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

EXECUTIVE SUMMARY

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16. Abstract

A cross impact model of the U.S. telecommunications system was developed. For this model, it was necessary to prepare forecasts of the major segments of the telecommunications system, such as satellites, telephone, TV, CATV, radio broadcasting, etc. In addition, forecasts were prepared of the traffic generated by a variety of new or expanded services, such as electronic check clearing and point of sale electronic funds transfer. Finally, the interactions among the forecasts were estimated (the "cross impacts"). Both the forecasts and the cross impacts were used as inputs to the cross impact model, which could then be used to stimulate the future growth of the entire U.S. telecommunications system. By varying the inputs, technology changes or policy decisions with regard to any segment of the system could be evaluated in the context of the remainder of the system. To illustrate the operation of the model, a specific study was made of the deployment of fiber optics throughout the telecommunications system.

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1. INTRODUCTION

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 as well as other decisions. In making decisions about space communications R&D, NASA administrators wish to choose 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.

2. APPROACH

The approach to developing a methodology to aid in decision making about space communications technology involved three aspects: forecasts of the growth and development of each major element of the U.S. telecommunications system; identification of the interactions among these major elements of the system; and development of a computerized model of the system which incorporates these forecasts and interactions. The resulting computer model can then be used to determine the consequences of introducing specific changes in the telecommunications system. Evaluation of the consequences revealed by the model can provide a guide to the relative desirability of various possible changes in the system.

There is no single deterministic future for any of the elements of the U.S. telecommunications system. From the viewpoint of the present, the future of that system can only be described in terms of a set of events, some of which may occur and some of which may not occur. In some cases, deliberate policy decisions will be made to cause certain events to occur and to prevent others from occurring. At the present, however, it is not possible to know what the outcome of those decisions will be. In other cases, a deliberate attempt may be made to cause certain events to occur, but the attempt may be partially or completely unsuccessful as a result of technological shortcomings, erroneous cost estimates, misreading of the demands of the market, etc. At the present, it is not possible to know whether these attempts will be successful or not. Thus, a forecast for any of the elements of the U.S. telecommunications system cannot specify a single trajectory for growth and development, but must include events representing policy or decision alternatives, and must include events representing possible alternative outcomes of various ventures with less than certain prospects of success.

The forecasts which were developed for each major element of the U.S. telecommunications system are discussed in Section 4 of this Summary, and in more detail in the main report. These forecasts reflect the various inherent uncertainties and alternatives specific to each of the elements of the system. For each alternative, an attempt is made to identify the factors which will influence the course of development, or affect the choice of options. Where technological or market uncertainties exist, an attempt is made to estimate the likelihood of occurrence of each of the possible outcomes. Each forecast can then, in general, be described as a set of events. Each event is assigned a date of occurrence (or a time span within which it may occur), and a probability of occurrence. In expressing the forecasts in this manner, full recognition is taken of the inherent uncertainties affecting future growth and development of the telecommunications system. Instead of a single deterministic trajectory for the future development of each element of the telecommunications system, the forecast for each element is expressed in terms of branches and alternatives. The various branches are identified with specific choices or alternative outcomes which determine the branch to be followed.

The future development of any element of the telecommunications system is affected not only by uncertainties and alternatives within that element, but also by occurrences in other elements as well. There are interactions among the elements, arising from the relationships of competition and complementarity among those elements. For instance, successful provision of some service by one element of the system may preclude the provision of that same service by another element of the system. Thus, events occurring (or not occurring) in one element of the system may affect events in some other element of the system. In particular, a change deliberately introduced in one element of the system may have consequences not only within that element, but in other elements as well. Some of these consequences may feed back upon the element in which the change was introduced either to enhance or to partially offset the effects of the original change.

Some of the more important interactions among the elements of the system are discussed in Section 5 of this Summary, and all interactions of any significance are discussed in the main report. These interactions result in changes in the forecast for one element of the telecommunications system, resulting from the occurrence or nonoccurrence of events in other elements of the system. These changes in the forecast are expressed in terms of alterations in the timing or probability of those events which are impacted.

The computerized model of the telecommunications system had to incorporate the uncertainties inherent in the forecasts of each element of the system, as well as the interactions among elements of the system. In portraying the future development and growth of the entire system, the model had to be able to display the possible branchings and variations in the growth of each major element. A cross impact model was selected as the most suitable form for the computer model of the telecommunications system, since such a model lends itself readily to portraying the growth of a system which is subject to uncertainties and to interactions among its elements.

The concept of a cross impact model is discussed in Section 3 of this Summary, and in considerable detail in the main report. The cross impact model is a relatively new technique which is gradually gaining acceptance as a means of forecasting future changes in complex situations. It is particularly suited for situations in which forecasts for elements of a system are obtained independently, then must be combined to produce a forecast for the entire system. In these situations it is a far more efficient type of model than any of the more conventional alternatives, in the sense that it requires far less computer storage and running time for a model involving a given number of elements and interactions than does any of the more conventional alternatives. This reduction of running time is particularly significant when the model contains probabilistic events. In order to explore the possible alternative outcomes of a situation including probabilistic events, it is necessary to run the model many times. That is, it is necessary to produce a large number of "future histories" or scenarios, with different possible outcomes for the probabilistic events in different scenarios. In the analysis of a specific problem using the telecommunications model, the model was typically run 100 times, utilizing less than 90 seconds of computer time for completion of the 100 runs and analysis of the run results.

Once the model was completed, including the forecasts of events and the interactions among the events, it was run on a test case to demonstrate its utility. The test case selected for analysis was the extensive use of fiber optics. Some of the more significant results of this analysis are presented in Section 6 of this Summary. All the results are presented in detail in the main report.

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3. CROSS IMPACT MODEL

A forecast is a statement about some event to take place in the future. In particular, it is a statement of when the event will take place (either a specific time or a span of time), and a statement about the likelihood of occurrence. The timing and probability assigned to the occurrence of some future event may themselves depend upon the occurrence or nonoccurrence of other events which also lie in the future. Thus, a forecast for a specific event necessarily involves the making of assumptions about whether or not other future events will or will not take place. If these assumptions are invalidated by the occurrence of an event assumed not to occur (or vice versa), the forecast for the specific event may be invalidated, in the sense that the timing or the probability of the event may be altered, or both. Thus, the forecast for a specific event may be "impacted" by the occurrence or nonoccurrence of one or more other events.

The cross impact model is specifically intended to take into account the cross impacts between events included in a forecast. The input to a cross impact model includes the forecasts of specific events, and the cross impacts among these events. The cross impact model depicts the future as an interconnected collection of potential events whose projected probabilities 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.

The use of a cross impact model involves production of a simulated future history or scenario. The earliest event incorporated in the model is selected, and tested for occurrence or nonoccurrence by drawing a random number. Once its occurrence or nonoccurrence is determined, the necessary changes are made in timing and probability of all other events impacted by that event. These changes may include altering the chronological order of events. Then the next event in chronological order is selected and tested for occurrence. This process of selecting events in order, testing them for occurrence, and making necessary adjustments in the timing and probability of the remaining events, continues until all events have been tested. The end result is a single scenario in which some events occur and others do not.

A single run of the cross impact model, producing a single scenario, is of little interest. Instead, the model is run many times (typically 100), using the same set of initial dates and probabilities for the events, but drawing different random numbers for each run. This large number of runs then gives a statistical picture of the future. The collection of runs may be analyzed for frequency of occurrence of individual events, frequency of cooccurrence of pairs of events in the same scenario, and the distribution of times of occurrence for individual events. The computer can, of course, produce these analyses automatically at the conclusion of the set of runs.

These statistical analyses of the set of runs allow the analyst to identify critical events, whose occurrence or nonoccurrence makes a big difference in the subsequent course of events. They also permit the analyst to identify events which are highly sensitive to the influence of the remainder of the events in the model. For instance, a specific event may initially be estimated to have a low probability of occurrence. However, it may receive small but favorable impacts from a large number of other events in the model. As a result, its probability of occurrence may be raised significantly, once it is placed in the context of all these other events, no one of which has a very strong influence.

In addition to the detailed analyses of specific events, it is possible to make more aggregated analyses of the set of runs. Using the technique of "cluster analysis", it is possible to group together runs which are similar in the sense that they show similar patterns of occurrence and nonoccurrence for the events. Clusters of 10 to 15 similar runs can be treated as composite scenarios. These composite scenarios can be described in terms of whether certain events or subsets of events tend to occur more frequently or less frequently than the average for all 100 runs. Thus, a specific cluster may represent a scenario in which one element of the telecommunications system grew more rapidly than the average for all scenarios, while another grew less rapidly. Thus, the scenario could be characterized as being "high" or "strong" on one element and "weak" on another. The analyst would then determine from the scenario itself whether this pattern of events could be traced to any specific occurrences, and whether the pattern had any consequences in terms of its effects on other elements of the system. The important point is that this approach produces scenarios which arise naturally from the output of the cross impact model. In more conventional approaches, the scenarios are imposed on the situation according to some predetermined scheme. This predetermined scheme may miss important scenarios, and it may even result in scenarios which are internally inconsistent. The cross impact model assures that all scenarios are internally consistent, and the use of a statistically sufficient number of runs makes it unlikely that important scenarios will be overlooked.

An important benefit from use of the cross impact model is the identification of "surprise" futures, either favorable or unfavorable. These generally arise from the combination of several unlikely events. These surprise futures are often not apparent in the original set of events because the chains of impacts which give rise to them are too hard to trace manually.

It is important to note that the surprise futures which may be identified, as well as the critical or sensitive nature of specific events, and the altered probability of specific events, are all implicit in the initial set of events and interactions. The model does not, in any way, add to or alter this initial input data. The task performed by the computerized model is to trace out for the user all the consequences which are implicit in the input data, including those which are not apparent because of the complexity of the situation. In particular, the model allows the user to trace out all the consequences of any changes deliberately introduced in the system. This includes not only the initial direct consequences, but the more remote consequences which may involve chains of impacts, or even positive and negative feedback loops. The model aids the user to make better decisions by revealing to him all the implications of the data given it as input.

It should also be noted that the model is programmed as a framework which accepts events and interactions as inputs. That is, none of the elements of the telecommunication system are permanently programmed into the model. This makes it possible to revise the model readily to test alternate assumptions, or to focus on a specific aspect of the system. Adding or deleting events merely requires adding or deleting lines of input data (or punched cards). Altering the timing or probability of an event, or an interaction between two events, simply means replacing one line of input data with another. Thus, the model can readily be used to investigate the significance of differing assumptions about events or interactions, when there is uncertainty or controversy about these assumptions. Any portion of the model can also readily be refined or expanded to provide additional detail when this is of interest.

4. THE FORECASTS

Forecasts were prepared for each of the major elements of the U.S. telecommunications system. These forecasts are given in detail in the main report. Some of the more significant aspects of these forecasts are discussed below.

4.1 Electronic Communications

Substitution of electronic communications for paper has been taking place since the middle of the 19th century, with the advent of the telegraph. For the past three decades, total communications expenditures by the American public have stabilized at about 5% of the Gross National Product (GNP). The share of that total taken over by electronic communications has followed a standard growth curve, as shown in Figure 1. Electronics captured 50% of the total in the 1950's, and has captured an increasing share of

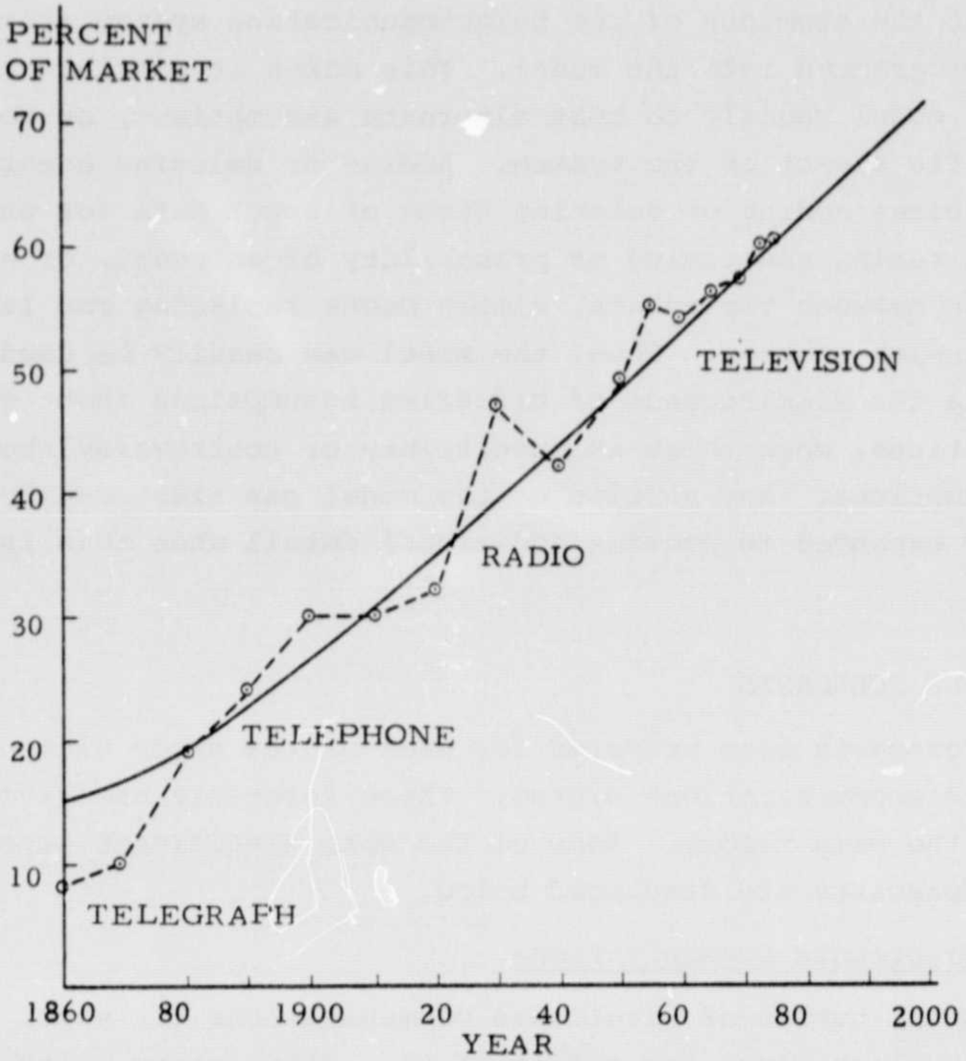

Figure 1. Substitution of Electrons for Paper and Ink in Communications (Based on Revenue Dollar Volume)

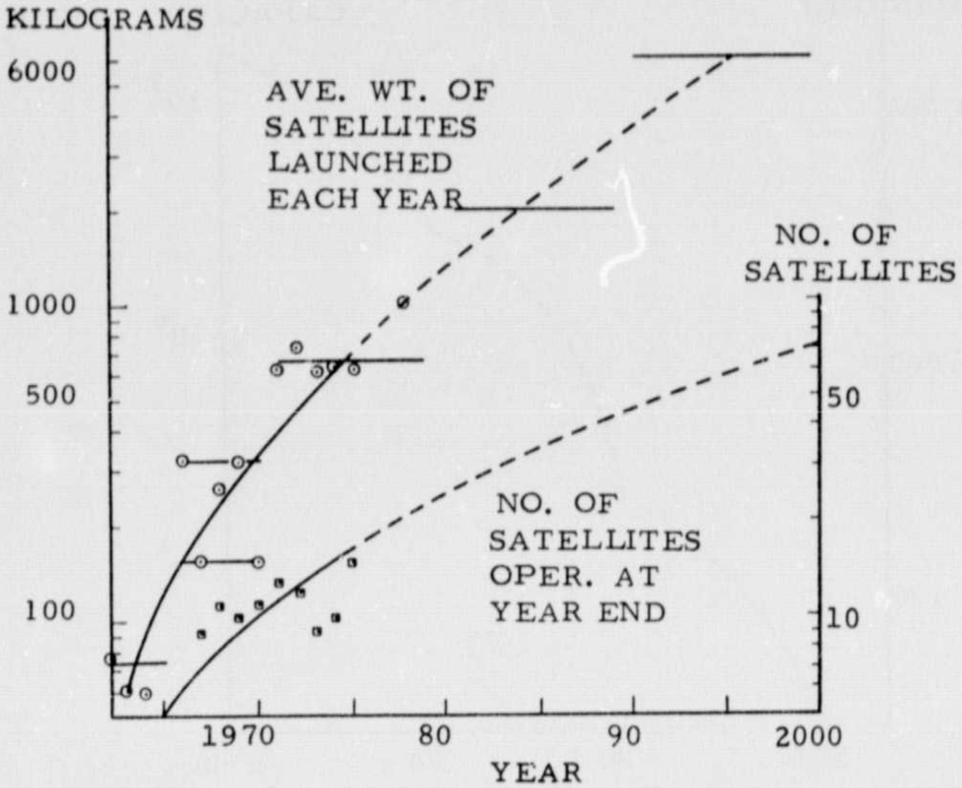

Figure 2. U.S. Communication Satellites

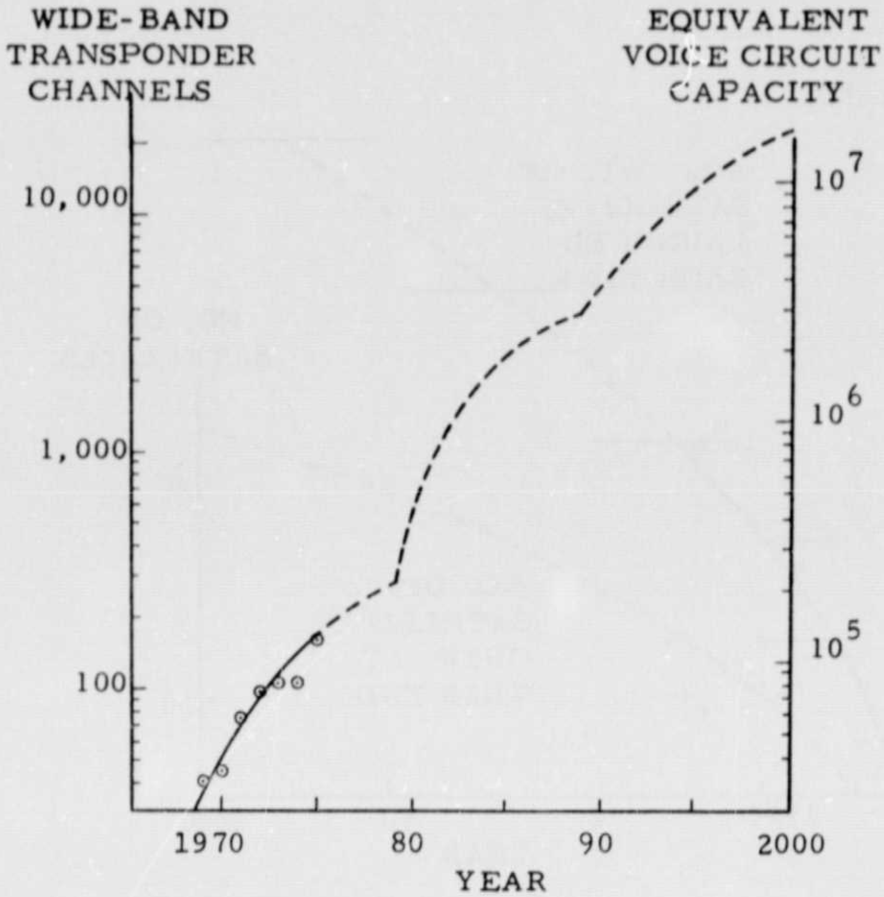

Figure 3. Total U.S. Commercial Communication Satellite Capacity

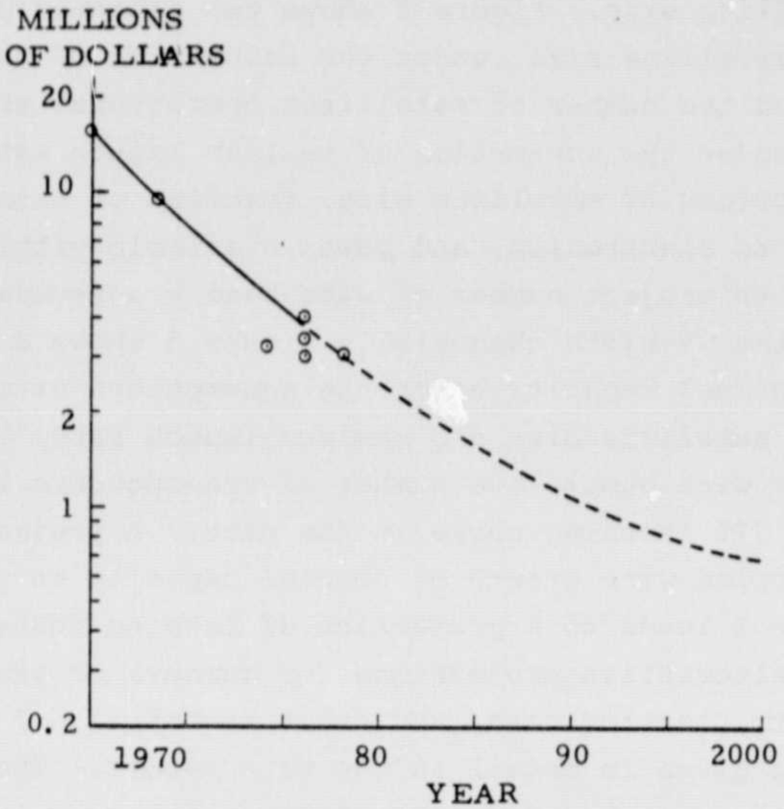

Figure 4. Leasing Cost per Wide-Band Transponder Channel

the market since then. The market share held by electronics is projected to grow as shown in the figure. This projection provides an estimate of the revenues available to pay for electronic communications.

4.2 Satellites

Several alternative projections were made for communications satellites, involving different assumptions about launch rates and growth in satellite size. Figure 2 shows two selected projections: the growth in satellite size, under the assumption of maximum growth rate; and the number of satellites operational at the end of each year, under the assumption of maximum launch rate. On the basis of projections of satellite size, fraction of satellite weight devoted to electronics, and power available within satellites, it is possible to project number of wide-band transponder channels (i.e., equivalent TV-width channels). Figure 3 shows a projection of available channel capacity under the assumptions of maximum growth rate in satellite size and maximum launch rate. The change in leasing cost with cumulative number of transponders in orbit has followed a 77% learning curve in the past. A projection of this curve, coupled with growth of channel capacity at the rate shown in Figure 3 leads to a projection of leasing costs as shown in Figure 4. Alternative projections for numbers of satellites, channel capacity, leasing cost, and other technical and economic parameters, are given in detail in the main report. These alternative projections are based on assumptions of lesser launch rates, lesser rate of growth in satellite weight, etc. The various alternatives are incorporated in the model, with appropriate events and decision points leading to one alternative or another.

4.3 Commercial Television

Growth of commercial television is assumed to be driven by TV revenues, which are projected on the basis of the growth of the economy. Two projections of the number of TV stations are made. The high projection is based on historical growth and the projected growth of TV revenues. The alternative projection depends upon whether (and when) direct TV broadcasting from satellites to householes is introduced.

4.4. Telephone

Three basic projections of the telephone network are made. One is the number of telephones in the U.S., based on historical market penetration coupled with a projection of future population. The next is number of local telephone calls, and the third is the number of long-distance telephone calls, projected on the basis of national income. Projections of numbers of telephone calls are shown in Figure 5. Additional projections for the telephone network include the conversion of local or long-distance equipment to digital transmission, and the conversion of local or long-distance equipment to use of optical fibers instead of wires or microwave links.

4.5 Cable Television (CATV)

Two projections of the growth of CATV are included in the model. Both are based on the same projection of future growth in number of households. The higher growth projection is based on the assumption that market penetration continues at the historical rate. This projection is shown in Figure 6. A lower projection is based on a drop to market penetration at half the historical rate. Other projections for the CATV industry include installation of return channels (from household to head-end of the CATV network), replacement of coaxial cable with optical fibers, and number of CATV systems (which, therefore, demand channel capacity).

4.6 Household Uses

Development and growth of the telecommunications network can to some extent be influenced by use of various telecommunications related devices in households. For instance, the introduction of return channels on CATV was assumed to be triggered by the growth

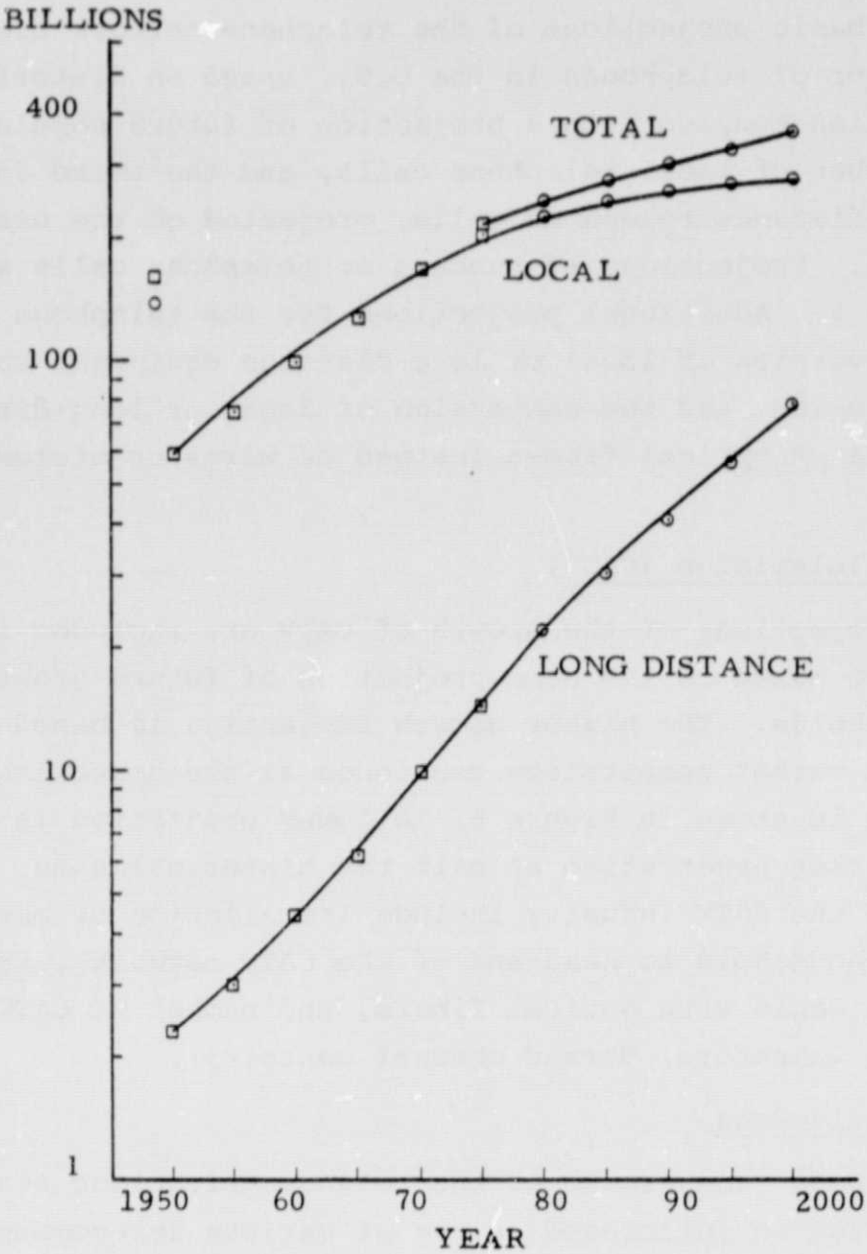

Figure 5. Telephone Calls per Year

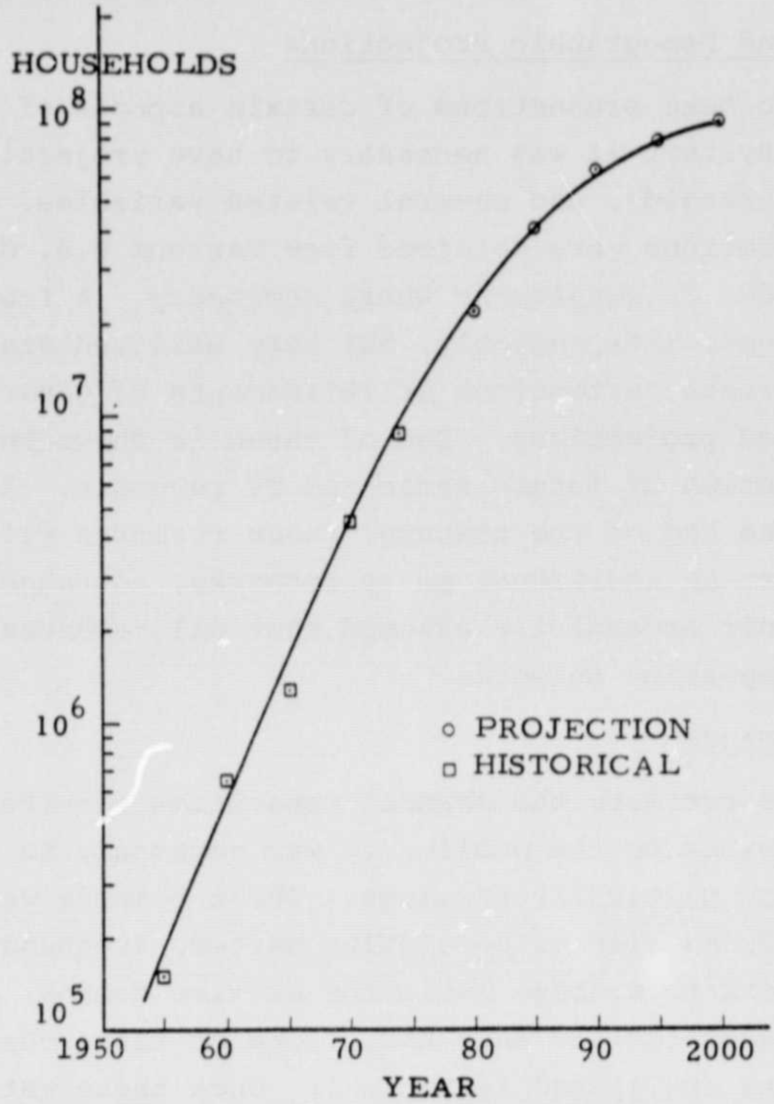

Figure 6. Households with Cable TV

of TV games, giving the CATV operators an incentive to tap the home market for CATV games. Thus, the model includes projections of the market penetration achieved by TV games, CATV games, and videodiscs. The projection of videodisc market penetration is shown in Figure 7.

4.7 Economic and Demographic Projections

In order to make projections of certain aspects of the telecommunications system, it was necessary to have projections of GNP, population, households, and several related variables. In general, these projections were obtained from various U.S. Government sources, extended or supplement where necessary. A few projections were developed independently, but they utilized standard methodology and represent extensions or refinements of Government or privately prepared projections. One of these is shown in Figure 8, which is a projection of future Radio and TV revenues. It will be noted that, by the end of the century, these revenues will be sufficient to support an additional seven networks, although, as noted above, it is not necessarily assumed that all revenues will actually go into supporting networks.

4.8 Traffic Demands

In order to estimate the channel capacities required to provide certain services to the public, it was necessary to estimate total demand for particular services. These demands were based on such factors as size of population served, frequency of service, expected peak to average ratio for service demand, and amount of traffic generated for each use. Some of these channel capacity requirements are listed in Table 1. Once these estimates were generated, they could be combined with market penetration models to estimate the burden placed on the telecommunications system year by year. Perhaps the most significant observation regarding these services is that when the traffic generated is inherently digital, total channel capacity required is quite small even for a widespread service (e.g., electronic check clearing). However, if the service is utilized by a significant

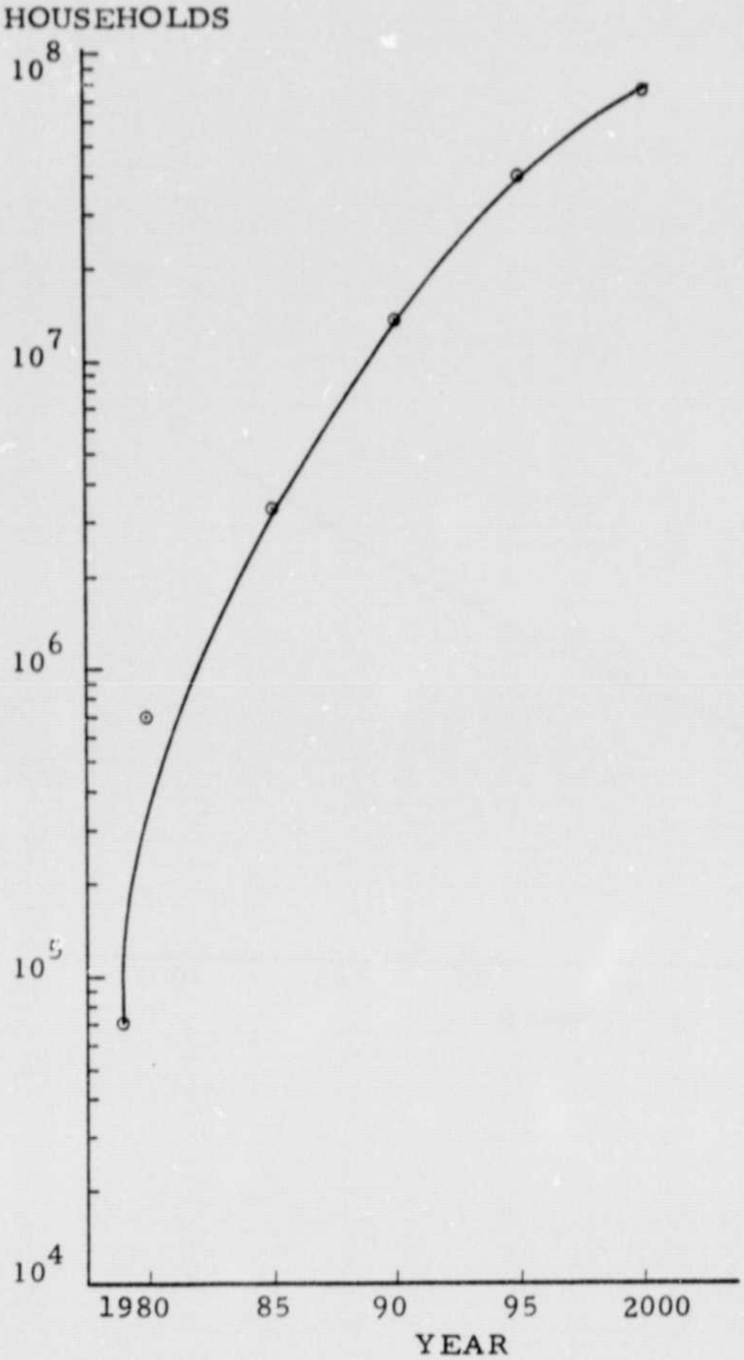

Figure 7. Households with Videodisc

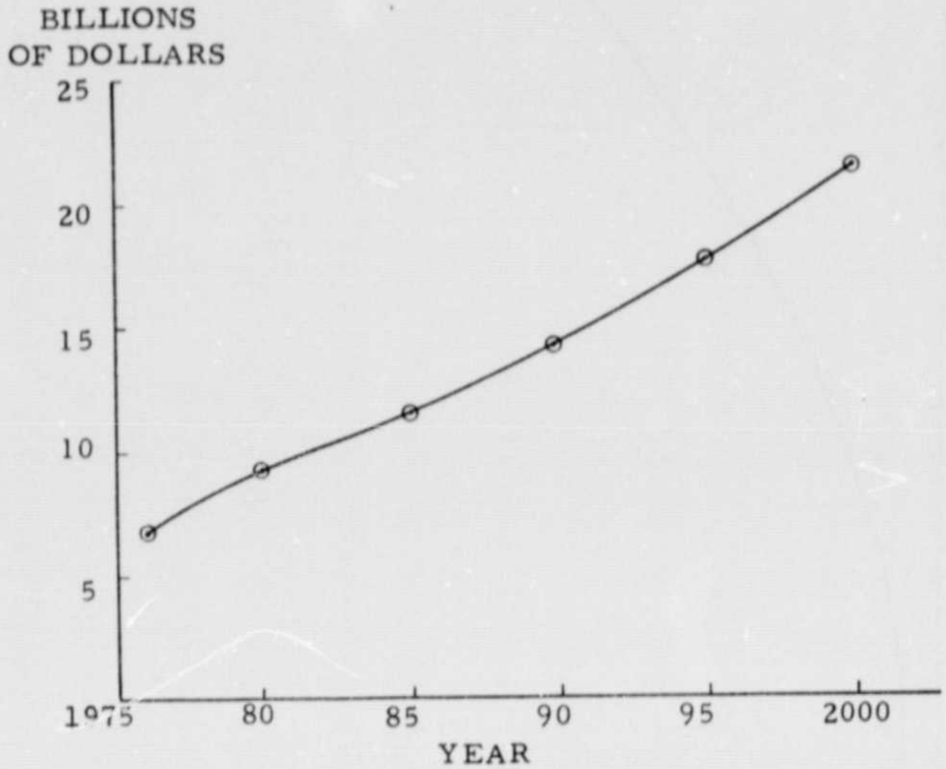

Figure 8. Radio and TV Revenues

TABLE 1

CHANNEL CAPACITIES REQUIRED

Service	Wide-Band Channels
Business Offices/Establishments	
Electronic Paychecks	.093
Check/Credit Card Verifications	.065
Data Base Search	.286
Computer Conferences	18.0
Telecommuting by Employees	35.15
Point-of-Sale Electronic Funds Transfer	.13
Video Conference	30,000.00
Special Business Applications	
Train Location for Traffic Control	.07
Audio to/from Trains	6.68 (89.0)
Audio to/from Trucks	147.0 (1956.0)
Audio to/from Taxicabs	6.67 (88.9)
Banks/Financial Institutions	
Electronic Check Clearing	.503
Electronic Bill Paying	.379
Professional Persons	
Mobile Two-Way Radio	710.0 (9467.0)
Computer Conferences	27.0
Electronic Library	247.0
Households/Invididuals	
Electronic Library	17.0
Computer Conferences	244
Schools/Education	
Access to Data Bases	1.4
Computational Support	57.6
Electronic Library	7,257.0
Computer Aided Instruction	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	20,096.0

NOTE: Wide-band channels in parenthesis indicates the capacity if the service is transmitted in digital form. These figures are not used in analyses in this report.

fraction of the population, even with digital input the channel capacity required can be large (e.g., computer conferences by individuals, for recreation or amusement). When the input is in analog form, particularly voice or graphics, channel capacity demanded can be quite large even when only a small fraction of the population is served (e.g., mobile two-way radio for professional persons). The assumptions behind these channel capacity estimates are detailed in the main report.

4.9 Market Penetration

In developing many of the projections of telecommunications use, it was necessary to estimate market penetration rates. To do this, a number of market penetration models were developed for specific market areas. These were based on the historical market penetration of electronic or telecommunications devices in the same markets. This approach is illustrated in Figure 9, which shows the diffusion of innovations in a particular market, that of small banks. As can be seen, the rate of market penetration was very nearly the same for all three innovations. The model then assumes that a similar innovation in this market would exhibit a similar market penetration rate. Thus, when the time of introduction is forecast, the subsequent market penetration can be projected readily.

5. INTERACTIONS

The forecasts described earlier in this Summary are not independent of one another. Changes in one element of the telecommunication system may cause changes to occur in some other element as well. These interactions among the elements are incorporated into the cross impact model, and represent the mechanism by which changes introduced in one element of the system are transmitted to other elements of the system. Use of the cross impact model involves tracing out the chains of interactions to identify consequences of changes.

A summary of the interactions in the model is shown in Table 2. In this table, the rows represent the major elements of

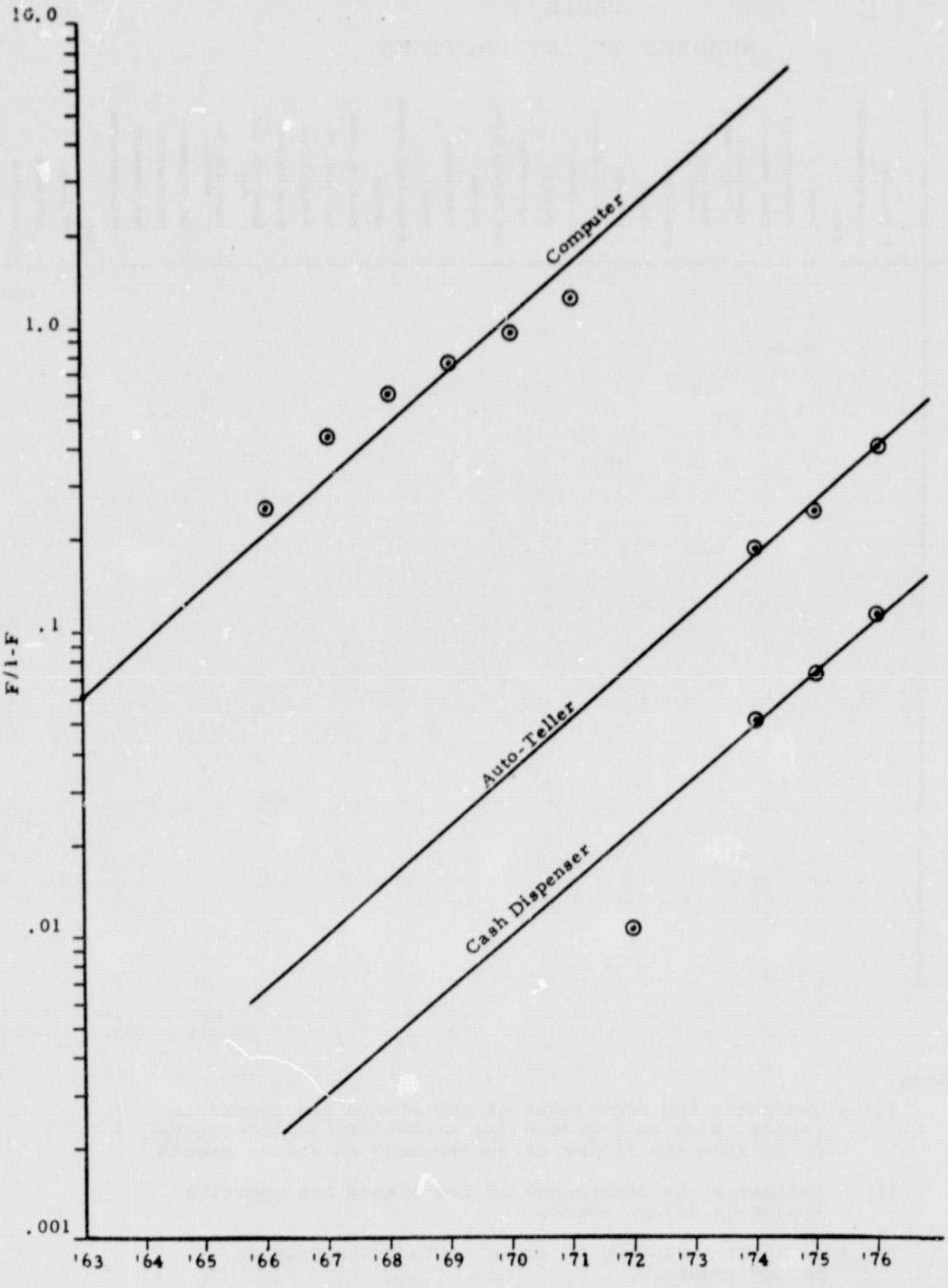

Figure 9. Diffusion of Three Innovations in the Small Banks Market

TABLE 2

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
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. 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		+		+		+													

FROM \ TO	Special Applications:	POS-EFT	Elect. ct. 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																			
Return chan.															+				
Fiber optics																			
Fiber opt. R.C.																			
Fiber opt. local loop																			
Satellites:																			
Weight																			
Channels																			
New technologies				+		+	+	+	+			+						+	+
Local phone:																			
Digital																			
Fiber optics																			
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																			

Keys:

(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.

(2) - indicates the occurrence of row events has negative impact on column events.

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

(4) The first element in parentheses indicates the type of impact caused by the occurrence of row events on column events, while the second element in parenthesis indicates the type of impact resulted from the non-occurrence of row events on column events.

the telecommunications system, and some of the more important subelements. The columns are the same elements and subelements as the rows. Interactions are shown by entries of "+" or "-" in the cells of the table. An entry means that the row item affects or impacts upon the column item. Some selected impacts are discussed briefly below. All the impacts are discussed in detail in the main report.

5.1 Satellite Channels

Certain telecommunication services require satellite communications facilities. Traffic volume estimates and alternate market penetrations of these services are examined in this study. The number of satellite channels available could be increased by large satellites (2000kg and 6000kg satellites) before the year 2000. Satellite orbit slots will become a limiting factor in extending the overall satellite communications capacity around the year 2010 if the demand for satellite communications services follows the baseline projection. Advanced satellite communications technologies have to be implemented by then in order to enlarge the total satellite communications capacity.

Advanced technologies considered in this study include digital coding methods with a compression factor of 2, 3 or 4, polarization technique, spot beam technology, and combinations of digital coding method and polarization technique. An increase by a factor of 4 could be achieved by those advanced satellite communication technologies.

Several satellite communication applications such as computer aided instructions in schools and households, electronic library services for schools or professionals, business video conferences, and special broadcast TV are not feasible until there is sufficient capacity available. Details of the requirements of advanced technologies for satellite communication applications are discussed in the main report.

5.2 Fiber Optics

Introduction of fiber optics into any of the four major elements where this technology has application, namely the local telephone network, long-distance telephone channels, Cable TV distribution systems and Cable TV return channels will have a favorable impact on the others. That is, successful demonstration of the application of fiber optics, as well as the price reductions likely to follow mass production, will encourage further applications. Thus, several interactions are shown in Table 2, in which the application of fiber optics in one element of the telecommunications system impacts on the application in other elements of the system. However, some issues of timing arise. Application of fiber optics is expected first in the local telephone system, second in the long-distance channels, and last in CATV distribution systems. Thus, the introduction of fiber optics in CATV is expected to benefit from earlier use in the telephone system, but is unlikely to affect the telephone system much since it is expected to be too late.

Development of the model requires examining all possible pairwise interactions among items in the model, and identifying the significant interactions. These significant pairwise interactions are then incorporated in the model. Thus, all the links in a chain of consequences are incorporated into the model, and if lengthy chains exist, they can be traced out. In the use of the model, all the chains of consequences are traced out automatically and the end results presented to the user. Moreover, because each of the links is specified in the model in terms of a quantitative measure of impact (on timing, probability or both), the model is capable of providing a quantitative estimate of the end result of a chain of consequences, and of combining the effects of several chains of consequences which impact the same event.

The complete model includes 181 events, and about 500 interactions. Thus, on the average each event impacts about 2.8 other events and is in turn impacted by about 2.8 other events. The model is therefore complex enough to adequately reflect the complexity of the U.S. telecommunications system. However, the model is build up from simple pairwise interactions, and is, therefore, not difficult to understand. Any interaction of interest can be identified readily, and other interactions which might be linked to it can also be readily identified.

6. A TEST CASE

Part of the research effort was to demonstrate the use of the model on a specific test case. The test case, selected in conjunction with the sponsor, was the impact of optical fibers in the future U.S. telecommunications system. The time period examined in the simulation study is from 1980 to 2040. Special attention was given to optical fibers' impacts on satellite communications. Brief discussions on the cross impact model for the test case and outputs of the model are presented below.

6.1 Cross Impact Model

A specific cross impact model was tailored from the general model for the U.S. telecommunications system. Major segments in the general cross impact model are television stations, Cable TV systems, local and long distance telephones, and satellite communications. In the corss impact model for the test case, specific optical fiber applications in the U.S. telecommunications system and satellite communications applications were incorporated. The matrix in Table 1 succinctly illustrates the telecommunications system analyzed in the test case. Concise descriptions for fiber optics applications, satellite communications applications, and advanced satellite communications technologies are given in the following material. Details of these and other segments of the U.S. telecommunications system are included in the main report.

Fiber optics technologies are undergoing rapid development. A great deal of uncertainty is involved in projecting the possibility and the pace of fiber optics applications in the telecommunications system. Therefore, results from a sensitivity analysis of fiber optics applications would provide valuable information for decision making concerning future telecommunications system.

6.1.1 Optical Fiber Applications

Fiber optics could be introduced in local telephone loops, long distance call facilities, Cable TV systems, and Cable TV return channels. The possibility also exists for introducing fiber optics into Cable TV systems through available optical fiber local loops owned by telephone companies. We examined three levels of market penetration (10%, 50%, and 90%). In addition, fast and slow schedules of market penetration for each application were provided. A fast schedule is based on a 10-year replacement plan, while a slow schedule takes 20 years for complete replacement of the existing facility.

Three deployment of fiber optics in the telecommunications system (high, low, and normal) were considered in the sensitivity analysis of the test case. Initial probabilities for fiber optics applications were set at 1.0 (certainty) under the high deployment situation at the start of the cross impact model simulation. On the other hand, initial probabilities of occurrence for fiber optics applications were set at zero for the case of low deployment. However, the progress of these fiber optics applications was still permitted under the influence of other segments of the telecommunications system. That is, the probabilities could be changed by impacts from other events. In the normal deployment case, probabilities were set at values considered most likely.

6.1.2 Satellite Communications Applications

Thirteen major satellite communications applications were studied in the test case. They are transportation, two-way mobile radio communications for professionals, electronic library services for professionals, electronic library services in schools, computer conferences in households, computer aided instruction in schools, computer aided instruction for home viewers, public services, business computing activities, electronic mail service, direct broadcast TV, special broadcast TV, and business video conferences. These applications could be classified into three categories. Members of Application Category 1 require the development of advanced satellite communication technologies providing maximum capacity expansion, such as the spot beam technology, the digital coding technique with a compression factor of 4 or higher, or combination of the polarization technology and the digital coding technique with a low compression factor (2 or 3). Application Category 1 covers electronic library services in schools at 50 and 90% market penetration, computer aided instruction in schools and households, business video conferences, and special broadcast TV at levels of 9000 or 13000 channels.

Satellite communications applications in Category 2 are feasible whenever any advanced satellite communications technology is available. Applications in Category 2 include electronic library services in schools at the lowest level of market penetration (10%), two-way mobile radio for professionals at 50 and 90% market penetration, computer conferences in households, and special broadcast TV at lower levels (i.e., 2000 or 6000 channels). The last category of satellite communications application does not need any advanced satellite communication technologies.

The total capacity of satellite communication could reach an artificial barrier around the year 2010 if no advanced satellite communication technology is available at that time and the growth of satellite channel demand follows the baseline projection. The reason is that the allocation of orbit slots for the U.S. will be a crucial factor in the total capacity of satellite communications. The allotment of orbit slot depends on international agreements. However, advanced technologies such as the spot beam technology, the digital coding technique could sufficiently increase the total capacity of satellite communication application to meet most of the demand projected. Large satellites weighing 6000 kg, or geostationary space platforms, are prerequisite for the spot beam technology.

6.2 MODEL OUTPUT

Outputs from the cross impact model reveals that the introduction of fiber optics in the U.S. telecommunications system under different deployments does have significant impact on the entire communication system in general, and the satellite communications segment in particular. Average aggregate demands for satellite communication channels for high and low deployments of fiber optics are presented in Figure 10. The figure indicates that a larger number of satellite channels is associated with the low fiber optics application case, while a smaller number of satellite channels is demanded under the high deployment of fiber optics in the U.S. telecommunications system. Final numbers of channels are about 12,000 and 9,000 through the time horizon of the simulation (2040) for the low fiber optics application and the high fiber optics application, respectively.

Statistical tests such as proportion test and Kolmogorov- Smirnov test are employed in the investigation of significantly different behaviors observed under two different deployments. Test results show that computer aided instruction in schools at 10% market penetration level, and fiber optics in Cable TV return channel at 50% market penetration level have distinctly different distribution patterns over years, and their relative frequencies of occurrence are significantly different. Differences in relative frequency of occurrence could be translated into difference in the demand for satellite communication channel.

Satellite Communication Channel Demands

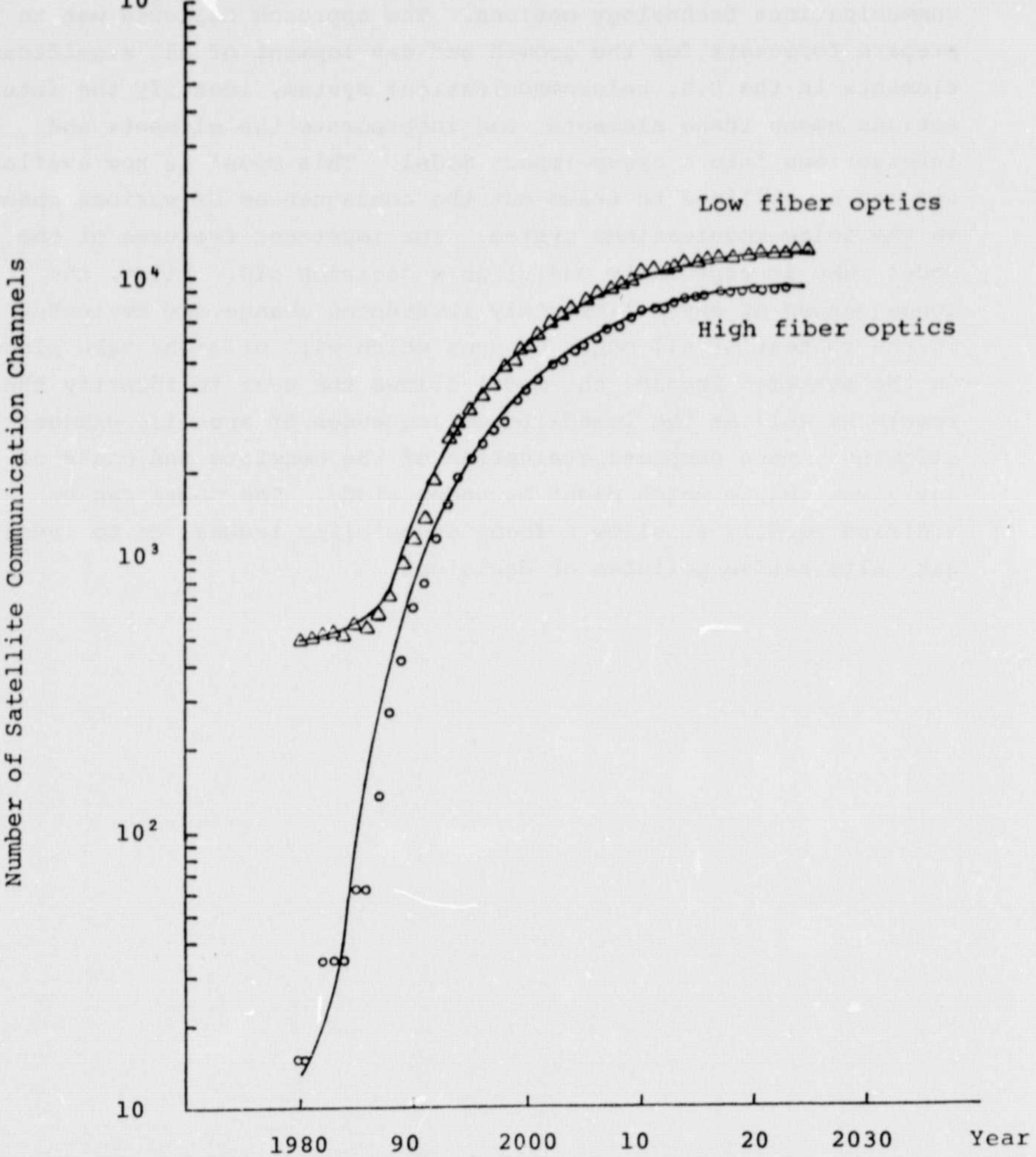

Figure 10. Average Aggregate Satellite Channel Demand for High and Low Fiber Optics Deployment (Average of 100 Simulation Runs Each)

7. RECAPITULATION

This research was intended to develop a methodology which could be utilized by NASA decision makers to help select among space communications technology options. The approach followed was to prepare forecasts for the growth and development of all significant elements in the U.S. telecommunications system, identify the interactions among these elements, and incorporate the elements and interactions into a cross-impact model. This model is now available and can be utilized to trace out the consequences of various changes in the telecommunications system. Two important features of the model make it especially useful as a decision aid. First, the consequences of any deliberately introduced change are evaluated in the context of all other changes which will or might take place in the system. Second, the model allows the user to identify the remote as well as the immediate consequences of specific changes, allowing a more complete evaluation of the benefits and costs of any given change which might be under study. The model can be modified readily to allow a focus on specific issues, or to investigate alternative policies or decisions.