted annually by fiber optic long distance trunks. Again schedule A is based on ten-year conversion of existing plant, and schedule B on a twenty-year conversion program.

Figure 9.3 shows a projection of the number of CATV systems utilizing fiber optics for transmission to the home. Again, two alternative projections are shown, a high-growth projection based on certain favorable assumptions, and a lower-growth projection based on less favorable assumptions. Fiber optics in CATV provide not only a means for transmission from the "head end" to the subscriber, they provide a ready means for a "return channel" from the subscriber to the head end. This return channel can be used for many purposes, including responses to current program materials, interaction with a computer at the head end, and communication with other subscribers. Figure 9.4 shows a projection of the number of CATV systems using fiber optics for a return channel from the subscriber to the head end.

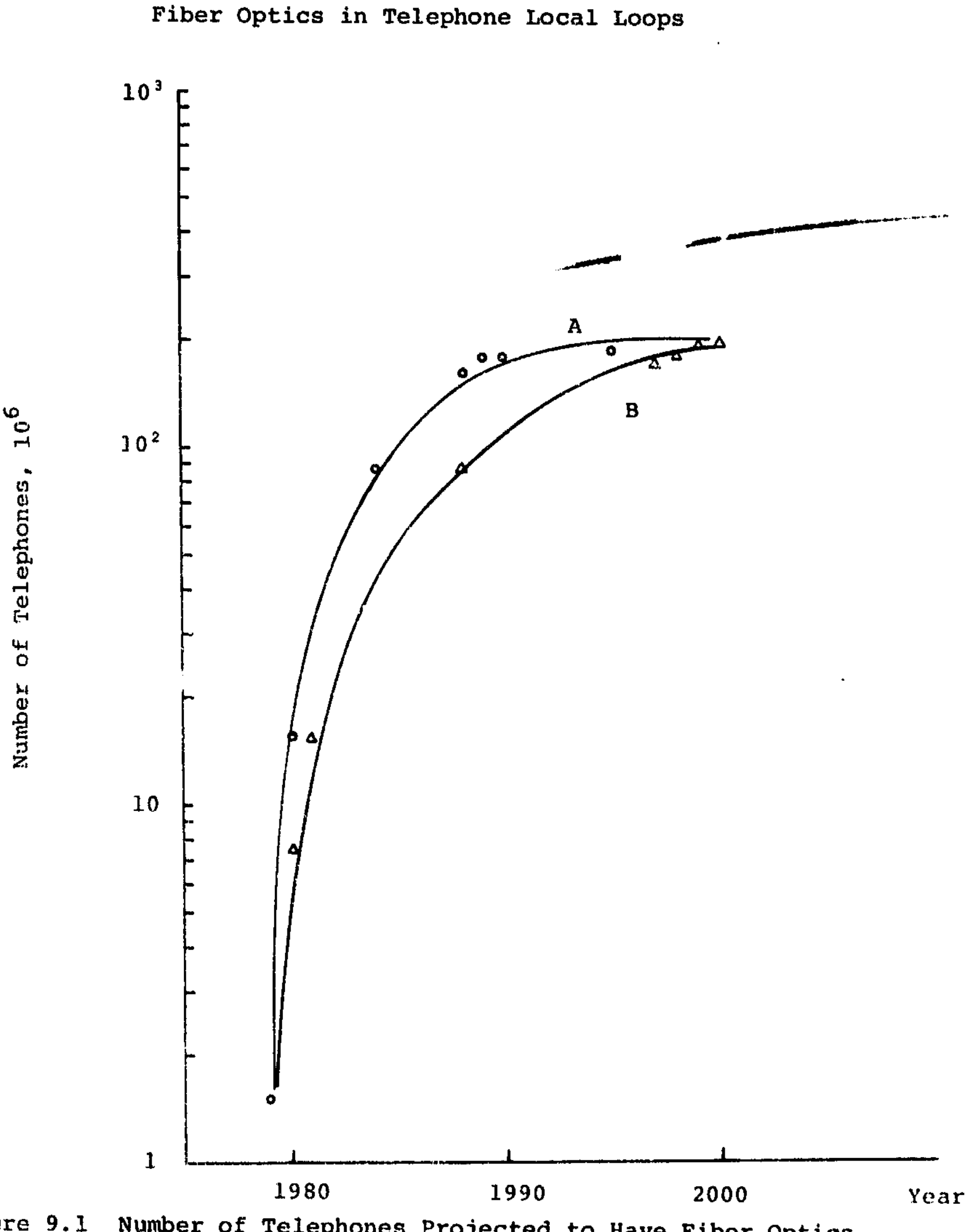

Figure 9.1 Number of Telephones Projected to Have Fiber Optics Local Loop Connections to Central Offices (Two Different Conversion Schedules)

Fiber Optics in Long Distance Calls

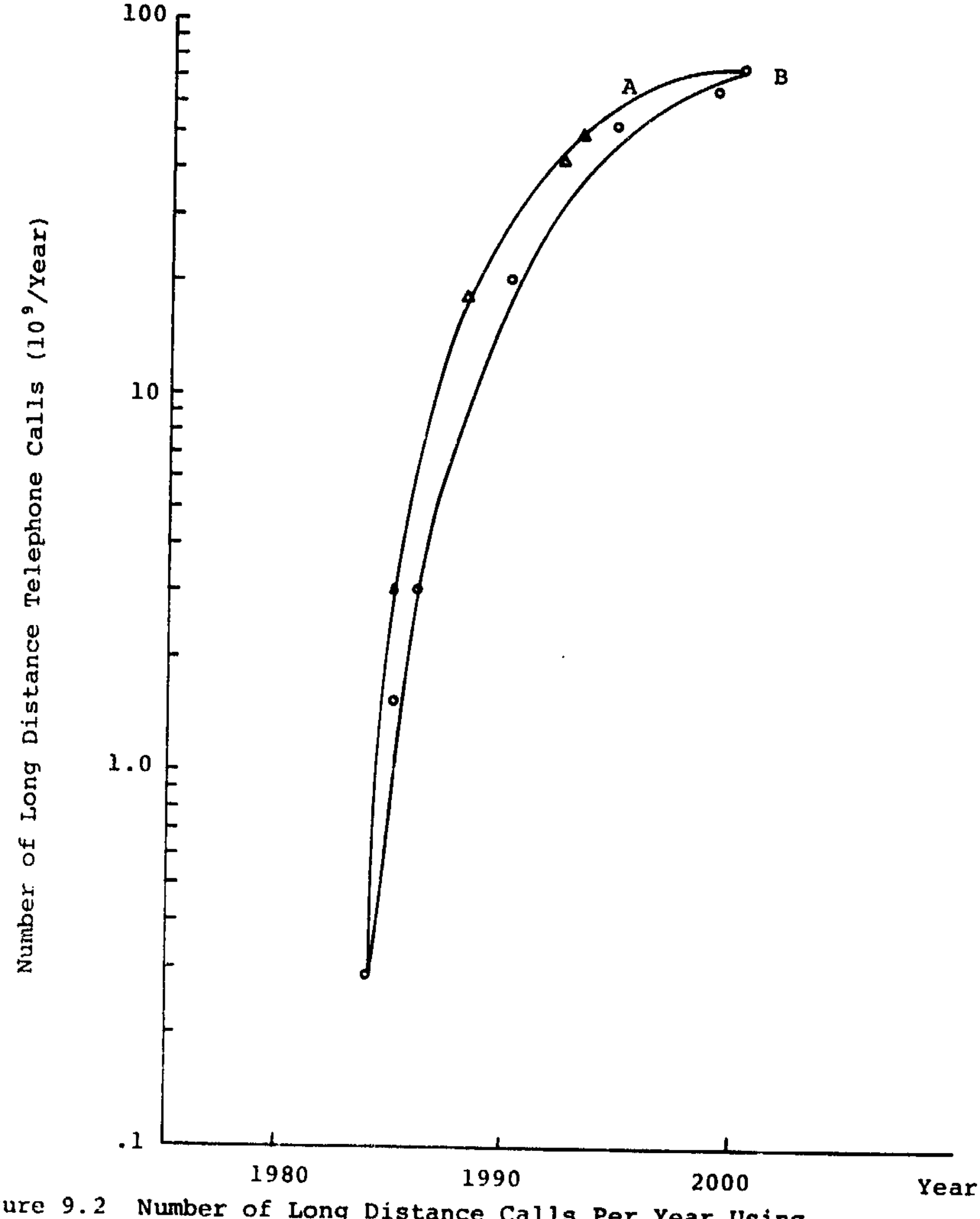

Figure 9.2 Number of Long Distance Calls Per Year Using Fiber Optics Long Distance Trunks (Two Different Conversion Schedules)

Fiber Optics in CABLE TV Systems

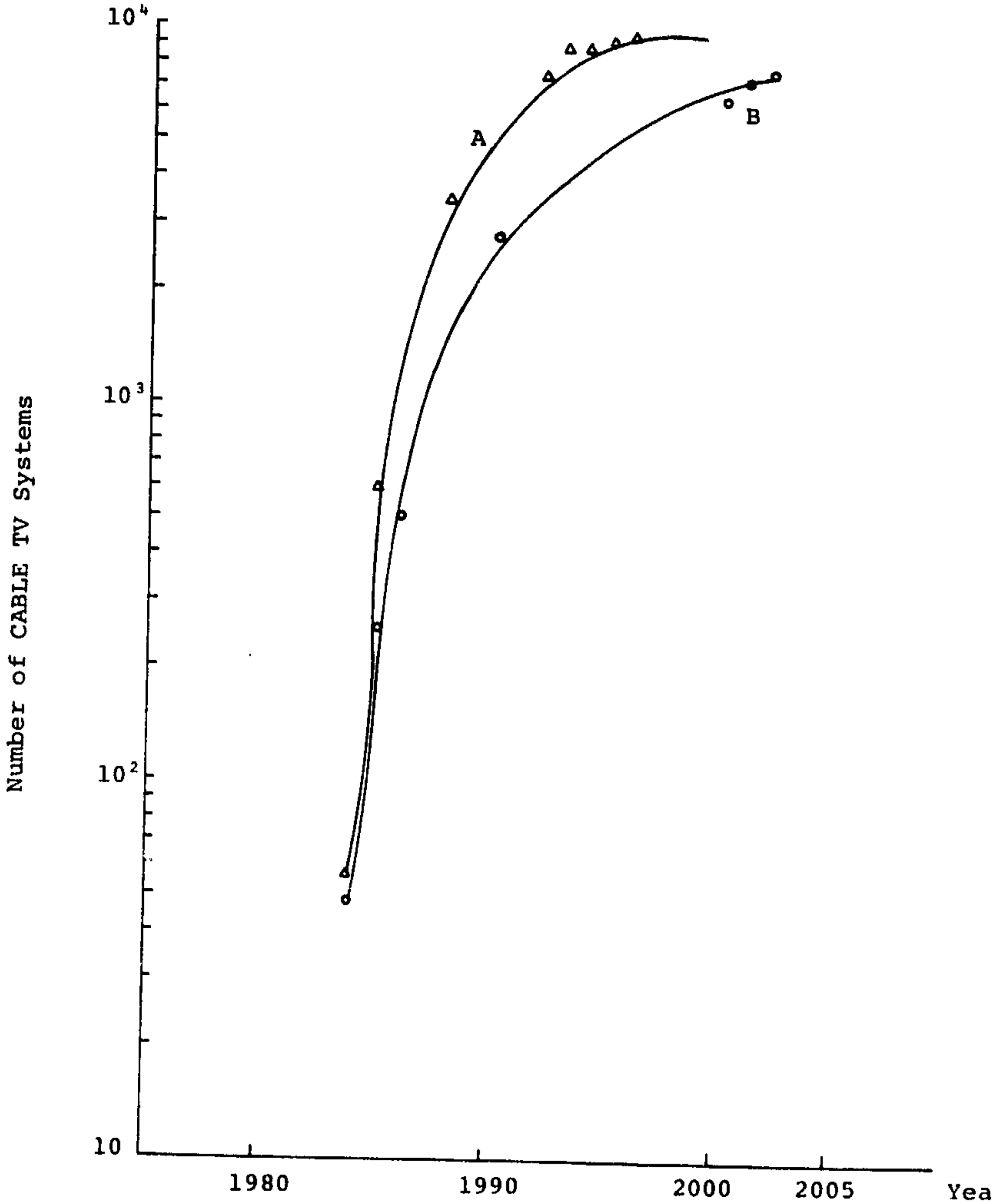

Figure 9.3 Number of Cable TV Systems Using Fiber Optics (Two Different Penetration Rates)

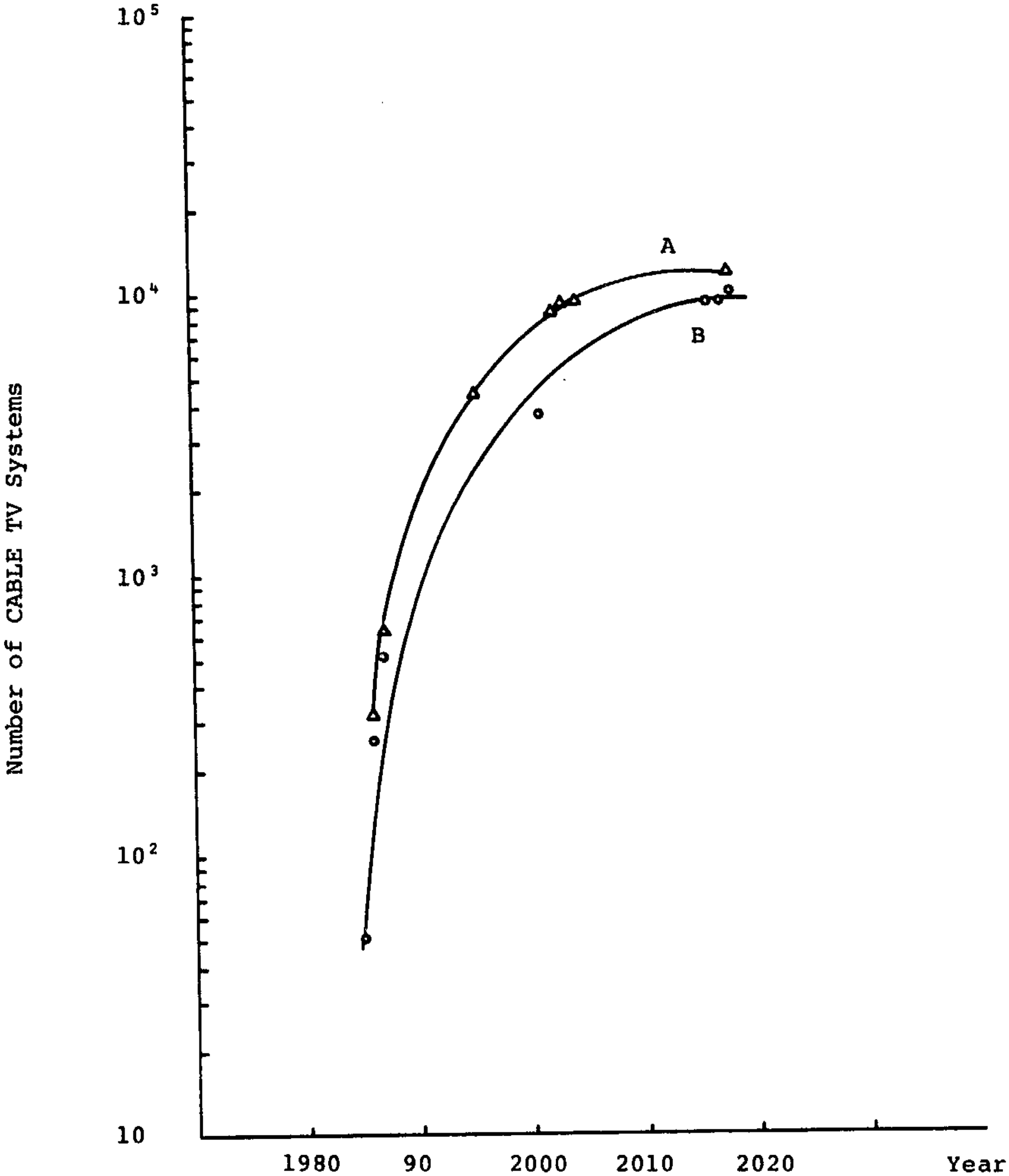

Figure 9.4 Number of Cable TV Systems With Fiber Optics Return Channels (Two Different Penetration Rates)

Once fiber optics are installed in the telephone local loop, the bandwidth of the telephone connection is increased enormously. It then becomes possible to utilize the telephone local loop for CATV, without interfering with the telephone connection. Figure 9.5 shows a projection of the number of CATV systems based on use of fiber optics local loops instead of a separate cable. Only one projection is shown, since this is a comparatively low-probability event.

9.2.2 Forecasts of Satellite Communications Applications

Figure 9.6 and Tables 9.7 and 9.8 show a very highly aggregated result of the deployment of fiber optics. Some of the applications included in the model may utilize either fiber optics or satellite communications. Two sets of 100 runs of the model were made, with fiber optics utilization deliberately forced low in one set and forced high in the other set. The average growth of demand for satellite channels (6 MHz-equivalent channels) was then determined under each of the two conditions. The cumulative demands (total channels in use by year) are shown in the Figure.

9.3 ANALYSIS OF MODEL OUTPUT

9.3.1 Fiber Optics Application

The most important information gained from use of the cross impact model involves those situations in which the output forecast is different from the input forecast, as a result of interactions with other elements of the model. To illustrate this, Figures 9.7, 9.8 and 9.9 show the distribution of years in which particular levels of market penetration are achieved by fiber optics in particular applications. These should be contrasted with the forecasts input to the model which were made without taking interactions into account, and which are shown in Table 9.3 These figures are based on 100 runs of the model, and show the distribution of outcomes among those 100 runs.

Fiber Optics in CABLE TV Systems Through Local Loops

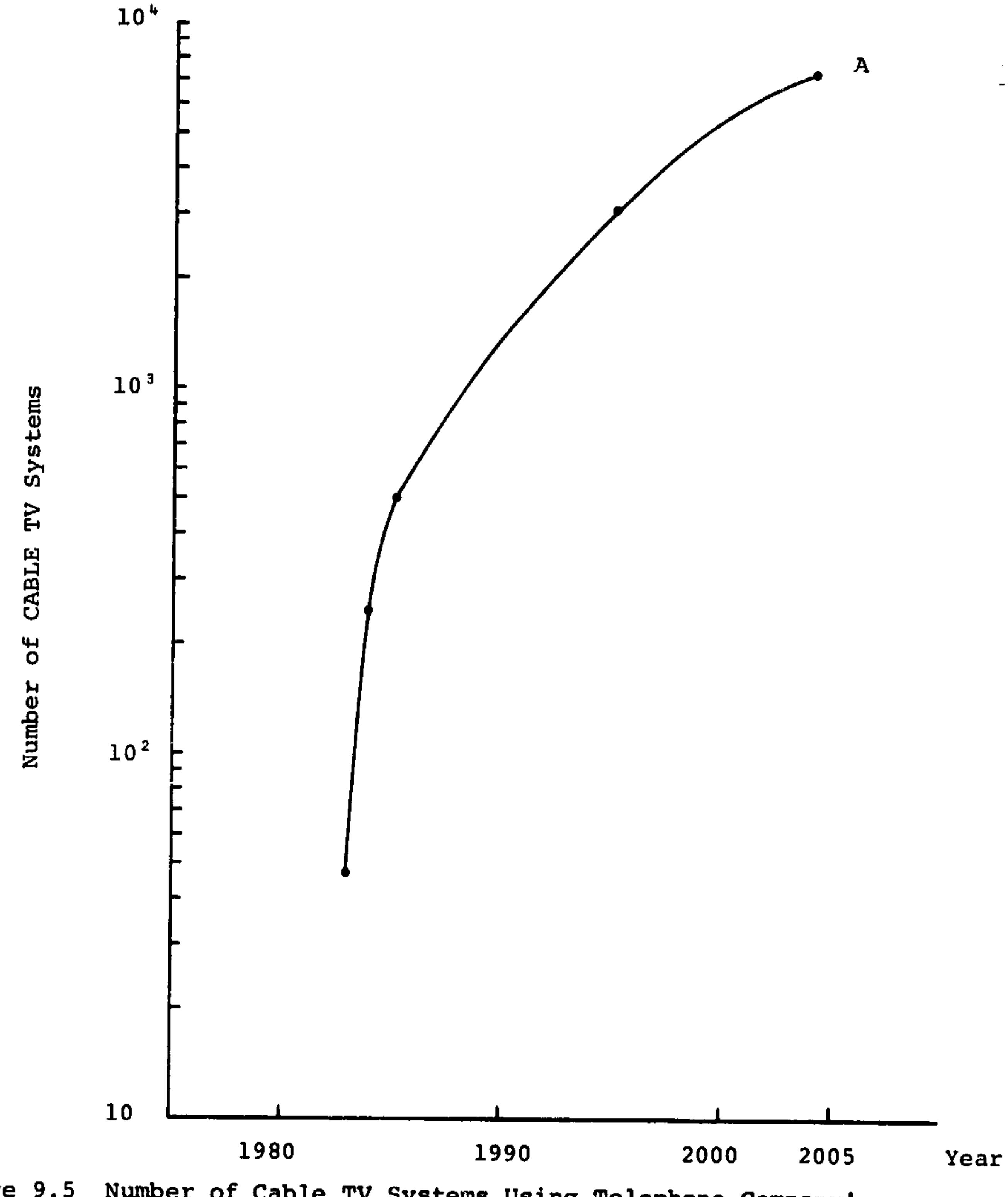

Figure 9.5 Number of Cable TV Systems Using Telephone Company's Fiber Optics Local Loop Instead of Separate Cable

Satellite Communication Channel Demands

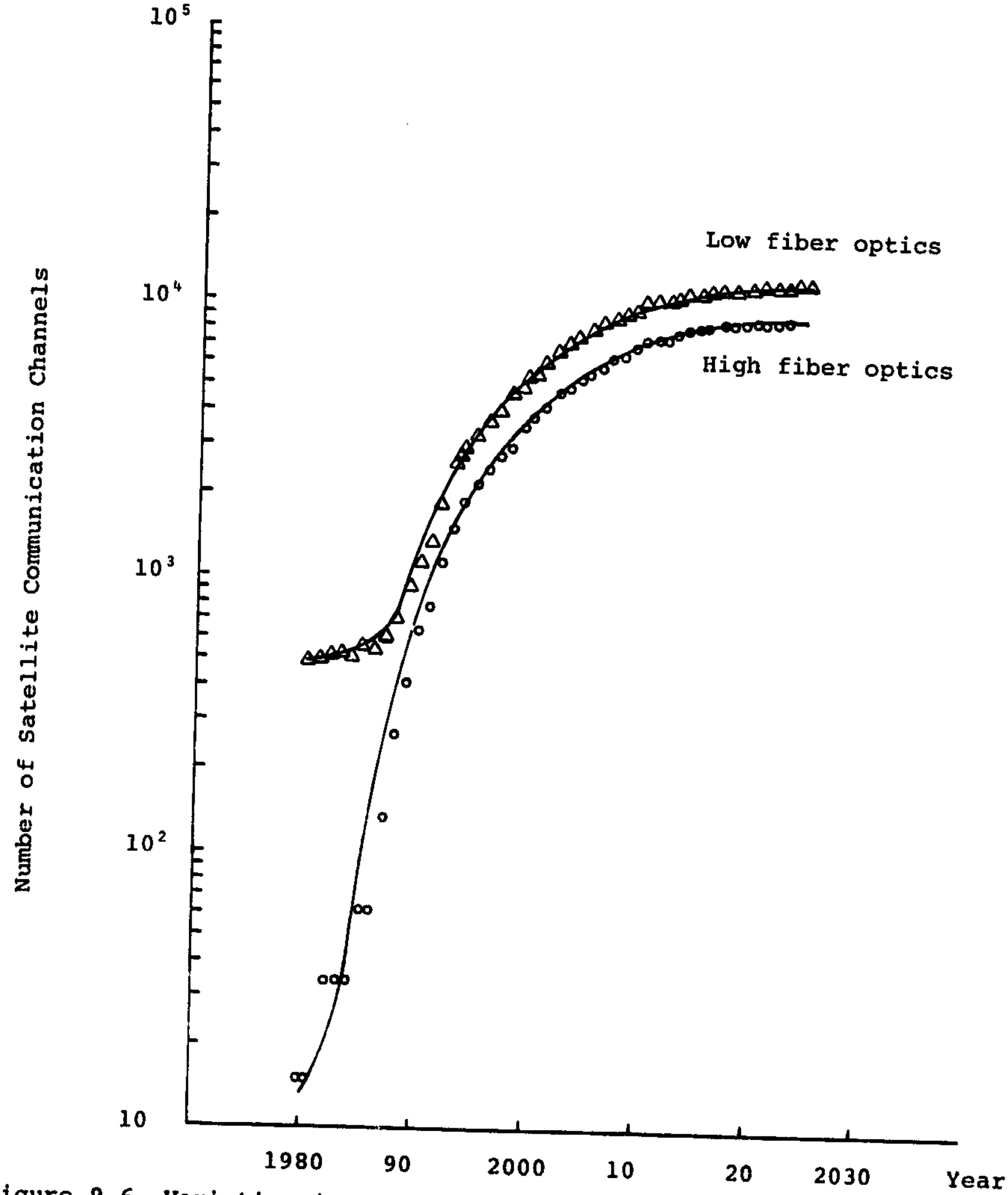

Figure 9.6 Variation in Average Satellite Channel Demand for High and Low Fiber Optics Deployment (Average of 100 Simulation Runs Each)

Table 9.7 No. of Satellite Communication Channels Under High Fiber Optics Deployment

YR	# of Channel	Cumulative # of Channels	YR	# of Channel	Cumulative # of Channels
1980	15	15	2007	427	6384
1981	0	15	2008	385	6769
1982	19	34	2009	230	6999
1983	0	34	2010	241	7240
1984	0	34	2011	322	7562
1985	27	61	2012	142	7764
1986	1	62	2013	251	7955
1987	72	134	2014	232	8187
1988	133	267	2015	75	8262
1989	141	408	2016	122	8384
1990	238	646	2017	139	8523
1991	142	788	2018	0	8523
1992	334	1122	2019	0	8523
1993	413	1535	2020	127	8650
1994	385	1920	2021	120	8770
1995	274	2194	2022	200	8970
1996	294	2488	2023	200	9010
1997	272	2760	2024	80	9090
1998	200	2960	2025	142	9232
1999	574	3534			
2000	245	3779			
2001	456	4235			
2002	444	4679			
2003	238	4917			
2004	383	5300			
2005	351	5651			
2006	306	5957			

Table 9.8 No. of Satellite Channels Under Low Fiber Optics Deployment

YR	# of Channel	Cumulative # of Channels
1980	501	501
1981	0	501
1982	21	522
1983	0	522
1984	0	522
1985	31	553
1986	0	553
1987	50	603
1988	97	700
1989	231	931
1990	205	1136
1991	211	1347
1992	549	1896
1993	787	2683
1994	261	2944
1995	300	3244
1996	443	3687
1997	339	4026
1998	600	4626
1999	418	5044
2000	611	5655
2001	360	6015
2002	868	6883
2003	324	7207
2004	405	7612
2005	590	8202
2006	363	8565

YR	# of Channel	Cumulative # of Channels
2007	329	8894
2008	518	9412
2009	283	9695
2010	616	10311
2011	152	10463
2012	211	10674
2013	232	10906
2014	202	11108
2015	158	11266
2016	69	11335
2017	9	11344
2018	0	11344
2019	2	11346
2020	178	11522
2021	160	11682
2022	40	11722
2023	120	11842
2024	120	11962
2025	27	11989

Histogram for FIBOP LD90

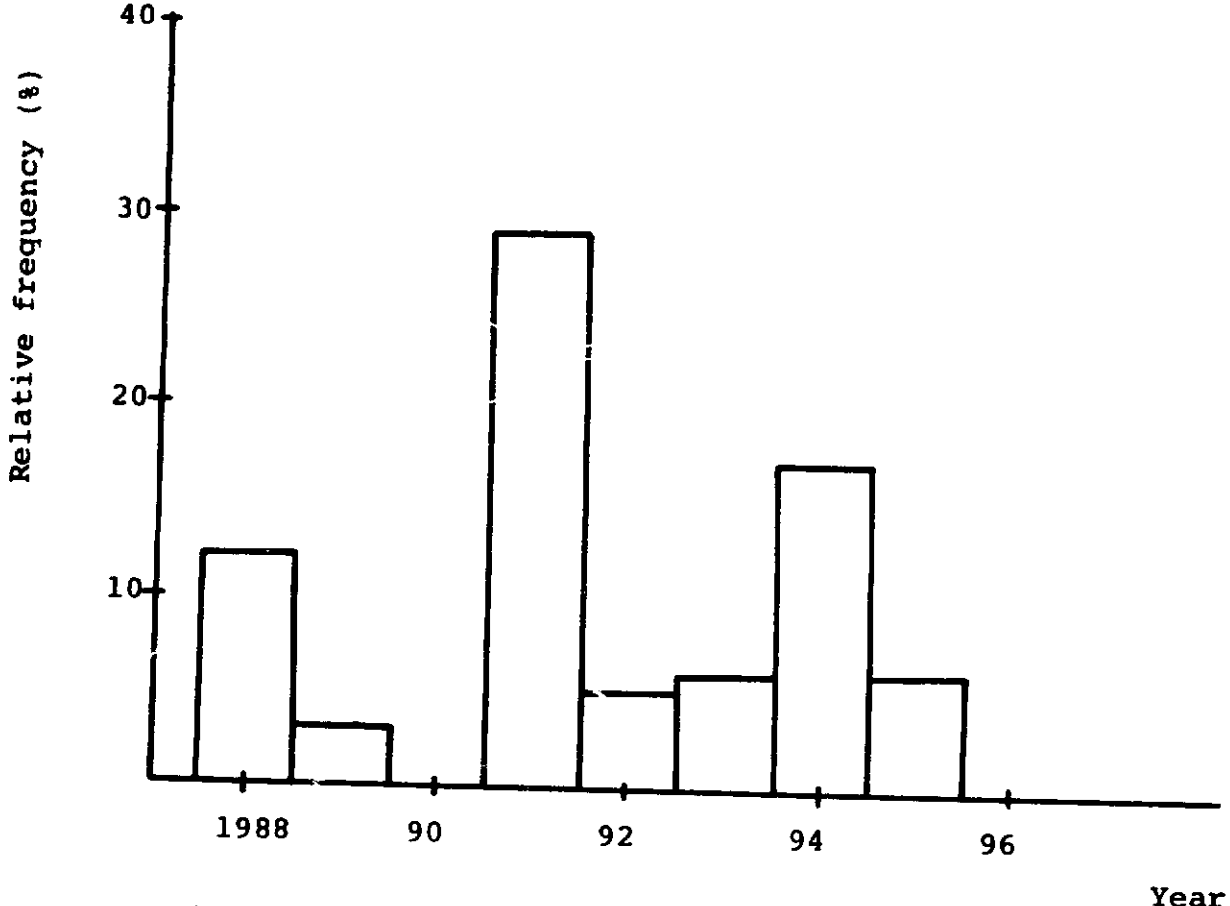

Figure 9.7 Distribution of Years in Which Fiber Optics Carry 90% of Long Distance Calls (From 100 Simulations)

Histogram for FIBOPCAB90

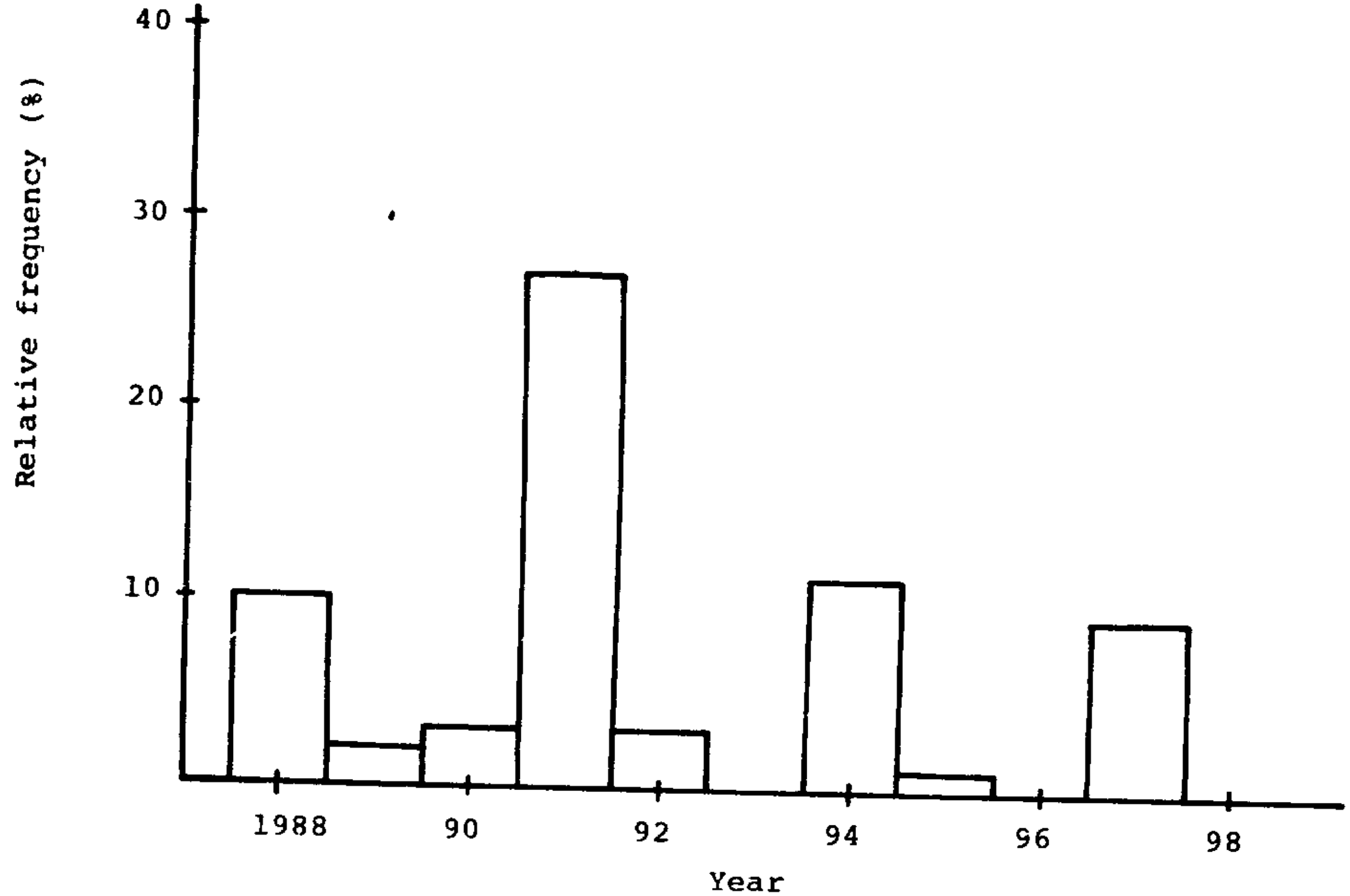

Figure 9.8 Distribution of Years in Which Fiber Optics Achieve 90% Penetration of Cable TV System (From 100 Simulation Runs)

Histogram for FIBOP LL50

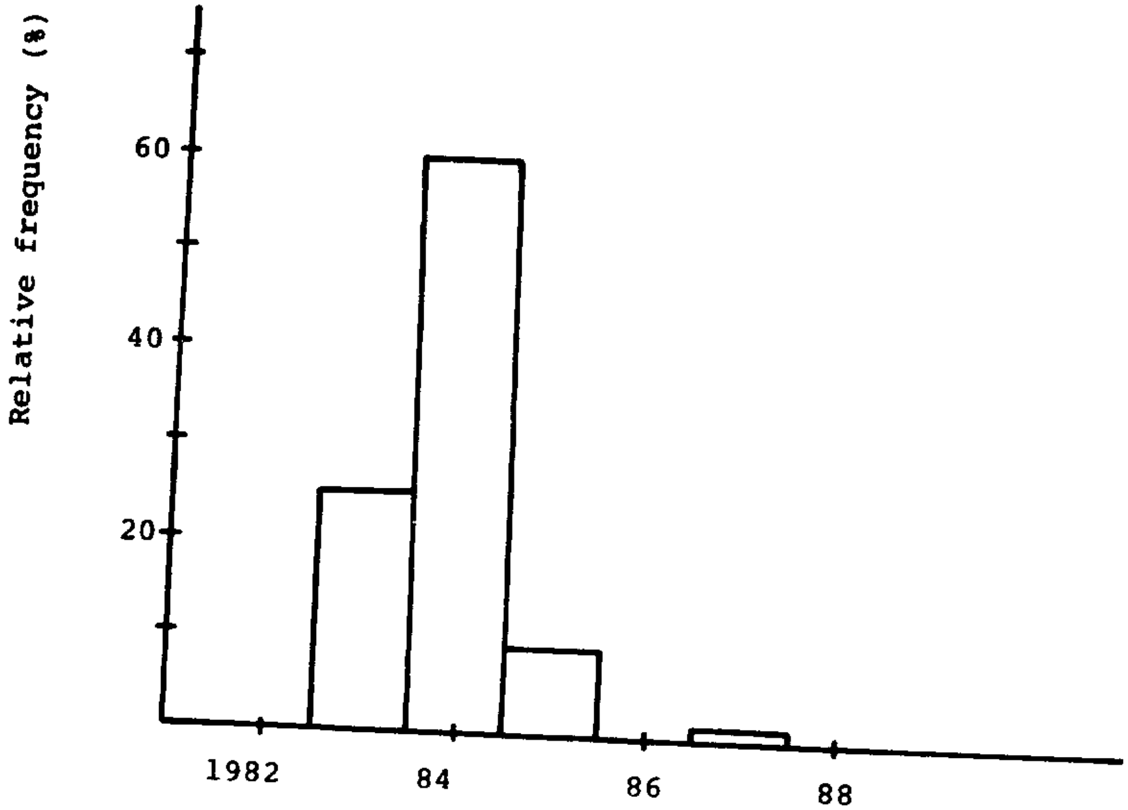

Figure 9.9 Distribution of Years in Which Fiber Optics Penetrate 50% of Local Loop Applications (From 100 Simulation Runs)

Figure 9.7 shows the distribution of years in which fiber optics achieve 90% penetration of the long distance trunk system (measured in terms of traffic carried). Table 9.3 showed that 90% penetration was projected for 1992 under the fast schedule and 1999 under the slow schedule. Figure 9.7 shows that the actual distribution was between 1988 and 1995, and that market penetration of 90% was achieved in 78 of the runs, while in the remaining 22 runs, 90% penetration was not achieved. This departure from the forecast originally provided as input to the model is the result of the interactions with other forecasts. These interactions were of course also provided as input for the model. Hence the output, as presented in Figure 9.7, is implicit in the input. However, it is not readily apparent in the input. The purpose of the model is to trace out the consequences of these inputs and the interactions among them, making it unnecessary for the user to do this in his head.

Figure 9.8 shows the distribution of years in which fiber optics reached 90% penetration of the Cable TV systems. This should be contrasted with the forecast of 1992 under the fast schedule and 2000 under the slow schedule. The effect of some of the interactions was actually to advance fiber optics in Cable TV to 1988, which is earlier than the original "fast" schedule. Ninety percent penetration was achieved in 66 of the 100 runs, and not achieved in 34 of the 100 runs.

Figure 9.9 shows penetration of fiber optics to 50% of the telephone local loop application, and Figure 9.10 shows penetration to 90% of the local loop application. There is significant variation among the various scenarios in rate of growth of fiber optics in local loops. In fact, there is some overlap, with fiber optics achieving 90% before 1986 or later in 10 of the runs. Thus the rate of growth of fiber optics in the telephone system is significantly affected by developments elsewhere in the telecommunications system.

Histogram for FIBOP LL90

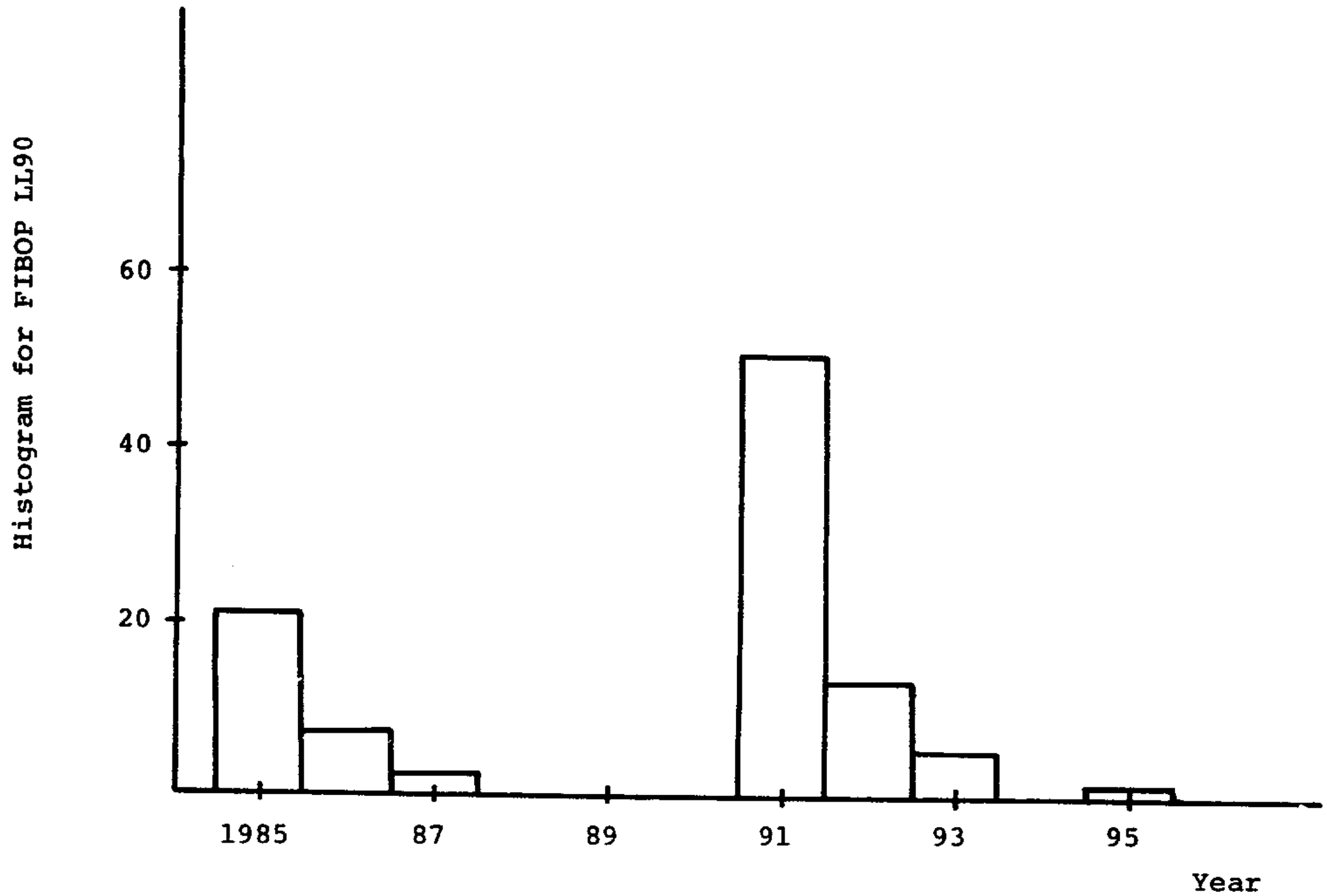

Figure 9.10 Distribution of Years in Which Fiber Optics Penetrate 90% of Local Loop Applications (From 100 Simulation Runs)

9.3.2 Aggregate Satellite Communications Application

Under conditions of slow deployment of fiber optics, the growth of demand for satellite channels is significantly higher than under conditions of fast deployment of fiber optics. By the year 2000 this could result in an average demand of 12000 channels vs. 9000 channels for the two different conditions. Note that these represent average demand over 100 runs. In individual scenarios, the cumulative demand curves could differ somewhat from these average cumulative demand curves. These two sets of model runs represent extreme cases, of course. The actual results are expected to be somewhere between the two curves. They serve to show, however, the impact that fiber optics may have on other elements of the telecommunications system.

A breakdown of channel demand on each satellite communications application is listed in Table 9.9 It is a breakdown on final channel demands reached at the end of cross impact simulation runs.

A Kolmogorov - Smirnov's two-sample test (K-S test) was used to determine whether there is a difference between two distributions of aggregate satellite communications channels required under high and low deployments of fiber optics in the U.S. telecommunications system. A very large discrepancy between sample distribution functions (cumulative frequency distributions) in the K-S test could reasonably serve as the basis for an inference that the two populations, which two sample distribution functions (two distributions of aggregate satellite communications channels) are derived from, are different. The probability for the computed K-S test statistic is 0.0004. Thus, the result of K-S test strongly indicates a very significant difference between the two distributions of aggregate demand of satellite communications channels.

Table 9.9 Average Channel Demands of Satellite Communication Applications (WBCH)

Applications	Normal Fiber Optics Deployment	High Fiber Optics Deployment	Low Fiber Optics Deployment
Special Broad-casting TV	6350	6290	6720
Transportation	198	198	198
Radio for Professionals	329	334	512
Electronic Library for Professionals	119	83	199
Household Applications	32	41	38
Electronic Library in Schools	2174	1849	3137
Computer Aided Instruction in Schools	0	123	451
Computer Aided Instruction in Households	0	0	0
Public Services	268	285	286
Business Community	44	39	34
Video Conference	270	90	420
Electronic Mail	29	32	29
Direct Broad-casting	1	1	1

9.3.3 Elements of Satellite Communications Application

The K-S test on distributions of aggregate demand of satellite communications channels reveals that they are not the same. However, it only indicates that high and low deployments of fiber optics applications in the U.S. telecommunications system have significantly different impacts on the overall progress of satellite communications application. A proportion test and a K-S test are needed to determine whether elements of satellite communications application behave differently under different situations.

A proportion test could detect the difference in the probability of occurrence for a satellite communications application event, and consequently the difference in the average demand of satellite communications channels by this event. The distribution of timing of occurrence for an application event provides another insight of the telecommunications system. A K-S test is used to examine the possible difference in distributions of timing of occurrence of satellite communications application events. Several satellite communications application elements which behave significantly different under different deployments of fiber optics are discussed below.

The timing of occurrence of CATVRTCH50 (Cable TV return channel at 50% market penetration) was enhanced by FBOPRTCH50 (optical fiber Cable TV return channel at 50% market penetration). FBOPRTCH50 in turn was heavily affected by the progress of optical fiber applications in the entire telecommunication system. Hence a high probability of occurrence for Cable TV channel could be credited to the high deployment of fiber optics.

The difference in CAISH10 (computer aided instruction in schools at 10% market penetration) could also be traced back to different deployments of fiber optics, through events CATVRTCH10, CATV GMS10 (Cable TV games at 10% market penetration), TVGAMES10 (TV games with 10% market penetration, VIDEODPU10 (video disc purchasing at 10% market penetration), and CAISLCAL10 (computer aided instruction through local centralized computer facility at 10% market penetration) in the cross impact model of the U.S. domestic telecommunications systems.

9.4 SUMMARY AND OBSERVATIONS

A cross impact model with emphasis on optical fiber applications in the U.S. telecommunications system has been constructed and investigated in this section. High, low, and normal deployment of fiber optics were considered in the sensitivity analysis. Outputs from the cross impact model were examined in detail. The impacts from fiber optics on satellite communications applications were traced through the mechanism of the cross impact model. Several observations are briefly discussed below.

The first observation is that fiber optics applications in telephone local loops, long distance calls, CABLE TV systems, and CABLE TV return channels have been greatly influenced by the deployment of fiber optics as shown in Figures 9.1 to 9.4. These two different sets of growth curves tend to converge to the market level in the year 2020. The case of slow market penetration and slow facility replacement schedule (20-year period) will finally reach a saturation state around the year 2020 in most fiber optics applications.

The second observation is that different deployments of fiber optics have generated significant differences in the actual demand of satellite communication channels as illustrated in Figure 9.6. The figure shows that there is a higher demand of satellite capacity under the case of low fiber optics application. On the other hand, a lower demand of satellite communications channels is associated with the high deployment of fiber optics in the U.S. telecommunications system.

The third observation reveals that elements in the cross impact model for the U.S. telecommunications system have substantial effects on the penetration of fiber optics applications as shown in Figures 9.7 to 9.10. Distributions of timing for fiber optics applications in long distance calls, local loops, and CABLE TV clearly illustrate a wide range of year of occurrence for certain levels of market penetration due to impacts from other elements in the cross impact model.

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USER'S GUIDE

CROSS-IMPACT MODEL WITH CLUSTER ANALYSIS

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DAYTON, OHIO 45469

August 18,1978

Dr. Joseph Martino
Peter Kahut

TABLE OF CONTENTS

INTRODUCTION

It is the intent of this document to provide a prospective user of the computer program with the following information.

1) The purpose and uses of the program.

2) A detailed explanation of all procedures required to submit a job for processing.

3) The type and form of the output variables.

This document is not designed as an explanation of the theory involved nor as a complete program documentation. Its scope is limited to that of an instructional reference with regard to the use of the computer program.

PURPOSE AND USE OF PROGRAM

The purpose of this program is to permit the user to trace out the consequences of the interactions among a large set of events. The events are specified as part of the input. The specification includes the possible year or years of occurrence, and the probability of occurrence. Interactions among the events are specified as changes in the probability of occurrence, or in the timing, of the impacted event as a result of the occurrence or non-occurrence of the impacting event. Once the events and their cross-impacts have been specified, the program examines the events in chronological order (selecting randomly among events specified for the same date). The occurrence or non-occurrence of each event is tested, and the appropriate changes made in timing or probability of all events whose occurrence or non-occurrence has not yet been determined. If all events are purely deterministic, the program is run once only. If the events are probabilistic, many runs are made, each run representing an independent Monte Carlo simulation of the course of events.

Each run of the simulation results in determining the occurrence or non-occurrence of each event, and the timing of occurrence, as a result of the impacts from occurrence or non-occurrence of chronologically earlier events. If all events are deterministic, a single run provides full information on the consequences of the interactions among the events. If the events are probabilistic, multiple runs are made and analyzed by the program. Program output includes a histogram of fraction of occurrences by year for each event, a table showing probability of joint occurrence for each pair of events, a cluster analysis of runs according to similarity of events which occur in those runs, and a cluster analysis of events according to similarity of runs in which they occur. These outputs permit a detailed examination of the consequencies of the interactions among events.

GENERAL PROGRAMMING INFORMATION

The computer program was written utilizing the 'FORTRAN Extended' language. It is currently operational on the CDC 6600 computer at Wright-Patterson Air Force Base (WPAFB), building 676 under the NOS/BE operating system.

The program requires three (3) disk/tape units for the storage of intermediate results in addition to the normal input (unit 5) and output (unit 6) devices.

In its maximum capacity, the program requires 67200 decimal words of central memory (203200 octal words). This storage is needed for the 200 events, 100 runs case.

The program utilizes bit manipulation to conserve storage. The program is therefore machine dependent (60 bit words).

Several internal functions peculiar to the CDC 6600 system are used. These include: SECOND, DATE, TIME, AND, OR, SHIFT, and ENCODE.

INPUT DATA PREPARATION

The input to the program consists of seven (7) card types. The variables punched on these cards employ one of three formats.

A/N	Alphanumeric (may include blanks)
I	Integer (all integers must be right justified in their respective fields)
FP	Floating Point (field must contain a decimal point)

Card type 1 --- one card

Variable	Card cols.	Type	Definition
TITLE	1-80	A/N	Title (job identification)

Card type 2 --- one card

Variable	Card cols.	Type	Definition
IX	1-15	I	Initial random number (if left blank, will be computed as function of time of day)

Card type 3 --- one card

Variable	Card cols.	Type	Definition
NE	1-5	I	Number of runs (max = 100)
NV	6-10	I	Number of events (max = 200)
ISTYR	11-15	I	Initial or starting year
ITHOR	16-20	I	Time horizon, year
IPRT	25	I	Input print option: 0=standard output only 1=standard output plus input summary
NUMSTG	26-30	I	Initial stage number for printout of histogram -- deviations from cluster centroid-- $1<\mathrm{NUMSTG}\leq(\mathrm{NE}-2)$

Card type 4 --- one card

Variable	Card cols.	Type	Definition
NTOUT	1-5	I	Tape/disk unit number for storage of event cluster data -- if omitted, unit 10 will be assigned
NTMAM	6-10	I	Tape/disk unit number for storage of the lower triangular similarity matrix-- if omitted, unit 11 will be assigned

Card type 5 --- one card per event

Variable	Card cols.	Type	Definition
Data type	1	I	'1'
IREF	3-12	A/N	Event name
I1	25-27	I	Set number -- used only if this event is one of a set, otherwise = 0. All events in a set must have same number. Sets are numbered sequentially starting at 1.
I2	29-32	I	Either = year in which event occurs or = initial year in which event may occur
I3	34-35	I	Span of years for this event ($1 \leq I3 \leq 10$)
Po	37-40	FP	Probability of occurrence, this event ($0 \leq Po \leq 1.0$)
Pc_i	41-44	FP	Either = conditional probability of occurrence for each year that event may occur ($\Sigma Pc_i = 1.0$) or if event is one of a set, Pc_i = probability that this event will occur

Card type 6 --- one card per impacting event

	Variable	Card cols.	Type	Definition
	Data type	1	I	'2'
***	IREF1	3-12	A/N	Name, impacting event
***	IREF2	14-23	A/N	Name, impacted event
	Δt_o	37-40	FP	Change in time due to occurrence of impacting event ($-1.0 \leq \Delta t_o \leq 1.0$)
	ΔPo	42-46	FP	Change in probability due to occurrence of impacting event ($-1.0 \leq \Delta Po \leq 1.0$)
	Δt_{no}	47-51	FP	Change in time due to non occurrence of impacting event ($-1.0 \leq \Delta t_{no} \leq 1.0$)
	ΔP_{no}	52-56	FP	Change in probability due to non occurrence of impacting event ($-1.0 \leq \Delta P_{no} \leq 1.0$)

Card type 7 --- one card

Variable	Card cols.	Type	Definition
Data type	1	I	'3'
IREF1	3-10	A/N	"END DATA'

*** Note - IREF1, IREF2 must correspond to event names input on type 5 cards

CHANGE IN TAPE/DISK NUMBERS

If for some reason it is desired to use tape/disk units other than 10, 11 for the storage of intermediate information, the following change is required in addition to that made on input data card type 4.

change --- sequence line number 000020

Replace 'TAPE10, TAPE11' with tape/disk unit numbers selected.

NOTE: The use of units 5 (input), 6 (output), and 9 (storage) are mandatory.

STORAGE ALLOCATION

The dimension of two arrays in the program determine the number of central memory words required for a specific job. Since it is desirable to minimize this storage requirement, it is recommended that the size of arrays 'IOC' and 'X' be limited to that sufficient to execute the program. Refer to the program listing for the location of the four (4) changes required.

Change #1 --- sequence line no. = CRIMP 20

DIMENSION IOC(N)

Change #2 --- sequence line no. = CRIMP 21

LIMIT = N

'N' will have the value (NV*NV) where
NV = no. of events, this job

Change #3 --- sequence line no. = CRIMP 645

DIMENSION X(M)

Change #4 --- sequence line no. = CRIMP 646

LIMIT = M

'M' will have the value equal to the maximum of four quantities ---

1) NE(13+NV)

2) 12NV $\frac{NV(NV-1)}{2}$

3) 36 NV

4) 36 NE

where NV = no. of events, this job
NE = no. of runs, this job

JOB CONTROL CARDS

A. Job Card: For a complete description of the job card, refer to 'ASD Computer Center, CDC NOS/BE User's Guide, pages 2-1, 2-2'. It is the intent here to provide the user with an estimate of three items which appear on the job card:

1) Central processor (CP) time, decimal seconds
2) Input/Output (IO) time, decimal seconds
3) The number of central memory words required in <u>octal</u>

- CP time estimate

time, sec.	NV
30	50
45	100
60	150
90	200

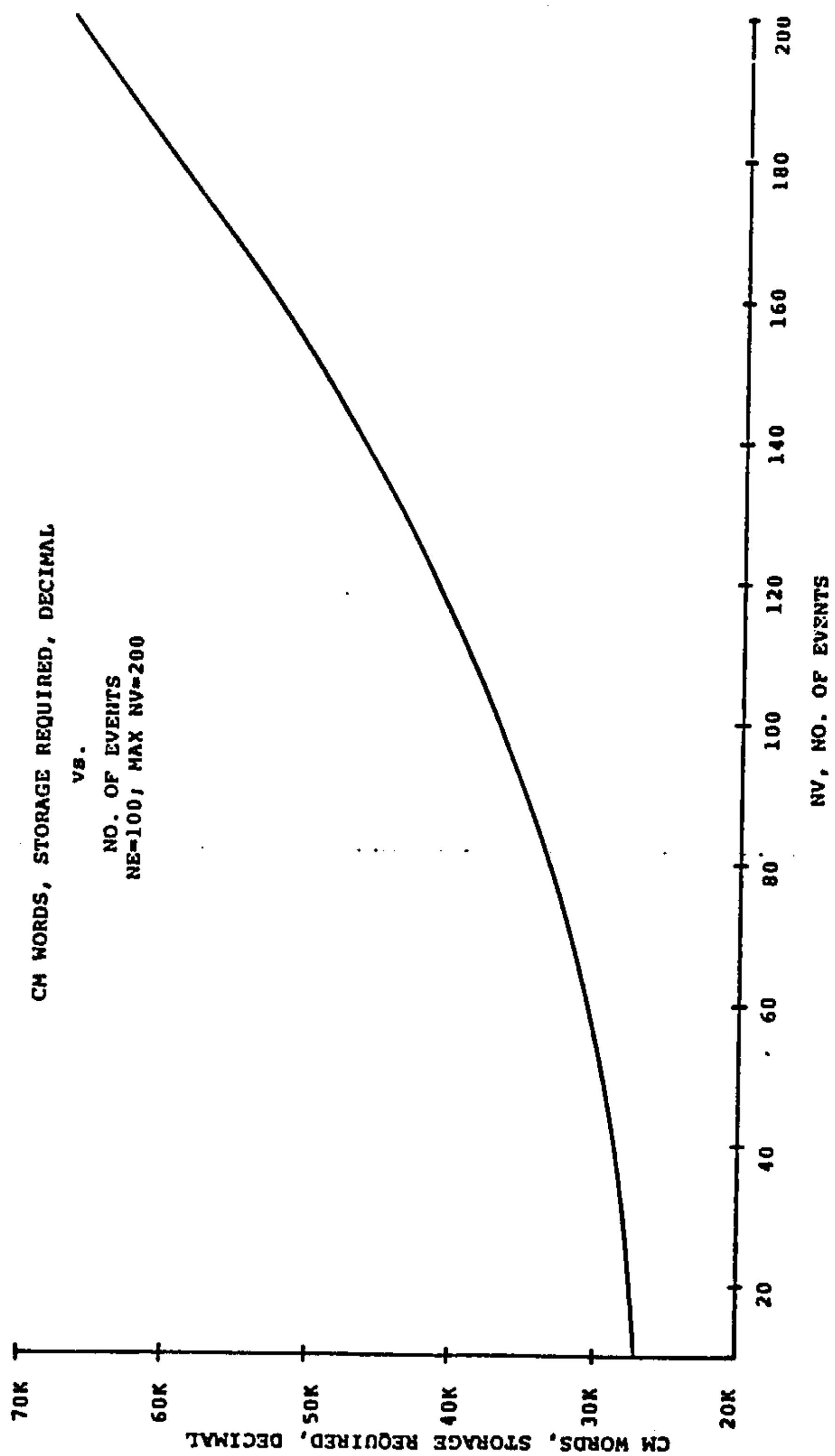
- IO time estimate -- use 60 seconds

- CM words estimate -- use the plot on the following page. The curve represents the minimum storage required as a function of NV, the number of events. To be on the safe side, add 500 words to that value as read from the plot. Note that this figure must be converted to octal, prior to keypunching on the job card.

B. Source Program on cards:

The job control cards required to compile and execute the program for this case are as follows:

1. JOB CARD
2. FTN.
3. LGO.
4. END OF RECORD CARDS (7/8/9 punched in column 1)
5. END OF JOB CARD (6/7/8/9 punched in column 1 -- must be an <u>orange</u> card)


CM WORDS, STORAGE REQUIRED, DECIMAL
vs.
NO. OF EVENTS
NE=100; MAX NV=200
70K
60K
50K
40K
30K
20K
CM WORDS, STORAGE REQUIRED, DECIMAL
20
40
60
80
100
120
140
160
180
200
NV, NO. OF EVENTS

C. Source Program on disk:

The job control cards required to compile and execute the program for this case are as follows:

1. JOB CARD
2. ATTACH, OLDPL, CLSTR2, CY = 1.
3. FTN (I=OLDPL, R=3, PL = 20000)
4. LGO.
5. END OF RECORD CARD (7/8/9 punched in column 1)
6. END OF JOB CARD (6/7/8/9 punched in column 1 --- must be an orange card)

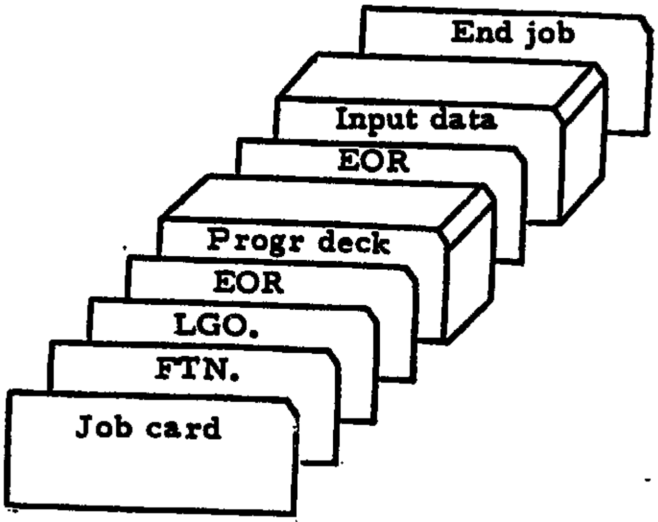
OLDPL = local file name, this job

CLSTR2 = permanent file name

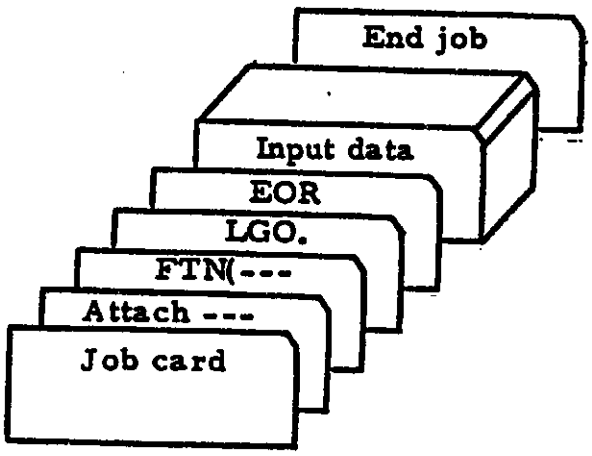
CY = cycle number

DECK SET-UP

Program on cards, input on cards:



Program on disk, input on cards:



PROGRAM OUTPUT

A. Standard output -- these items will always appear as a result of the program running to a 'normal' completion.

Item 1 -- job title, date and time job was processed, the initial random number

Item 2 -- the storage required and allocated for the 'IOC' array

Item 3 -- the tape/disk unit numbers assigned (other than 5 and 6)

Item 4 -- table of relative frequency of occurrence of events by year -- the total probability of occurrence appears in the column following the last year

Item 5 -- the storage required and allocated for the 'X' array (as used for run clustering)

Item 6 -- stage of clustering, run number, number of subjects in cluster, variance and cluster centroid for run clustering

Item 7 -- segmentation of the criterion values for run clustering

Item 8 -- the tree structure in tabular form for run clustering

Item 9 -- the tree structure in graphic form for run clustering

Item 10 -- the JACCARD COEFFICIENT, lower triangular similarity matrix

Item 11 -- the storage required and allocated for the 'X' array (as used for event clustering)

Item 12 -- segmentation of the criterion values for event clustering

Item 13 -- the tree structure in tabular form for event clustering

Item 14 -- the tree structure in graphic form for event clustering

Item 15 -- the RUSSELL AND RAO COEFFICIENT (probability of joint occurrence), the lower triangular similarity matrix

Item 16 -- histogram; deviation of individual cluster centroid from the centroid of all clusters

Item 17 -- the message ***** NORMAL TERMINATION ***** if the program has executed and terminated in 'normal' fashion

B. Input Summary

If the input print option has been selected (see data preparation, card type 3), the following information will appear in addition to the standard output -- number of runs, number of events, time horizon, the initial year, a listing of the event and impact data cards, and a tabulation of the event names.

C. Error messages

Two types of errors may occur during program execution: type 1 errors -- those resulting from erroneous or mis-punched data, and type 2 errors -- those which may occur only as the result of a compiler error or computer malfunction. Type 2 errors have a very minute probability of occurring, but are checked for in the program to prevent needless expenditure of processing time on faulty data. For type 2 errors, consult a programmer.

Type 1 errors

1. 'IOC ARRAY -- STORAGE REQUIRED = XXXXX,
   STORAGE ALLOCATED = XXXXX

If the storage allocated < storage required, the program will terminate at this point. To correct error, rerun program after increasing dimension of the 'IOC' array.

2. 'YEARS GT 10 FOR EVENT = AAAAAAAAAA'

The program will not accept more than 10 years of data (10 conditional probabilities) for a specific event. When this error is encountered, the number of years for the event is set = 10 and processing continues.

3. 'CONDITIONAL PROB NOT = 1 FOR EVENT AAAAAAAAAA'

The sum of the conditional probabilities for a specific event must always = 1.0. Program termination occurs as a result.

4. 'TYPE 2 CARD --- IREF = AAAAAAAAAA NOT IN LIST'

An attempt has been made to input data pertaining to an <u>impacting</u> event not previously defined on an event card. The result is program termination.

5. 'TYPE 2 CARD --- IREF1 = AAAAAAAAAA NOT IN LIST'

An attempt has been made to input data pertaining to an <u>impacted</u> event not previously defined on an event card. The result is program termination.

6. 'NO EVNTS INPUT = XXXX
NO EVNT CDS READ = XXXX'

The number of event cards read does not correspond to the number of events input on card type 3. Result: termination.

7. 'REQUIRED STORAGE = XXXXX
ALLOCATED STORAGE = XXXXX'

If the storage allocated < storage required for the 'X' array, the program will terminate at this point. To correct error, rerun program after increasing dimension of the 'X' array.

8. 'ERROR WHILE BACKTRACKING FROM KLAST XXXXXX
K WAS FOUND OUT OF RANGE
K = XXXXXXX'

Error occurs in subroutine 'TREE', program attempts to correct error by recomputation.

Type 2 errors

1. 'SRT SELYR --- IY = XXX ISUM = XXX I = XXX'

In selecting a year for an event, the sum of the conditional probabilities now exceeds 1.0.

2. "SRT SELYR --- ISUM = XXX IY = XXX'

In selecting one event from a set of events, the sum of the probabilities for all events in the set now exceeds 1.0.

3. 'YEAR = XXXX CUR YR = XXXX FOR EVENT = AAAAAAAAAA'

Indicates that a year has not been selected in the proper order.

4. 'SRT SELEVT --- ICURYR = XXXX NO EVENT SELECTED = XXX'

Indicates that an event has not been selected in the proper order.

APPENDIX A - Sample Input

```
TEST CASE
    29506791471
  100     6 1980 2005    1    78
   10   11
1 TESTEVENT1                   0 1980  1 0.50
1 TESTEVENT2                   0 1990  1 1.00
1 TESTEVENT3                   0 1985  1 0.50
1 TESTEVENT4                   0 1995  1 1.00
1 TESTEVENT5                   0 1985  1 0.50
1 TESTEVENT6                   0 1995  1 1.00
2 TESTEVENT1 TESTEVENT2
2 TESTEVENT3 TESTEVENT4
2 TESTEVENT5 TESTEVENT6
```

The listing of the computer program has been deleted to reduce the size of this report. Any persons desiring a card deck for the program can obtain one for the cost of keypunching from:

Technological Forecasting Group
Research Institute (KL462)
University of Dayton
Dayton, OH 45469