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by
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P. G. Sassone, Associate Project Director
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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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16. Abstract
This research program addresses the questions of (1) whether or not NASA should support the further development of space communications technology, and, if so, (2) which technology's support should be given the highest priority. Insofar as the issues deal principally with resource allocation, an economics perspective is adopted. The resultant cost benefit methodology untilizes the Net Present Value concept in three distinct analysis stages to evaluate and rank those technologies which pass a qualification test based upon probable (private sector) market failure. User-preference and technology state-of-the-art surveys were conducted (in 1975) to form a data base for the technology evaluation. The program encompassed near-future technologies in space communications earth stations and satellites, including the non-communication subsystems of the satellite (station keeping, electrical power system, etc.). Results of the research program include confirmation of the applicability of the methodology as well as a list of space communications technologies ranked according to the estimated net present value of their support (development) by NASA. Volume I is the Executive Summary (21 pages) and Volume II is the Final Report (449 pages).

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FOREWORD

The "Cost Benefits of Space Communications Technology" project under Contract NAS 3-19700 was conducted by the Engineering Experiment Station (EES) at Georgia Tech in conjunction with the School of Industrial Management (IM). The program was administered under Georgia Tech Project A-1739 by the Systems Engineering Division of the Applied Engineering Laboratory.

This report describes the work performed during the period May 1975 through May 1976. The program was managed by the NASA/Lewis Research Center Space Flight Systems Study Office. The NASA Program Manager was Mr. Steven M. Stevenson.

The Georgia Tech Project Director was Mr. Larry D. Holland with Dr. Peter Sassone serving as Associated Project Director. The project was conducted under the general supervision of Mr. Robert F. Zimmer, Chief of the Systems Engineering Division. In addition to the project director, the project team was comprised of the key personnel listed below along with their principal area of contribution.

P. G. Sassone (IM/EES)	Cost-Benefit Methodology
J. G. Gallagher (EES)	Millimeter and Optical Systems
S. L. Robinette (EES)	Applications
F. H. Vogler, Jr. (EES)	Communication Systems/Systems Analysis

SUMMARY

This research program addresses from an economic point of view the questions of (1) whether or not NASA should support the further development of space communications technology and (2) which technology support, if any, should be given the highest priority. The objective of the program is an assessment of the potential benefits from a cost-benefit viewpoint of NASA space communications technology. The developed cost-benefit methodology consists of a qualitative test for appropriateness of government support and a set of three quantitative stages of analysis based on the concept of net present value (NPV). The qualification test for government involvement is based upon probable market failure from such phenomena as externalitites, public good, excessive risk, unemployment, economies of scale, balance of payment, and national security. The overall methodology is sub-divided into three parts: screening, assessment, and ranking. Screening is composed of the qualitative test for government involvement, NPV estimation, and NPV sensitivity analysis. The assessment methodology approximates the probability density function of the net present value whose mean is estimated in the screening methodology. The ranking methodology is based upon several statistics which are measurable from probability density functions.

User-preference and technology state-of-the-art surveys were conducted to form a data base for the technology evaluation. The research program encompasses near-future technologies in space communications, earth stations, and satellites, including the non-communication subsystems of the satellite such as the station keeping, electric power, attitude control, etc.

Results of the research program include the conclusion that the screening, assessment, and ranking methodology provide a consistent, tractable, defensable, and quantitative approach to evaluating potential NASA R & D programs. The five technologies ranking highest in terms of their mean net present value are, in decreasing net present value, as follows:

(1) Millimeter Communications Systems
(2) Solid state power amplifier
(3) Low cost earth station
(4) Multi-beam antenna
(5) Ion engine.

Economic evaluation of the technologies from a cost-benefit viewpoint has shown that certain technologies should be implemented with government support to accrue maximum benefits to the nation as a whole. Based on this analysis, NASA should play an important role in advancing future communications technology.

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SECTION I

INTRODUCTION

This research program, Cost-Benefits of Space Communication Technologies, addresses what is at once a very important practical problem and a very difficult conceptual problem. The practical problem is the decline of the U.S. position of leadership in the world market for space communications technology. The once unchallenged U.S. lead in this area has wavered considerably since the federal government budget cuts of a few years ago which forced the cancellation of most government supported advanced space communication technology development. Other nations, with considerable R&D backing from their governments, have established aggressive programs in space communication systems development and marketing. U.S. private industry has apparently been unable to match the competition imposed by the foreign government-supported communication programs.

The conceptual problem in this research has two aspects. First, while there is widespread agreement that NASA should re-enter this research area and, indeed, is highly qualified to do so, is such work justifiable in terms of widely accepted criteria for government action? Second, assuming a positive answer can be given to the first question, how does one select which of many possible R & D projects NASA should pursue?

The Georgia Tech research team's approach has been to address both of these questions directly. We have maintained the position, buttressed by an apparently strong consensus among economists, that government's proper role is to fill perservering vacuums left by the private sector, not to displace private activity nor to create its own R & D niches. The tell-tale signs of a persevering vacuum are the dual observations that some activity would be in the best interests of society while, at the same time, no private firm is motivated to undertake that activity. The economic theories of externalities and public goods go a long way toward explaining how such seemingly anomalous circumstances may arise. Thus, the mere absence of private sector R & D in some area is <u>not</u> taken as sufficient evidence that government activity is warranted. Rather, it must also be shown that the R & D is, in fact, in the best interests of society <u>and</u> that private sector reluctance is more than a temporary phenomenon. The former is established by the methods of cost-benefit analysis, while the latter bears on the underlying economic characteristics of the R & D activity and its potential market.

The research activity performed under this contract can be divided into three parts: methodology development, data gathering, and methodology applications. The overall methodology is referred to as, simply, the evaluation methodology. As will be discussed, it has three component methodologies: screening, assessment, and ranking.

SECTION 2

COST BENEFIT METHODOLOGY DEVELOPMENT

The identification of input data, the processing of that data, and the interpretation of quantitative results can all be placed under the rubric of evaluation methodology. The methodology in a cost-benefit analysis is as important as, indeed is analogous to, the experimental design in a laboratory study. Both must be designed so that observed results logically support or refute the points being tested. Both must be carefully implemented so actual results are not biased by unknown factors. And both must be carefully documented so that conclusions may be verified by independent reproductions. These are the overriding considerations in the Georgia Tech team's approach to analytic cost-benefit methodology.

The methodology in this study has been shaped by two further considerations: the large number of technology items (hence potential R&D programs) which need to be evaluated, and the peculiar potential impacts that some NASA R&D programs would have on the private R&D sector. With regard to the latter, consideration must be given to whether the potential NASA R&D program would displace a similar private program, or whether it would be in addition to private programs. In the case of displacement, would the NASA Program be undertaken sooner than the displaced private program? If so, would the temporal advantage outweigh the displacement disadvantage? However, to what extent would the NASA R&D, even if it were a displacement, stimulate further private R&D?

The R&D evaluation methodology was developed to meet five criteria. First, the overall methodology must be internally consistent. It was recognized early in the research program, indeed in the program RFP, that the methodology would have to be developed as a series of filters. Since a large number of advanced technologies would have to come under scrutiny, it was recognized that time and resources would not permit a detailed investigation of each one. Hence, a screening of technologies was demanded, where the screening would filter the entire set of technologies and reject the least promising. Only those technologies successfully passing through the screening would be subjected to a formal assessment. Finally, only those technology development programs which proved worthy under the formal assessment would go on to be ranked for implementation priority. Thus, the evaluation methodology consists of three steps: screening, assessment, and ranking. It is clear that these three methodologies which comprise the overall evaluation methodology must be consistent with each other. That is, each should be based on the same conception of what constitutes a "good" R&D program. It would be self-defeating if, for example, projects which failed screening would tend to do very well in a formal assessment. Internal consistency among the three methodologies is achieved by grounding each in the same cost-benefit criterion: net present value. The difference among the steps are accounted for by the level of detail, not by the conceptual approach.

The second criterion is relevance. By this, it is meant that the methodology must properly address the correct research issue, and must lead to quantitative results which logically establish the true value of a specified potential NASA R&D program. Simply put, the methodology must be relevant to the issues. The importance of the formal consideration of this criterion becomes evident when one faces the distinction between the social value of an R&D project and the social value of NASA's performance of the R&D project. Ordinary cost-benefit analysis would address the former. However, the latter is the real issue in this research. The methodology must be so framed as to address the latter issue.

The third criterion is tractability. The methodology must strike the proper balance between realism (thus complexity) and abstraction (simplification). The methodology must account for the salient aspects of the problem, yet remain simple enough to be operational.

The fourth criterion is replicability. The methodology must be consistent with the scientific method: i.e., it must permit the same results to be achieved by different investigators. Thus, as much as possible, the methodology must be based on objective rather than subjective, inputs.

The final criterion is defensibility. The methodology must be theoretically and practically sound. It must prove reasonable to even avowed critics.

These criteria, coupled with the necessity to treat numerous technologies and the complications of government undertaking activities which might be considered to be in the private domain, gave rise to a three-stage evaluation procedure. The three stages, as mentioned, are screening, assessment, and ranking.

2.1 Screening Methodology:

The Screening Methodology has three components: qualification, net present value (NPV) estimation, and sensitivity analysis. By qualification is meant that an attempt is made to determine whether, and to what extent, the technology in question qualifies as a legitimate government research program. Legitimacy is established by reference to the set of characteristics which economists have determined apply to projects more efficiently undertaken in the public, rather than the private, sector. That is, priority is always accorded the private sector because, if competitive conditions are dominant, the private sector will most efficiently pursue the maximum welfare of society. However, certain structural conditions of the economy and/or characteristics of the project itself may intervene to foil the blind beneficience of the competitive economy. In these cases, it may be argued, government is properly involved in the provision of the good.

The NPV estimation is accomplished via an equation which partitions the flow of benefits and costs of NASA's undertaking the project into stages of unequal time length. The stages roughly correspond to periods in the life cycle of the technology. A key parameter in the estimating equation is the "delay factor" which indicates how long private development of the technology would lag its NASA development. This factor results in assigning a NPV of 0 to a project which simply displaces an equivalent private program, and assigns the full project NPV only when the private sector would never undertake the project.

Sensitivity analysis is performed on the parameters of the NPV estimating equation. One at a time, each parameter is varied over ± 50% while all other parameters remain fixed at their most likely values. For technologies which survive screening, the sensitivity analysis highlights the critical parameters deserving most attention in the subsequent, more detailed assessment and ranking methodologies.

2.2 Assessment Methodology:

The assessment methodology involves a more sophisticated use of the basic NPV estimation equation. The equation is linearized by a Taylor expansion and probability density functions (PDF) are determined for the input parameters. A NPV PDF is analytically derived. This PDF not only allows an estimate of the mean NPV, but its distribution as well. In general, for a given mean NPV of R&D programs, lesser variance is preferable to greater variance.

2.3 Ranking Methodology

The ranking methodology acts on those potential R&D projects which survive assessment. Ranking is a two-step process. First, a Monte Carlo simulation of the NPV of the project is performed, resulting in an empirical probability density function and its associated cumulative density function. Since each PDF has a number of statistics associated with it, ranking cannot be reasonably based on a single statistic, such as mean value. Rather, different positions toward risk are parametrically adopted, along with relevant statistics, and rankings are derived for each risk attitude.

SECTION 3

SURVEYS OF USER NEED AND TECHNOLOGY

Contact was established with the communications industry, government agencies, and other entities that provide communications services and who make use of space communications technology in order to ascertain and define their present and future needs. Their technology preferences, demand projections, and estimate of other factors influencing the rate of innovation introduction into their systems were polled. Opinions on the degree of demonstration required for user acceptance of new technology has been sought. Also, a survey of the state-of-the-art of space communications technology has been made in order to relate specific technology items to particular needs and to identify areas of new technology that if developed would best satisfy those needs. Emphasis has been placed on items which have not yet been incorporated into operational systems but which indicate potential benefits. In contacting the appropriate groups, consideration has been given to the total communications system including directly associated ground equipment as well as the space segment. Based on this survey, particular technology items or areas have been specified for cost benefit analysis.

3.1 User Need Survey

The purpose of the user survey was to ascertain and define the needs, choices, and preferences of the providers/users of space communications technology, which would influence the rate of innovation introduction into future satellite communication systems. The survey sought to determine user acceptance of (or resistance to) new concepts, and to measure demand for space communications.

The survey elements consisted of a list of user organizations to be contacted and a set of questions to be asked of each user contacted. The list of user organizations was structured to include providers of satellite communication services (since providers of service are users of the technology) and also users of satellite communication services. The latter category included business, government, and social service agencies.

The questions to be asked in the course of the survey were designed to elicit information deemed to be useful for the cost-benefit study. The structure of the cost-benefit screening methodology itself depended to some extent on the user survey information, while the information required depended on the demands of the cost-benefit methodology.

Users of presently active space communications facilities were unaware of the implications of the new technology. Many of these contacted were immersed in problems common to any new, high technology enterprise during 1975--adequate financing. They were preoccupied with converting existing technology into productive enterprises.

Contact was established with representative members of the satellite communications industry, government agencies, and others who either provide or use satellite communications technology. The initial list assembled for the survey was generated from news items and other references in technical and trade literature and included 60 organizations. Thirteen were providers; 47 were users of satellite communication services. Providers were defined as those organizations which owned a working satellite, or had active applications for licenses before the FCC to own satellites. Users were defined as those organizations which neither owned nor intended to launch satellites. The 47 users included 19 government and non-profit public service organizations and 28 profit-oriented organizations.

Out of the initial list of providers and users of satellite communication technology, 42 were contacted. Eight were providers of satellite communication service; 34 were users. Of the users, 17 were government/ public service agencies and 17 were private corporations. (Table 3.1 lists the organizations contacted.)

3.2 Technology State-of-the-Art Survey

The main objective of this study was to assess the potential benefits of NASA space communications technology. As a part of that assessment, a survey has been made of technology currently available for application, technology in the development stage, and technology in the planning stage. This survey of the state-of-the-art of space communciations technology has considered the total communication system, including directly associated ground equipment as well as the space segment. Correlations have been established between new technology items and the forecasted needs and applications for space communications.

TABLE 3.1

ORGANIZATIONS CONTACTED IN SATELLITE COMMUNICATION USER SURVEY

Providers	Users	
	Government Related Agencies	Private Industry
Amercian Satellite Corporation	Educational Television Center	American Broadcasting Co.
AT & T/GTE/COMSAT	Archdiocese of San Francisco	American Television and Communications Corp.
INTELSAT	Corporation For Public Broadcasting	Cox Cable Communications, Inc.
RCA Global Communications	Educational Television Services	National Data Corporation
CML (IBM/COMSAT)	Georgia Department of Education	Teleprompter Corporatior
Western Union Telegraph Co.	Bureau of Mass Communications	United States Lines, Inc.
National Satellite Service (Hughes)	New York State Department of Education	American Can Company
Western Tele-Communications, In.c	Appalachian Regional Commission	American Trucking Association
	Department of Justic (LEAA)	Home Box Office
	Office of Telecommunications Policy	Muzak Corporation
	Public Broadcasting Service	Prudential Grace Lines, Inc.
	U.S. Postal Service	Canadian Broadcasting Corporation
	Federation of Rocky Mountain States, Inc.	American Petroleum Institute
	Southern Education Communications Association	Coca-Cola Company
	U.S. Geological Survey	Southern Pacific Communications
	Department of Transportation	Telecable Corporation
	Federal Aviation Administration	ITT World Communications
	Maritime Administration of Department of Commerce	
	Medical University of South Carolina	
	American National Red Cross	

A review of related technical reports and articles available in the open literature was conducted by (1) reviewing literature already available in the Engineering Experiment Station staff files, (2) using the technical indices of the Georgia Tech Library, (3) reviewing pertinent literature supplied by NASA/Lewis, (4) monitoring related periodicals, and (5) periodically reviewing the NASA/SCAN abstracts. The relevant articles were copied and filed according to the technology classification structure described below.

A literature review provides a broad basis of information on the related technologies, but current state-of-the-art information is available only through direct contact with those engineers in industries and government agencies currently working with the fast-moving space communications technology. Accordingly, telephone interviews and visits by Georgia Tech personnel were conducted with several companies and agencies. Space communication industry facilities visited during the technology survey include Scientific-Atlanta, Inc., Westinghouse (Baltimore), General Electric (Valley Forge, Pennsylvania), Watkins Johnson (San Francisco), Comsat Laboratories (Clarksburg, Maryland), Varian (San Francisco), Aerospace Inc., TWR, Aeronutronic/Ford, Lockheed Missile and Space Division, AYDYN Energy Systems, Hughes Space and Communication Group, and Hughes Electron Dynamics Division. Government agencies visited included U.S. Air Force SAMSO, NASA/Ames, and NASA/Goddard. In addition to the visits at these facilities, later telephone conversations were held with these "experts" to discuss specific technologies and to solicit opinions as to parameter values for the cost-benefit analyses.

A technology classification structure (TCS) was developed for orderly handling of technical literature and interview documents. The TCS is as shown in Table 3.2, and serves as an outline for the major portion of this section. Subsection 8.2 of the project report [1] contains a detailed listing of many sub-technologies and devices classified according to the structure.

Results of the user survey and the technology survey have been combined to select a set of conceptual technology systems which will meet the near future user needs by incorporating technical innovations. These conceptual systems are then analyzed by the cost-benefit methodology developed in Section 1 through 5 of the project report [1]. The selected conceptual

TABLE 3.2

TECHNOLOGY CLASSIFICATION STRUCTURE (TCS)

- I. Ground Station
    - A. User Connection
    - B. Modulation Techniques
    - C. Receiver/Transmitter
    - D. Antenna
    - E. Propagation Media
- II. Launch and Injection
    - A. Launch
    - B. Transfer Orbit
    - C. Synchronous Orbit (Satellite Locations)
- III. Satellite
    - A. Structure
        - 1. Station Keeping
        - 2. Attitude Control
    - B. Support
        - 1. Electric Power
        - 2. Thermal Control
    - C. Communication Equipment
        - 1. Antenna
        - 2. Transponder

systems range from ground station items to satellite subsystems to total communication systems. They have been selected so as to be representative of the total group of space communication technologies. The conceptual systems technologies are as follows:

- **Low Cost Earth Station Receiver Technology**
- **Ion Engine Technology**
- **Millimeter Communication System Technology**
- **Laser Communication System**
- **RF Attitude Sensor**
- **Satellite Solid State Power Amplifier**
- **Multibeam Antennas**
- **Advanced Solar Arrays**
- **Adaptive Heat Pipes**

Each of these conceptual system technologies is analyzed in Sections 11 through 14*, and a description of the concepts and the mechanisms of the benefits are given there. Ion engine technology is analyzed in Section 11; low cost earth station technology is analyzed in Section 12; and the remaining seven technologies are analyzed in Section 13. Section 10 describes the baseline scenarios used in application of the methodology to the conceptual systems.

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* All section references in this Executive Summary refer to the main project report [1].

SECTION 4

ASSESSMENT OF SELECTED TECHNOLOGIES

4.1 Methodology Implementation

Application of the screening methdology produces both the estimated NPV of the proposed technology development program and a graphical sensitivity analysis of the NPV with respect to each input parameter. In the assessment methodology, each of the screening input parameters is supplemented with an estimate of the range of parametric values in either standard deviation of the NPV of the proposed technology development program. This estimate assumes a Gaussian NPV distribution. (This is an assumption which can be intuitively argued from the law of large numbers.) The ranking methodology is a comparison of key parameters of the NPV cumulative distribution functions (CDFs) for the individual technology development programs. This CDF is generated for each technology being ranked by a Monte Carlo simulation which utilizes either a Beta or a Gaussian random number generator for selecting input parameters of the NPV equation and repeatedly evaluates the NPV for the random samples of input parameters.

The Monte Carlo simulation used in the ranking process produces a sample-estimate NPV CDF; the analytic estimation of the CDF's standard deviation (σ) calculated in the assessment methodology assumed a Gaussian CDF. The Monte Carlo simulation requires significantly more computer time than does the analytic (assessment) method. Application of the Chi-squared confidence test to specific examples during this project has indicated that the Monte Carlo simulation results are close to being Gaussian such that the analytic estimation is generally a valid approximation.

Since each stage of the quantitative cost benefit methodology is an evaluation of the NPV of NASA-induced early technology development, each methodology requires estimation of the same parameters (but to varying degrees of specification). The overall methodology not only has commonality between its three parts, but also is intentionally formulated for the maximum commonality in its application to widely varying technologies. This commonality is accomplished in the computer programs by use of a NPV model with four generalized phases of the scenario: (1) basic R&D (NASA), (2) applied R&D (industry), (3) prototype development, and (4) operation. Input data for each methodology includes (a) the probability of going into the phase, (b) the time duration (length) of the phase, (c) the annual costs of the phase, and (d) the annual benefits of the phase. In addition, one specifies the discount rate to be used in the analysis and the expected delay time in development of the technology without NASA efforts. The assessment and ranking programs also require specification of ranges for these variables.

By allowing the benefits of the technology development program to be entered into the methodology models as an estimate of the annual benefits during the operational phase, one can use the same basic methodology for all technologies even though the form of their benefits may be radically different. Estimation of the annual benefits for technology development is made separately in the analysis of each technology by methods appropriate for the technology.

4.2 Summary of Screening and Assessment Results

Screening and assessment methodologies have been applied to nine space communication technologies in Sections 11, 12 and 13. The assessment methodology was applied to each example technology here in order to allow investigation of the consistency of screening and assessment; normal application would result in assessment of only a higher-scoring subset of the screened technologies.

The nine space communication technologies analyzed above are listed in Table 4.1 in decreasing order of screening scores, along with their screening scores (estimated NPV) and their NPV standard deviations as calculated by the approximate Gaussian technique of the assessment methodology. It can be seen from this table that the three top-scoring technologies (millimeter, solid state power amplifier, and low cost earth station) have estimated NPVs approximately an order of magnitude greater than the lower-scoring technologies. The millimeter communications technology is estimated to have a $24 million NPV as a result of (1) its significantly increased channel capacity and (2) its long delay time for non-NASA development. The latter factor follows from the very large investment required for development and flight demonstration of the millimeter technology. Solid state power amplifier (14 GHz) technology scored well as a result of the low estimated development cost and associated satellite useful-lifetime extension. The relatively high screening score for the direct demodulation receiver technology for low cost earth stations resulted from the anticipated large number of applications.

TABLE 4.1

TECHNOLOGY SCREENING AND ASSESSMENT RESULTS

Technology	Screening Score NPV(M$)	Assessment Standard Deviation (M$)
1. Millimeter Communications System	23.8	11.5
2. Solid State Power Amplifier	22.5	5.6
3. Low Cost Earth Station	10.9	2.1
4. Multibeam Antenna	4.0	1.1
5. Ion Engine	3.2	0.8
6. Adaptive Heat Pipe	1.8	0.5
7. RF Attitude Sensor	1.7	0.4
8. Laser Communication System*	1.1	2.7
9. Advanced Solar Array	0.5	0.1

*Laser system data based upon use of approximate break-even benefits.

Midway in the screening score range are the satellite multibeam antenna and ion engine technologies. The multibeam antenna technology score was held down by the relatively large development cost, while the ion engine technology score was lowered by the small estimated delay time without NASA support. The score of the laser communication system is not particularly significant since it is based upon an equivalent annual benefit selected near the break-even value in the absence of quantified benefits. It should be noted that the sensitivity plots of Appendix II can be used to recompute the screening score for a change in estimated value of one or more screening input parameters.

In addition to the screening scores, Table 4.1 also contains the approximate (Linearized Gaussian) standard deviation of the technology project NPVs determined by the risk analyses in the assessment methodology. Figure 4.1 shows the Gaussian PDF and CDF curves as functions of mean (μ) and standard deviation (σ). By using the screening score and standard deviation (assessment) from Table 4.1, one can sketch the approximate NPV, PDF and CDF for each of the technologies to gain additional insight into the likely outcomes of the technology development projects. A large standard deviation, relative to the mean, indicates a high degree of uncertainty or difference of opinion among the "experts" polled for the input parameters; it is inversely proportional to the confidence one has in the screening prediction of project value.

4.3 Summary of Ranking Results

Our methodology to this point results in each technology being characterized by its NPV PDF which cannot be adequately summarized by a single statistic. Rather, each PDF exhibits a number of potentially equally interesting statistics, e.g., mean, mode, minimum, maximum, standard deviation, range, PROB(NPV>K)(K=constant), size of confidence intervals, etc. In general, it is one's attitude toward risk which influences which is the most useful ranking statistic.

Following the concept of a risk spectrum, the nine technologies can be ranked according to statistics which appear to capture the sense of the spectrum points. These points, their associated statistics, and the corresponding rankings are presented in Table 4.2. Five technology rankings have been developed, which one is best? The Georgia Tech research team would opt

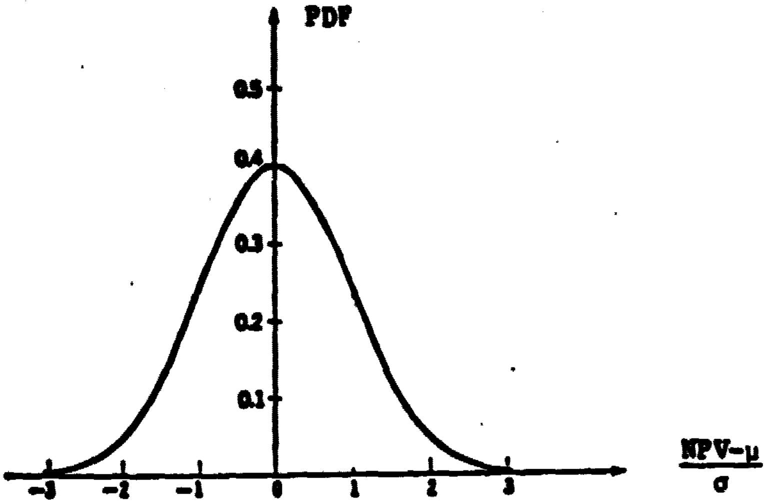

Figure 4.1a

Gaussian Probability Density Function, Normalized for Mean μ and Standard Deviation σ.

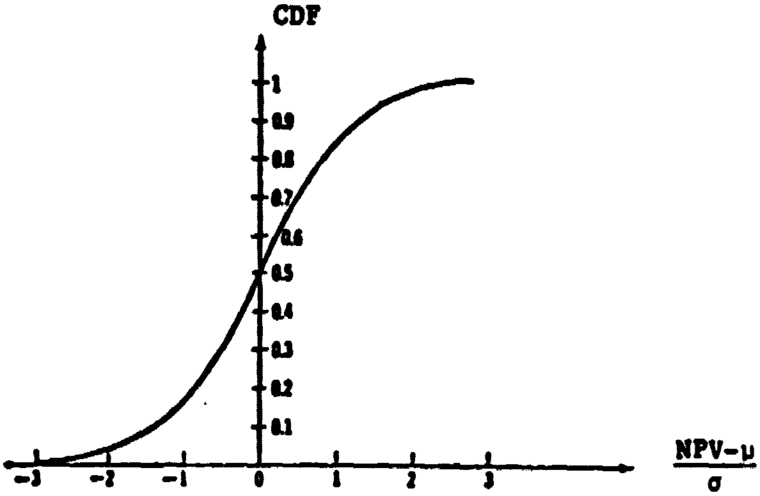

Figure 4.1b

Gaussian Cumulative Distribution Function, Normalized for Mean μ and Standard Deviation σ.

TABLE 4.2

RANKING TECHNOLOGIES

		RANKING*								
RISK ATTITUDE	STATISTIC	1	2	3	4	5	6	7	8	9
Ultra Conservative	MIN NPV	C	E	B	F	J	A	D	G	H
Somewhat Conservative	PROB(NPV 0)	(A	B	C	D	E	F	J)**	G	H
Moderate	$\hat{\mu} - \hat{\sigma}$	C	G	E	B	F	J	A	D	H
Somewhat Risky	$\hat{\mu}$	G	C	E	B	F	A	J	H	D
Very Risky	MAX NPV	G	C	E	H	B	F	A	J	D

*Code letters identifying technologies are

Letter	Technology
A	Adaptive Heat Pipes
B	Multibeam Satellite Antennas
C	Solid State Power Amplifiers
D	Advanced Solar Arrays
E	Low Cost Earth Station
F	Ion Engines
G	Millimeter Communication System
H	Laser Communication System
J	RF Attitude Sensor

for the ranking given by the moderate risk attitude, using the statistic $\mu-\sigma$. There is very substantial agreement between the $\hat{\mu}-\hat{\sigma}$ and $\hat{\mu}$ and MAX NPV rankings where the designation "^" denotes our estimated value. We take the estimated values to be the best estimates of the true values. The only substantial difference between $\hat{\mu}-\hat{\sigma}$ and MIN NPV or PROB(NPV>0) is the placement of Technology G, Millimeter Communication Systems. These differences are easily explained. With regard to MIN NPV, G has a large possible range, which is expected from a technology with a high mean value. Certainly a low MIN NPV should count against a technology. However, the probability of a negative NPV is only 2%. The technology is not as risky as the ordinal MIN NPV ranking might overtly suggest. With regard to the PROB(NPV>0) statistic, G ranks a poor 8th only because 7 technologies have a probability of unity that NPV>0. For G, its probability of a positive NPV is 98%. Again, this ranking seems to overplay the risk of G. Thus, the moderate attitude toward risk, using the $\hat{\mu}-\hat{\sigma}$ criterion best represents the Tech team's assessment of the <u>one</u> best ranking.

The final rankings have methological implications as well as the obvious operational ones. First, the final rankings provide a test of the screening methodology. Screening was meant to be a predictor of final ranking. It is only in this sense that screening allows the "worst" technologies to be filtered away. It turns out there is 100% agreement between the screening results and the $\hat{\mu}$ ranking, and a 99% agreement between screening and the $\hat{\mu}-\hat{\sigma}$ ranking. Thus, the validity of the screening approach is upheld.

In addition, is the notion of the risk spectrum valid? Do the rankings change systematically across the spectrum? A test of this systematic change was devised, and was passed 100%. This established that rankings are not too sensitive to small changes along the risk spectrum. This means that rankings are not drastically changed if risk attitude vacillated between for example, moderate to somewhat risky. This is a characteristic one might well demand from a spectrum of ranking criteria.

SECTION 5

CONCLUSIONS

The questions of whether or not NASA should support the further development of space communications technology and which technologies, if any, should be given the highest priority have been attacked from a cost-benefit point of view. Both qualitative and quantitative methods for addressing the issues have been formulated and applied. The screening, assessment, and ranking methodologies have been applied to conceptual communications systems and subsystems which resulted from the user preference and technology state-of-the-art surveys. Baseline scenarios with associated forecast demands for communication channels and forecast channel capacity per satellite have been used together with estimates of improvements in communication systems resulting from specific technology developments to estimate the value to the nation of U. S. government support of the development of space communications technology.

A set of nine technologies have been carried through the screening, assessment, and ranking methodologies. Eight of the nine technologies (all except low cost direct demodulation earth station equipment) passed the qualification test based upon market failure (the failure of the private sector to provide adequate financial incentives to potential developers). The quantitative methodology application resulted in mean and standard deviation values for the net present value of each proposed technology development program. A ranking of the technologies according to several statistics of interest has been developed and is presented below. The technologies are listed in order of decreasing value.

(1) Millimeter communications systems
(2) Solid state power amplifier (satellite)
(3) Low cost earth stations
(4) Multi-beam antenna
(5) Ion engine
(6) Adaptive heat pipe
(7) RF attitude sensor
(8) Laser communication system
(9) Advanced solar array

This ranking is according to economic considerations only, and is to be used as a design aide by the decision maker; it is not an end in itself.

Some general conclusions, in addition to the specific ranking of the above technologies, have been made. The screening, assessment, and ranking methodologies developed within the program provide a consistent, tractable, defensable, and quantitative approach to evaluating potential NASA R & D programs. Economic evaluation of the technologies from a cost-benefit viewpoint has shown that certain technologies should be implemented with government support to accrue maximum benefits to the nation as a whole. NASA, as the appropriate government agency, should play an important role in advancing future communications technology.

REFERENCES

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