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COST-BENEFIT ANALYSIS OF SPACE TECHNOLOGY

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16. Abstract

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COST-BENEFIT ANALYSIS OF SPACE TECHNOLOGY

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SUMMARY

A discussion of the implications and problems associated with the use of cost-benefit techniques is presented. Knowledge of these problems is useful in the structure of a decision making process. A methodology of cost-benefit analysis is presented for the evaluation of space technology. The use of the methodology is demonstrated with an evaluation of ion thrusters for north-south stationkeeping aboard geosynchronous communication satellites. A critique of the concept of consumers surplus for measuring benefits is also presented.

INTRODUCTION

The question of whether government programs are worth the price first appeared in literature in 1844 in a paper by Jules Dupuit a French engineer. Since that time there have been many developments and refinements of methods used in what is now called cost-benefit analysis, but in many ways Dupuit's criticism remains valid. His complaint was that "... political economy has not yet defined in any precise manner the conditions which these (public) works must fulfill in order to be really useful" (ref. 1).

The initial works dealing with the evaluation of public projects began in the U.S. with the passage of the River and Harbors Act of 1902 which required a board of engineers to report on the desirability of Army Corps of Engineers' river and harbor projects, taking into account the amount of commerce benefited and the cost (ref. 2). From an economic point of view, a significant event occurred in 1936 with the passage of the Flood Control Act. Federal participation in flood control programs was authorized "if the benefits to whomsoever they may accrue are in excess of the estimated costs." It is important to note several consequences of this particular law. The first was that the Congress stipulated a necessary condition for federal participation: the benefits must exceed the costs. But the act does not demand participation when benefits exceed costs; it only authorizes participation. Thus in 1936 Congress recognized the importance of leaving a final decision with a decision maker rather than with the outcome of an analytical technique. The second consequence of the 1936 legislation was that Congress approved the use of a decision criterion derived from the branch of economics dealing with public or government expenditures. The criterion allows for the fact that individual citizens of the United States will incur costs and receive benefits from public programs. The criterion further allows for the compensation of individuals for costs directly incurred beyond taxation but does not require compensation for indirect effects such as loss of trade resulting from changes in demography. On the other hand, individuals are not prohibited from benefiting directly or indirectly from the effects of public expenditures regardless of social status.

Since 1936 there have been many accomplishments in the development of cost-benefit methodology, but, when the need to use cost-benefit analysis arises today, it is usually not apparent what should be included in such an analysis. As resources become more scarce in the public domain, there will be a continuing need to determine whether benefits exceed costs. In addition to making cost estimates and determinations of monetary benefits, there is a need for estimating the monetary value of benefits and costs of things more difficult to quantify in dollar analogues. Social impact assessment is the determination of the effects of public programs on society beyond those things which may be measured in monetary terms. What used to occupy government analysts and researchers from the social and economic areas of academic institutions has slowly evolved into rather controversial issues at a time when resources are becoming scarce; and decision makers in the public domain are in need of evaluative techniques for assessing the merits of the government programs competing for these scarce resources.

One of the primary difficulties of cost-benefit analysis, economics, and social impact assessments is that they are not exact sciences and are therefore somewhat lacking in the consistency which is attainable in engineering and other exact sciences. This lack of exactness is not a weakness, although many engineers and scientists label the social sciences as being inferior for this reason. If the task of modeling society were as simple as that of modeling a transformer, it would have been accomplished by now. Despite these difficulties, the need exists for information with which to make decisions in the public domain. This need goes beyond the evaluation of technical plans. Unfortunately no one has yet determined how far and exactly what should be considered when performing cost-benefit and social impact assessments for the expenditure of public funds. Some of these considerations and the mechanics will be discussed further in the next section.

A DISCUSSION OF SOME OF THE PROBLEMS

Within the past few years, the terms cost-benefit analysis and impact assessment have begun to receive widespread attention. Much of the literature devoted to these topic deals with methodology, but a considerable portion deals with criticism of the many techniques that have been proposed for use in the process of allocating expenditures. Much of the criticism is formulated with perspectives that reflect an extreme point of view, whether from a position of advocacy or adversity. There are those who believe that the methodology is useless because it is so eclectic as to be incomprehensible. Others assail the techniques because benefits and costs can be manipulated to yield a predetermined answer or because the role of the decision maker is rendered superfluous. At the other extreme are those who would allow the quantification of all costs and benefits in order to develop a benefit-cost ratio, and those who say that cost-benefit analysis may be used in lieu of a decision.

A more reasonable perspective is that cost-benefit analysis is an aid to decision making. The analysis is based primarily on economic science and may be used to estimate whether, and to what extent, the economic benefits of a proposed project outweigh the economic costs. Not all costs and benefits can be transformed to dollar analogues, and so this analysis constitutes only a segment of the information required to make a decision. Cost-benefit analysis might more properly be termed a state of mind rather than a method. Within this perspective, an examination will be made of some of the problems associated with this type of analysis. Some examples will be developed to demonstrate that despite shortcomings, this type of analysis can be used to evaluate <u>some</u> of the economic value to be gained from the expenditure of <u>some</u> resources.

Two of the most difficult areas in which to apply cost-benefit analysis are the evaluation of the benefits of research and development programs and the evaluation of social programs. There are fundamental reasons for these difficulties. Rather than resort to criticism of research and social programs or of cost-benefit methods, it is imperative to first examine the nature of each in order to determine the source of some of the criticism and difficulties encountered in the application of cost-benefit analysis in these areas.

The branch of economics that deals with the optimal allocation of public (or government) funds is known as welfare economics. Despite the connotations associated with the term welfare, it is used here in a broader sense than is normally construed; welfare economics relates to the spending of <u>all</u> government funds. With this in mind, let us examine some of the problems encountered in the process of managing the distribution of public funds for federal programs.

During the past few years, many forms of technology have been criticized because of the inability of anyone to foresee the adverse consequences of the implementation of the technology. As a result of some of these inadvertently created problems, managers have had to contend with demands to demonstrate beforehand that a program is worthwhile and that the deleterious effects are minimal. They are asked to deliver in addition to the usual technical plans such things as benefit-cost ratios, social impact scenarios, quality-of-life considerations, risk assessments, and other reports that have little apparent relevance to what is being proposed.

On the other hand, there are those who object to the reduction of a technical plan to a number (the benefit-cost ratio) which is then compared with the ratios assigned to other plans in order to select what should be done with the resources at hand. The benefit-cost ratio is subject to criticism from different directions and for different reasons. Cost-benefit analysis is criticized because many important considerations are overlooked in the generation of the benefit-cost ratio. There simply is no way to generate a number that can consider the effects of polluting a stream or of saving a person's life.

Many managers object to the comparison of their projects with others because the competition is decided by the best salesman rather than the merits of the proposed work. The skepticism is typified by the words of a retired Army colonel which appeared in the New York Times in 1972 and again in a journal article: (referring to the b-c ratio) "Its nothing but a ritual. They come down the aisle swinging their incense and chanting 'benefit-cost.' You can adjust the b-c ratio to justify any project. I did it myself a few times" (ref. 3). It is unfortunate that the colonel completely misunderstood the purpose of the methodology.

Another alleged weakness of cost-benefit analysis is that the same agency that proposes and sponsors a particular project performs the benefit-cost analysis (ref. 3). This criticism likewise indicates a misunderstanding of the purpose of using such techniques to evaluate project proposals. It is a matter of good business to gather information and use it to rank alternatives when making a decision concerning the expenditure of resources.

In addition to technical evaluations and consideration of other factors, it is reasonable to expect a decision maker to formally consider the economics of various proposals for the allocation and spending of public monies. Because the goals of the nation are considerably less tangible than maximizing profit or minimizing cost, the decision criteria and methods used in the evaluation of public expenditures are more complicated than the methods encountered in private enterprise.

To begin an elaboration of methods and some of their implications, it is necessary to define the principal caveats associated with cost-benefit analysis or the numerous designations and names associated with this portion of policy analysis. Whether one is a practitioner, a manager, or a bystander, it is well to remember that there is no substitute for good judgment, common sense, and logic. Cost-benefit analysis is one of many basic information requirements a decision maker may use. The information itself should not force a particular decision, but merely serve as a source of information and an explicit declaration of the assumptions made by an analyst.

The use of this information to construct a ratio of benefits to costs for comparison with other proposals is, in general, not recommended. The results of such use of cost-benefit analysis techniques are not generally valid when used to compare benefit-cost ratios of many different types of programs. Inevitably such use will result in the selection of those programs with the largest ratio of benefits to cost. The implication of such use is that this ratio is a sole criterion and thus there is little need for a decision maker. The logical extension of comparing the benefit-cost ratio of one program with another is that all benefits and needs are of equal weight, which is not generally true. Suppose a policy analyst has determined that two programs, A and B, have quantifiable benefit-cost ratios of 10 and 5. Suppose further that program A is a new and innovative method of providing remote health care delivery and that program B is the development of a hybrid food staple. Since the benefit-cost ratios considered only those aspects of each program that could be quantified in dollar values, a comparison of the ratios on this basis will only result in the implication that A should be funded before B. However, the decision should not be made before considering program priorities, the needs of the target populations, the impact of implementing or not implementing either program, and the policy objectives of the funding organization. In actual practice, the priorities and needs are not obvious; hence, the requirement for the decision maker.

Another implication of the benefit-cost ratio is that the magnitude of costs involved is not important. Thus a very costly project may be preferred over one costing much less if the more costly project has a higher benefit-cost ratio. Again, the need for a decision maker is obvious to prevent the methodology from dictating policy to the organization. The purpose of these naive examples is to demonstrate that there are many things to consider in a decision making process and that cost-benefit or economic analysis is only a part of making the decision.

A distinction often overlooked is that there are certain endeavors that simply do not submit to economic analysis. Some programs are so exploratory in nature that there is no reasonable way of estimating the monetary value of the outcome. The conduct of basic research provides a good example. This is not to say that basic research should not be goal directed (quite the contrary). It simply means that basic research is exploratory in nature whereas cost-benefit analysis of necessity is product oriented. Basic research is a fundamental part of the business of operating a laboratory or R & D organization. It should require justification only to the extent that other overhead items do. It is no more feasible to justify exploratory research with cost-benefit analysis than it is to apply these procedures to a justification for turning on the lights. The alternative is to abandon research activities and wait for development and applications to stop.

In addition to the conceptual problems associated with placing economic value of exploratory research, there exist similar problems in the social and political mileau. One easily comprehends the necessity of comparing apples with apples and oranges with oranges, but the dictum loses significance when the apples are changed to dollars and the oranges are relegated to units of measure not readily transferrable to dollar analogues. An example of this is the attempt to display the monetary merits of social programs that save lives. The literature is replete with methods of assigning a dollar value to human life such as pareto optimality and compensating variation. But the use of such techniques assumes a priori that there is a value to saving human life before giving any consideration to more fundamental questions. The result is a contest of one-upsmanship in which none of the methods of valuing human life provides an acceptable measure. A more reasonable approach for an organization might be to pose the question: Is there value to human life? Or, should resources be expended for saving lives? Going to the fundamental question and defining it in a way that is amenable to solution within the confines of organizational policy should result in a definitive answer. If the outcome is positive, an approach to defining effectiveness should be in units of lives saved since this is the common denominator, which is also irreducible to dollar analogues.

The point of this example is that considerable thought should be given to defining the problem. When problems are not defined accurately, it is possible to make assumptions which imply a solution to the genuine problem. The implied solution may be incorrect but without a proper definition, there is no way of knowing that an error has been made.

Another item requiring care is the selection of units of measure. Many things may be valued in terms of money, but many more cannot. These may be termed incommensurables and intangibles. Incommensurables are those things that have valid units of measure but which cannot be equated with monetary values. Examples include lives saved and level of achievement. Intangibles consist of those things that cannot be measured validly with any system of units. Examples here include patriotism, good will, and national prestige.

When measuring incommensurables, the unit of measure is valid but irreducible. This does not detract from the value of the unit; it implies that regardless of the value scale attached to the unit, the unit itself is a meaningful measure and may be used as such. Intangibles may also have value but there is no meaningful unit of measure. If one is dealing with a problem involving incommensurables or intangibles that are the primary output of a program, these things must be dealt with directly and without transformation to dollar analogues.

In the event that there exist secondary effects or spillover, there is often a tendency to include such effects in the calculation of benefits and costs, whether the effects are measurable in monetary units or consist of incommensurables and intangibles. Benefits and costs may generally be divided into project costs and benefits and other costs and benefits. This division gives rise to two classification schemes known as internal and external effects and direct and indirect effects.

Internal effects are those which are directly attributable to the project objective. External effects are neither deliberately produced nor deliberately consumed and may be valued but not priced. External benefits are involuntarily received by others for which they are not charged. External costs are imposed on others without compensation.

Direct benefits from a project are increased real values of output associated with the project. Indirect benefits reflect the impact of the project on the rest of the economy.

No one would deny that economic impact should be a consideration in the evaluation of large public programs, but one should consider the implication of including secondary benefits in the calculation of a benefit-cost ratio. An excellent example comes from a technology program designed to increase the availability of a certain type of ground transportation. This particular mode of transportation was the least expensive mode when compared with two others. The policy analyst calculated a value for the increased availability and then reasoned that this increased availability would represent a net gain in income for the geographic region of analysis. This additional regional income would then have a multiplier effect on the regional economy. The total benefits included the amounts saved from the increased availability of the lower cost transportation plus the increase in regional income multiplied by a number representing the multiplier effect. The secondary regional benefits were enormous compared with the primary benefits.

Several aspects of this analysis merit closer scrutiny. The stated objective of the analysis was to determine the benefits associated with increased availability of a certain mode of transportation. However, calculated benefits included the effect of this increase on the regional economy thereby implicitly changing the stated objective to one of maximizing regional income. The analysis fails to consider whether this new income is a growth in total income or comes at the expense of other modes of transportation. It is possible that other modes of transportation may incur displacements which would result in serious economic problems for the entire region. Finally, there appears to be a fallacy in the reasoning used to calculate benefits. The analyst assumed that regional income would be maximized by using the advocated method of transportation, and that transportation income should be maximized in order to maximize the benefits to the region. This occurs when transportation charges are maximized. Therefore, all shipping should be accomplished by the most expensive form of transportation rather than the form advocated by the analyst. If one chooses to include secondary benefits in support of an objective, then the true objective will usually be altered.

Although many analyses include secondary benefits in the calculations, secondary costs are often overlooked because it is difficult to anticipate deleterious effects 5 or 10 years before they occur. A reasonable approach to secondary costs and benefits is to attempt to calculate them but not to include them directly in the economic evaluation. A decision maker should consider the effects of his decision on the economy both in terms of benefits and costs, but only if the project is of such magnitude as to have a significant social or economic impact. In the event that social and economic impact assessments are conducted, the starting points lie in an analysis of all institutions and commodities affected by the decision. For very large programs social and economic researchers would be required to perform some of the analysis. When multidisciplinary research of this kind is conducted, the project manager must carefully structure the problem in order to obtain the information he is seeking.

Example of Cost-Benefit Methodology

It is possible to use the methodology of cost-benefit analysis as a consistent structure to develop information required for policy decisions regarding government investment in technology programs. The purpose of such an analysis is to estimate the potential economic and social impact of government investment in technology. In many cases the methodology has been used as a device to convince government agencies and legislative bodies of the need to fund particular programs. Rather than use the methodology as an internal mechanism to supplement decision information, the methodology has been used as a marketing tool. Although there is nothing objectionable about such practice, many cost-benefit studies used for marketing purposes tend to concentrate on "making the system look good" rather than being an objective assessment of the potential benefits and costs.

The example presented here was developed because of an interest in determining potential benefits and costs of various technologies used in space communications. The subject technology appears to have more benefits than costs, and so it was selected to demonstrate the benefits associated with funding a technology development program.

Ion thrusters are engines that generate a very low thrust but are capable of sustaining this thrust for very long periods of time. Chemical propulsion works on the principle of releasing large masses at high velocities through an exhaust. Because of the principle of conservation of momentum, the vehicle is propelled in the opposite direction. Ion propulsion likewise is an application of the conservation of momentum. Instead of burning and releasing pressurized gases as in chemical propulsion, an element such as mercury is ionized and then accelerated in an electric field. The ions are then neutralized in charge, and the element is ejected through an exhaust. Because the mass flow rate is so much less than in chemical propulsion, the propellant lasts much longer. However, the individual ions are accelerated to much greater velocities than are the particles in chemical propulsion. This results in a much higher specific impulse which is a performance measure for rocket propulsion systems. Despite having a greater specific impulse, the ion thruster is of no value for overcoming the gravitational field of the Earth at low altitude since the thrust generated is on the order of hundredths of a pound. For deep space probes or the thrust required to perform the stationkeeping on a geosynchronous orbit satellite, the thrust of an ion engine is quite sufficient.

Although ion engines have been available for a decade or so, these engines have not been used in an operational propulsion system aboard a spacecraft. Instead, hydrazine thrusters have supplied the stationkeeping requirements for geosynchronous orbit communication satellites.

Because of the limitations of the launch vehicles used to deliver commercial communications satellites to geosynchronous orbit, these satellites have been limited in weight to approximately 726 kg (1600 lb). Although the weight constraint may be relaxed in future years, this constraint presently limits the communications capacity of a commercial satellite.

Quantifying Benefits

The primary difficulty encountered in quantifying the benefits of space technology is that the technology has never been deployed and thus cannot fully be assessed. With the proper qualifications, however, it is possible to gain some information regarding the potential impact of introducing new flight hardware. The ion thruster has been selected to serve as an example for this procedure. A relatively conservative position must be taken because the ion thruster is competing against hardware that has proven itself to be reliable. Thus it is necessary to place the burden of proof on the ion thruster.

Since the cost incurred for a space mission is in dollars, it would simplify the benefit assessment if dollar benefits could be specified. At present, most of the spacecraft producing dollar benefits are those operated by Intelsat and its U.S. subsidiary Comsat.

The example developed here will be the comparison of ion thrusters with the hydrazine thrusters, that are presently used on Intelsat spacecraft. The expendable launch vehicle used for Intelsat IV spacecraft imposes a 726-kilogram (1600-lb) weight limit on the satellite. This weight limit places a limit on the revenue generating capability of each satellite. Increases in profits for Intelsat are transformed into rate reductions for customers because of legal limits on the rate of return. However, the concept of transforming a weight savings into increased profit is valid since this must be accomplished before rate reductions can be made. One method for obtaining the increased profit would be to use fewer satellites. In 1974 the Atlantic region path consisted of three Intelsat IV series geosynchronous satellites located at 19.5°, 24.5°, and 30° west longitudes. The satellite at 30° west longitude serves as the major path satellite, handling large volume traffic (ref. 4). Communications satellites are designed so that capacity use is normally reached in the last year of the satellite design life. But for a major path satellite, full capacity use may be reached early in the satellite life; thus the major path satellite is the prime generator of revenue. The major path system offers a means of examining the effect of using the ion thruster. Because weight savings may be transformed to additional communications capability, which in turn may generate additional revenue, the Intelsat IV over the Atlantic path offers a means of examining the benefits of one application of an ion thruster system if it were to replace the hydrazine thruster system presently in use.

The example presented here will provide information relating to the use of an ion thruster in one specific application. The benefits of ion thrusters cannot be measured as such since there are many possible applications of these thrusters. It would be very difficult to measure the value of using an ion thruster for a deep space probe because the benefits of such a probe would be scientific knowledge (an intangible). However, it is possible to measure the effectiveness when compared with conventional thrusters. For those missions that produce revenue, a product oriented analysis may be constructed to examine the potential value of a thruster system, but to measure the total benefits, all possible products would have to be specified. A more reasonable approach is to develop a lower bound estimate based on a single use. The analysis does not necessarily represent the manner in which an individual corporation would implement technology, but rather one rational policy of many.

The example deals with a proposal to fund a flight program designed to gain information about various aspects of spacecraft technology and to flight qualify and ion thruster for north-south stationkeeping in geosynchronous orbit. There are many benefits to be gained in terms of knowledge but the primary measurable benefit would be the flight qualification of the ion thruster. Until this is accomplished, the thruster will probably not be used because of the risk associated with a thruster failing in orbit if deployed on a commercial satellite.

Before proceeding with the analysis, a digression into the nature of decisions is in order. Figure 1 is a summary of this discussion. Before one is faced with a decision, there is the status quo or what presently exists. If a proposal is made to alter the status quo, the decision must fall into one of three types of selection with respect to the new proposal: either accept or reject the proposal; select one of several proposals; or select several of many proposals. The next consideration is whether there is a capital constraint. If there is none, then from an economic point of view any proposal whose benefits exceed costs is acceptable. The last consideration is that of dependence or whether the costs and benefits of a proposal are invariant with respect to whether other proposals are accepted or rejected.

The decision structure of this example is accept or reject. The decision information process is depicted in figure 2. The economic analysis represents part of the information required to make a decision. Assuming that the technical evaluation has been completed and the external factors have been considered, the remaining information gathering function is the economic analysis. All assumptions will be stated explicitly in order to establish the results. From that point on the results are irrefutable. Thus if one chooses to counter the results of the analysis, the assumptions offer the only point of attack.

When dealing with an accept-or-reject decision structure, one should specify two *scenarios, the status quo and that of the proposed alternative. In this way incremental* costs and benefits may then be specified. The decision rule associated with this structure is that the new proposal is economically attractive if the net present value (NPV) is greater than zero. Other criteria may be specified (e.g., return on investment or annual worth), but these criteria are variations of NPV. All three are ranking techniques and will usually give the same rankings. The NPV equation is the preferred method here.

The equation form of net present value is

$$NPV = -Co + \frac{B_1 - C_1}{(1 + D)} + \frac{B_2 - C_2}{(1 + D)^2} + \ldots + \frac{B_N - C_N}{(1 + D)^N}$$

where C_t is the cost for period t, B_t is the benefit for period t, D is the discount rate (or interest rate), and N is the project life. The value of D is usually dictated by policy. The number presently recommended by the Office of Management and Budget is 10 percent.

The status quo scenario is relatively simple for the example and has been stated previously, namely, the use of hydrazine thrusters for north-south stationkeeping requirements of geosynchronous orbit satellites. The scenario for the new proposal is somewhat more complicated: it is desired, among other things, to flight-qualify ion thrusters in orbit for north-south stationkeeping to prove their advantages over hydrazine thrusters. Other experiments would be carried on the spacecraft. The spacecraft will be put in orbit on a piggyback flight.

Some launch vehicles carry payloads into orbit with large weight margins; that is, the launch vehicle has more capability than is used. It is possible to orbit an additional payload on these flights without incurring additional launch vehicle costs, because the flights will be made whether the weight margin is used or not. There is an additional cost for the payload integration. Thus piggyback flights offer a rather cost effective method of performing flight experiments.

The assumptions and cost considerations for the analysis are as follows:

(1) There is a finite planning horizon of 11 years, 5 of which will be for the test program and 6 for the useful Intelsat IV spacecraft life. The design life for these spacecraft is 7 years, but there are some reasons to believe that this may not be achieved (ref. 4).

(2) The development and flight cost for the test program will be paid by the government. After the proof flight of the ion thrusters, it is assumed that ion thruster technology will be used on only one commercial revenue generating satellite and never used again, thus establishing a very conservative lower bound for benefits to one corporation. The return to the government will be additional taxes on the marginal revenue generated.

(3) The weight savings resulting from the use of ion thrusters on the commercial satellite will be used to add additonal operation and backup transponders thus increasing the revenue generation capability of the satellite (ref. 5).

(4) A market exists for the additional capability. This assumption is justified by the fact that growth of satellite communcations has been very large in recent years and is projected to range from 15 to 35 percent annually for the next decade or so (ref. 4).

(5) The average monthly revenue of a Comsat telephone channel in 1971 was 2900. There are about 750 channels per transponder. It is assumed that on the average 600

were utilized to generate the 2900 per channel month (ref. 6). It is further assumed that only half of this revenue will be generated by the additional communications capability in the first year of use.

(6) Forty percent of marginal revenue is taxable at a rate of 48 percent. The 60 percent not taxable is assumed to cover the hardware and operations costs of the additional communications capability (ref. 6).

(7) This analysis is based on the Intelsat IV class of satellite.

(8) The operational cost of ion thrusters is commensurate with hydrazine thrusters.

(9) Fifteen million dollars is the estimated cost of the proof flight, including launch vehicle costs (even though the experiment might be made on a piggyback flight). A 25 million dollar upper bound cost estimate allows for considerable overrun and risk.

(10) No benefits will be obtained from the experiment other than the proof test of the ion thrusters. It is assumed that the test will be successful because of life testing conducted previously.

(11) Ion thrusters yield a 16 percent increase in communications capability (two operational transponders, two backup) (ref. 5).

(12) Marginal revenue is generated according to the 1974 Comsat rate schedule (ref. 6).

The flow of funds is shown in table I.

The net present value of the flow of funds was calculated for both program costs using the relationship for NPV stated previously. The NPV's are shown in table II. The present value of the additional taxes to be paid on the new revenue at a 10 percent discount rate was \$19.53 million. The present value of the expenditures for the low and high program costs are 11.37 and 18.95 million dollars, respectively. Thus federal money spent on the program would be recovered at a 10 percent interest rate in this case.

OPPORTUNITY COST

The opportunity cost does not represent a real cost but rather what is foregone by not taking advantage of a good investment as quickly as possible. The opportunity cost can be used to compare one investment with another to determine the benefits delayed by not taking advantage of a particular investment.

The shaded region of figure 3 represents the bounds of the opportunity cost for high and low costs of the project. The interpretation given to figure 3 is that if the investment is delayed 1 year, approximately 8 million present value dollars will be foregone. It is not an out-of-pocket loss, but rather the opportunity of gaining the return is lost because of the delay.

The point of the example is to illustrate that the use of ion thrusters for north-south stationkeeping in a commercial communications satellite is economically productive even under some rather conservative assumptions. In a more realistic situation where thruster technology would be used more than once, the benefits to be gained would be enormous.

In many cases the development of an economic worth for a program is much more difficult than the example presented here; in some it is impossible. However, one can always develop an estimate of the change in productivity that may be associated with a program. It is unreasonable to expect the analysis to render a dollar value in all cases. The use of incommensurable units may provide all the information required for a cost-benefit analysis, and the use of the incommensurable unit has the advantage of not being ambiguous as the case would be if the unit were transformed to a dollar analogue.

In the event that a quantitative cost-benefit analysis cannot be performed, a qualitative analysis is acceptable. The requirement for a quantative cost-benefit analysis where it is not feasible guarantees the decision maker an erroneous analysis. When such a situation occurs one must conclude that either there is a lack of understanding of the nature of the methodology or the program being analyzed or that the methodology is being used for a purpose other than to examine the benefits and costs associated with the program.

One final point should be made regarding the measurement of benefits. In recent years economists have revived Marshall's concept of consumer's surplus as a means of estimating benefits. Consumer's surplus is defined as "the amount over and above the price actually paid that one would be willing to pay for a given amount of a commodity rather than go without it" (ref. 7). The economist derives a price demand relationship similar to the one in figure 4. If a consumer will purchase Q units of a commodity at a price of P per unit, then the shaded area under the curve is an estimate of the excess utility over and above the purchase price that he derives from Q units of the commodity at a price P per unit. There are several reasons why consumer's surplus is meaningless when used to estimate the value of benefits of public expenditures. In the first place it is impossible to derive a demand schedule which accurately describes the relationship between price and quantity since data are unavailable. If it were possible to construct a demand schedule for public expenditures for a particular program, the consumer's surplus would not be a measure of benefits of the program but rather an indication of the government's willingness to pay for the program.

Another reason the concept is inappropriate in welfare economics is that the concept requires that the marginal utility of income be a constant. This in laymen's terms means that there are no priorities in program selection. This fallacy needs no commentary.

A situation often encountered in the expenditure of public funds is depicted in figure 5. The quantity Q in many instances is one; that is, the program will either be accepted or rejected. The cost of the program might be a range from P_0 to P_1. Even if the concept of consumer's surplus were meaningful as a measure of benefits, it would be zero in all situations or decisions to either accept or reject a proposal.

A more detailed discussion of consumer surplus appears in appendix A.

SUMMARY AND CONCLUSIONS

Although there many problems associated with the use of cost-benefit analysis in welfare economics, it is possible to use the methodology to obtain useful information required for the proper evaluation of public alternatives. The methodology is eclectic and not fully developed. Much work must still be completed; most of it should be concentrated in the areas of incommensurables and intangibles. Of one thing we can be sure: the future of all nations holds a continuing competition for resources, and thus, a continuing need for evaluative tools. When properly used, the methods of cost-benefit analysis or the more comprehensive tools of technology impact assessment will provide a logical structure for gathering and evaluating the information required for meaningful decisions in the public domain.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, July 23, 1976,
644-04.

APPENDIX A

CONSUMER'S SURPLUS

As stated previously, consumer's surplus is "the amount over and above the price actually paid that one would be willing to pay for a given amount of a commodity rather than go without it" (ref. 7). It is understandable that economists might wish to use the concept to measure benefits because if society were to go from economic state A (where Q_0 units are demanded at price P_0) to economic state B (where Q_1 units are demanded at price P_1), then it would be a simple matter to calculate the value of the savings to society. In some cases where productivity is increased, this calculation does indeed give the value of some of the benefits, but in welfare economics (or government spending) such is not the case.

To adequately develop the concept of consumer's surplus in the public domain, it is necessary to review the concepts of marginal utility and diminishing marginal utility. The law of diminishing marginal utility states that as the amount of a good consumed increases, the marginal utility of the good tends to decrease (ref. 8).

Utility is a measure of the usefulness of a commodity. If utility is negative, one would not consume the good in question. The law of dimishing marginal utility states that as more units of a good are consumed, the incremental utility placed on the next unit is equal to or less than the previous unit. The situation is shown in figure 6 and table III. An interesting facet of the law of diminishing marginal utility is that it has never been proven but rather is an empirical observation derived from original assumptions (ref. 7).

One of 10 requirements for calculating the consumer's surplus is that the marginal utility of income be a constant. This is a rigid requirement which most economists who use the concept dismiss with various assumptions, but which nevertheless does not disappear with a wave of the hand. The implications of the requirement are that marginal utility of income is independent of income (constant) and that total utility of income is linear since marginal utility is the first derivative of the utility function. In general, the requirement of constancy of marginal utility of income contradicts the law of diminishing marginal utility. The only point at which there is no conflict is the limiting value of marginal utility of income, which must be zero. If and only if this condition of equilibrium is achieved, consumer's surplus is a measure of these benefits of public expenditures.

Consumer's surplus may then be obtained from the demand relation. Referring to figure 7, consumer's surplus is the area ABC and is obtained from

$$ABC = \int_B^A f(P)dP$$

where $f(P)$ is the price demand relation. (Note: Economists use the ordinate for the independent variable and the abscissa for the dependent variable. In this case, quantity demanded is a function of price.)

The interpretation of the concept is that the shaded area in figure 7 represents the cumulative value over and above the price that consumers place on D units of the commodity in question. To apply the concept to welfare economics, it is necessary to develop the price demand relation that would portray the situation encountered in large government programs. The first requirement is that marginal utility of income be a constant (zero). This occurs only when the national debt is zero or when there is a surplus. Otherwise incremental income could be used to reduce the debt, in which case the marginal utility is positive. The first requirement has not been met in quite a long time. But let us proceed further. The true situation encountered in government spending for large programs is a scaled step function. The budget is the predetermined quantity and Congress makes a go or no-go decision based on a range of estimated costs for a single program. Congress approves one unit of the program over a range of prices. Eventually a price is reached to which Congress says no, and the program is not funded. The demand schedule is portrayed in figure 8. If B' is the cost of the program, then the consumer's surplus is given by the area

$$A'B'D'C' = \int_{B'}^{A'} f(P)dP$$

where $f(P)$ in this case is a step function $U(P)$. By performing the integration it is found that

$$A'B'C'D' = A' - B'$$

Either A' and B' are equal or they are not. If they are unequal, then there is no practical way of determining A'. The argument in the event that A' and B' are equal is that programs are funded with a budget limitation which is the cutoff point in figure 8. If the budget is not exceeded, it is absurd to say that the amount not spent equals the benefits of the program. Thus in welfare economics consumer's surplus is

$$A'B'D'C' = \int_{B'}^{A'} f(P)dP = \int_{A'}^{A'} f(P)dP = 0$$

since B' and A' coincide; therefore, consumer's surplus is not a measure of the benefits of public expenditures.

When A' does not equal B', the cutoff cannot be determined and the program <u>may</u> be funded. *Since it is impossible to determine* A', $\int_{B'}^{A'} f(P)dP$ *is not convergent and* is therefore not defined. The most important aspect of this situation is that the program can be priced but not valued. Therefore, demand is not an indication of the benefits to be derived from the program.

Consumer's surplus is further muddled by Alfred Marshall's time varying interpretation of his own concept. The Nobel laureate Paul Samuelson has rigorously developed mathematical proofs which demonstrate that consumer's surplus is "superfluous" (ref. 9).

In addition to these difficulties there remains a question of whether consumer's surplus is a stationary random process. In the strict sense such a process is not affected by a shift in the time domain, so the statistics of such a process may be recovered despite changes in the time reference. Since the problem has not been addressed, there is no reason to assume that consumer's surplus is stationary. In fact, many examples exist in the social and political domain which demonstrate that any surplus in these areas varies in time and space. Thus what may appear to be a surplus to consumers in the public domain often becomes a deficit before completion. Moreover, the conjured surplus exists only in the analytical sense and bears little or no resemblance to the reality the analyst has attempted to portray.

With so many disadvantages it would seem that the concept of consumer's surplus should be abandoned in favor of more realistic and recoverable concepts of measuring benefits in the public domain.

APPENDIX B

WEIGHT AND AREA CHANGE IN THE SPACECRAFT

In the example it was stated that the replacement of hydrazine thrusters with ion thrusters would result in increased communications capability for an Intelsat IV class satellite. To achieve the increased capability, the satellite will require more transponder units, additional array area, and a larger battery (in size and area).

For the class of satellite in the analysis, 40 percent of the total weight (726 kg; 1600 lb) is used for power and communications (290 kg; 640 lb). The use of the ion thrusters rather than the hydrazine results in a 7 percent overall weight savings of 58 kilograms (128 lb). Any changes in the satellite configuration would be constrained to less than 58 kilograms (128 lb).

Array Size and Transponder and Battery Weights

The beginning of life (BOL) power in the spacecraft in 660 watts. There are 12 active and 12 backup transponders. Each unit has one active and one backup transponder; thus, each unit requires 660/12 = 55 watts of BOL power. The array area is 20.4 square meters (220 ft^2), and the array weight is 72.6 kilograms (160 lb). The array density is 3.55 kilograms per square meter (0.727 lb/ft^2), and the array power density is 32.3 watts per square meter (3.0 W/ft^2) at the beginning of life. The additional array area and weight required to add one unit is then

$$\Delta A = \frac{55 \text{ W/unit}}{32.3 \text{ W/m}^2} = 1.7 \text{ m}^2\text{/unit} \qquad (\text{or } 18.33 \text{ ft}^2\text{/unit})$$

and

$$\Delta W = (3.55 \text{ kg/m}^2)(1.7 \text{ m}^2\text{/unit}) = 6.04 \text{ kg/unit} \qquad (\text{or } 13.32 \text{ lb/unit})$$

The change in drum size is given by the following equation:

$$\Delta A = \pi D \, \Delta l \qquad \text{or} \qquad \Delta l = \frac{\Delta A}{\pi d}$$

where d is the drum diameter and Δl is the incremental length. The diameter is 2.38 meters, and the calculated ΔA was 1.7 square meters per unit. Therefore,

$$\Delta l = \frac{1.7}{7.792\pi} 0.23 \text{ m/unit}$$

The drum length increase for two units is 0.46 meter (18 in.). The launch vehicle used for Intelsat spacecraft can accommodate this change. The drum length increase for the Intelsat IV-A was larger than 0.23 meter. Both types are launched with Atlas Centaurs.

The difference in battery weight is obtained by multiplying the present battery weight by this new capacity:

$$\Delta(\text{battery weight}) = (39.92 \text{ kg})(0.167) = 6.80 \text{ kg} \qquad (\text{or } 15 \text{ lb})$$

The total weight change is

Four transponders (2 active, 2 backup), kg (lb)	27.2	(60)
Additional array (two active transponders), kg (lb)	12.25	(27)
Battery weight, kg (lb)	6.80	(15)
Total added weight, kg (lb)	46.27	(102)

The added weight is 11.8 kilograms (26 lb) less than the 58 kilograms (128 lb) saved by using ion thrusters.

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TABLE I. - FLOW OF FUNDS

	Program year											
	1	2	3	4	5	6	7	8	9	10	11	Total
	Millions of dollars											
Cost of experiment:												
Expected	3	3	3	3	3	--	--	--	--	--	--	15
Pessimistic	5	5	5	5	5	--	--	--	--	--	--	25
Revenue generated	-	-	-	-	-	21	42	42	42	42	42	231

TABLE II. - NET PRESENT VALUE OF ION THRUSTER SYSTEM

[At a 10 % interest rate, the present value of taxes on new revenue is $19.53 million which exceeds present value of both cost estimates.]

Program cost	Present value of costs	Net present value,[a] NPV
Millions of dollars		
15	11.4	90.4
25	19.0	82.8

[a]Present value of new revenue minus present value of program costs.

TABLE III. - TOTAL UTILITY AND MARGINAL UTILITY

Quantity consumed	Total utility	Marginal utility
0	0	4
1	4	3
2	7	2
3	9	1
4	10	0
5	10	

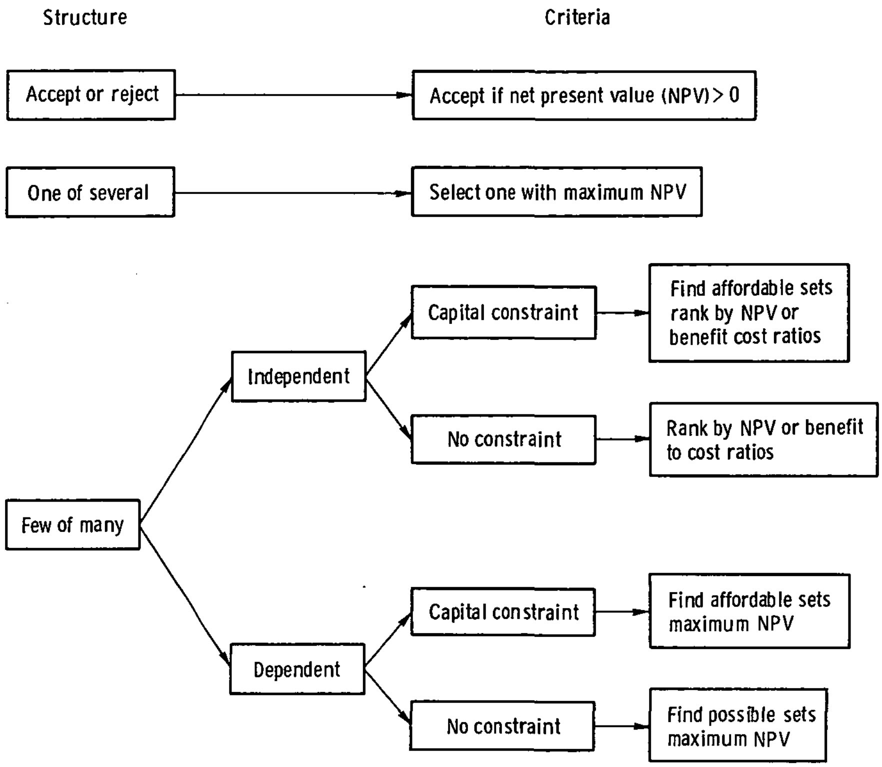

Figure 1. - Problem structure and decision criteria of new proposals.

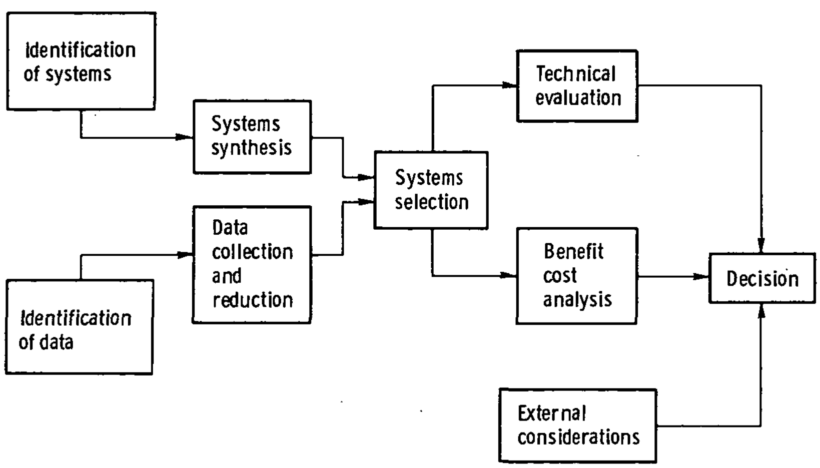

Figure 2. - System engineering perspective.

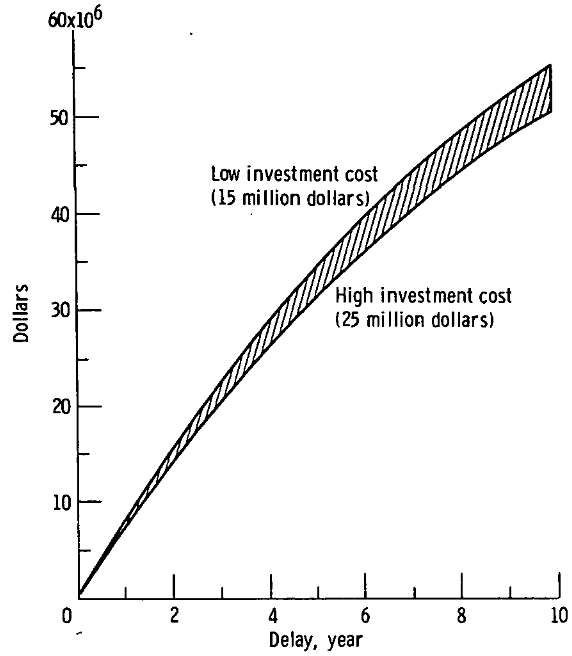

Figure 3. - Present value of opportunity cost of delaying use of ion engines for north-south stationkeeping at interest rate of 10 percent.

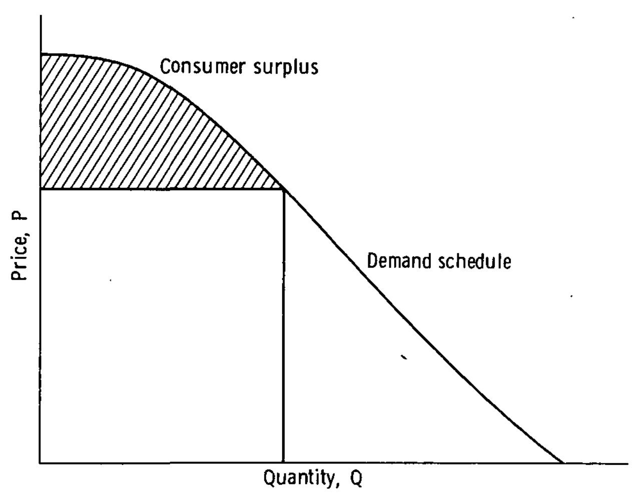

Figure 4. - Price demand relationship.

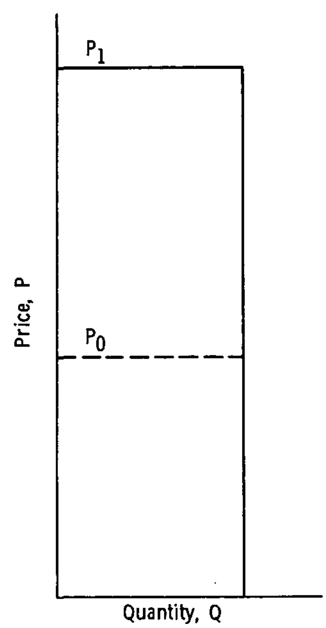

Figure 5. - Price demand relationship for a government program.

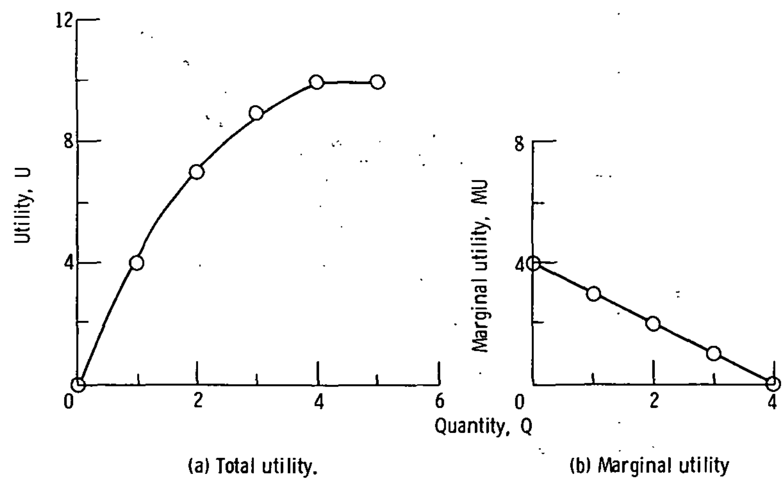

Figure 6. - Total utility and marginal utility.

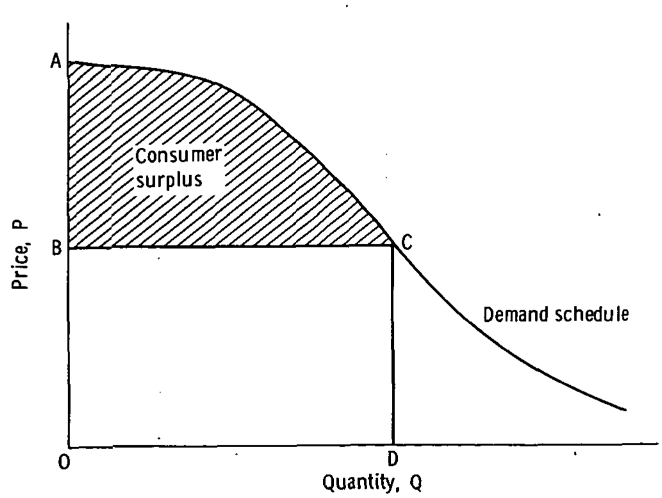

Figure 7. - Consumer surplus.

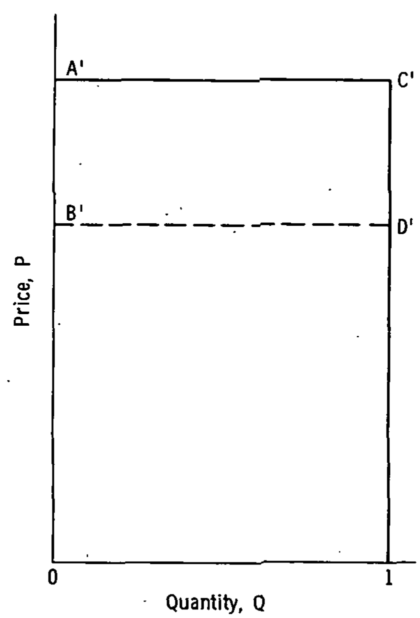

Figure 8. - Demand schedule for large government programs.

NASA-Langley, 1976 E-8796

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