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ECON INCORPORATED

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A PLAN FOR THE ECONOMIC ASSESSMENT OF THE BENEFITS OF IMPROVED METEOROLOGICAL FORECASTS

ECON INCORPORATED

Report No. 75-128-1
NINE HUNDRED STATE ROAD
PRINCETON, NEW JERSEY 08540
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FINAL

A PLAN FOR THE ECONOMIC ASSESSMENT OF THE BENEFITS OF IMPROVED METEOROLOGICAL FORECASTS

Prepared For

National Aeronautics and Space Administration

Office of Applications

Washington, D. C.

Contract No. NASW-2558

August 31, 1975

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NOTE OF TRANSMITTAL

Since the launching of TIROS I in April of 1960, the science of meteorology has been changed by the introduction of global synoptic data and measurements provided by instrumented satellites. In the same period of time, sophisticated numerical forecasting models have been developed embodying the state-of-the-art understanding of the physics of the atmosphere and the oceans, and large scale computer facilities have been acquired to provide forecasts through these models.

During 1975, ECON was requested to prepare a plan for the economic assessment of the benefits of improved meteorological forecasts. The objective of this plan is to establish the framework for the further analysis of the economics of improved meteorological forecasts. The plan is intended to provide a basis for the analysis of this area, proceeding from the identification of the users and uses of meteorological forecasts through the estimation and verification of the benefits.

In the process of preparing this plan, our research has led us to the conclusion that, while many studies have been made of the economics of current and improved forecasting capabilities, nearly all of these studies have been made without user involvement. Moreover, the resulting benefit estimates have not been verified experimentally. We conclude that the process of user involvement in both the estimation and

NOTE OF TRANSMITTAL (Continued)

verification must be an important element of future work in this field. An important byproduct of this study is a comprehensive list of references of previous work relating to the economics of meteorology.

ECON acknowledges the contributions of Dr. Ranendra Bhattacharyya and Joel Greenberg, who performed the study and authored this report. ECON also acknowledges the assistance of Ms. Olimpia Safai, who was responsible for the data collection and research of weather-sensitive industries.

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1.0 STATEMENT OF PROBLEM

Since 1959, several satellites launched by NASA have provided remotely sensed data by the observation of land, water and atmosphere of the earth. Satellites such as Nimbus, Tiros, ITOS, ATS, SMS and GOES have provided valuable meteorological data for a better understanding of weather phenomena, and have led to some improvements in weather forecasting. With the increasing sophistication of space and related technology, more ambitious projects are now being conceived. Efforts are being focused on satellites such as Tiros-N, Nimbus-F, STORMSAT and SEOS. Tiros-N, planned for launch in early 1978, will be the forerunner of a new operational polar orbiting system, with microwave channels for improved soundings in the troposphere and stratosphere. Nimbus-F is characterized by improved atmosphere temperature profiling capability. STORMSAT and SEOS will be geo-synchronous satellites especially suited to observe fleeting phenomena. STORMSAT will be equipped with an advanced atmospheric sounding and imaging radiometer (AASIR) to provide visual and infrared imagery with a resolution of 750 m. and 4.5 km., respectively. SEOS will utilize a 150 cm telescope and achieve a much greater resolution than STORMSAT.

Each of the contemplated satellites is characterized by its unique observational capabilities defined by its sensor complement and orbit characteristics. This, in turn, is

reflected in the cost of the overall system as well as the benefits that can be accrued from the gathered data. Thus, in order to objectively determine the need for and the value of a proposed satellite system, it is necessary to analyze the resultant incremental costs and benefits. The benefit-cost analysis concept is illustrated in Figure 1.1. The point X on the abscissa defines the overall capability of a forecasting system utilizing meteorological data obtained from existing satellite systems. Both the cost and the benefit associated with the existing forecasting system are treated as the reference level which is defined as zero in the figure. With a forecasting system which utilizes meteorological data obtained from a new satellite system with greater capability, both the cost and the associated benefit will, it is assumed, increase. From the curves of the present values of the incremental cost and the incremental benefit, it is clear that there is a capability X* which defines a new capability level for which the "net incremental benefit," i.e., the incremental benefit minus the incremental cost, is maximized. Hence, assuming that the incremental annual cost that corresponds to PX* (where PX* is the present value of the incremental benefit) does not exceed the annual budget constraints, the optimal course of action is to pursue the design of a new system which will achieve the capability X*.

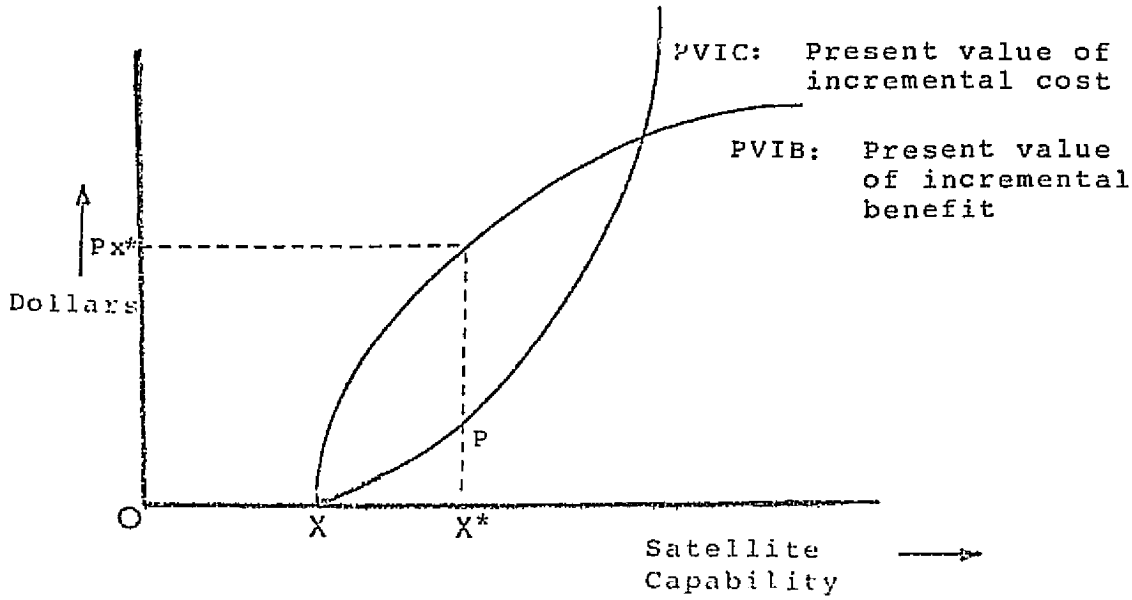

Figure 1.1 Incremental Cost-Benefit of Satellite System

However, cost considerations are not included in the present task. Therefore, the remainder of the report deals only with the benefits associated with the weather forecast capabilities of the various weather satellites - past, present and future. Weather forecasts are provided for a wide range of phenomena which can be categorized according to their time durations and the extent of the areas affected. There are three major weather categories: (1) slow changes of global climate that introduce variations in rainfall patterns, temperature distributions, polar ice variations, etc., (2) mid-latitude cyclonic storms with dimensions of the order of thousands of square miles and life cycles of several days and (3) small-scale phenomena such as thunderstorms and tornadoes lasting

for a few hours over several square miles. Because of the intrinsic differences in these three categories of weather phenomena, their forecasts require different approaches and different satellite systems.

During the last few years, NASA, along with other governmental and scientific institutions, has undertaken an extensive study of climatic history and recent climatic anomalies. These studies have demonstrated that long-range climatic variations are related to the earth's radiation balance, the ice boundaries, the oceans, the ozone layers in the upper atmosphere, and the changes in greenbelt due to various factors such as industrialization, over-grazing, etc. LANDSAT has proven effective in gathering data on some of these slow variations. The seasonal polar sea-ice boundaries have been regularly monitored by Nimbus-5. Nimbus-4 has provided data on the ozone concentration of the stratosphere. Both ITOS and Nimbus have gathered data on the high altitude circulations between the northern and the southern hemispheres. Elaborate mathematical models for climate studies are being developed to correlate these data with long-term climatic forecasts.

In the area of the medium scale phenomena such as mid-latitude cyclones, significant forecast improvements have been made through the Global Atmospheric Research Program (GARP) which, as a part of its overall function, has analyzed the Nimbus-5 data. Further, satellites such as ITOS and SMS have

made significant contributions to the 24 to 48 hour forecasts of the medium-scale phenomena. It is felt that, with improved mathematical models of the atmosphere, it may be possible to make reasonably accurate forecasts over a period of one to two weeks.

The synchronous satellites are especially suited for the detection and possibly the forecast of small-scale fleeting phenomena. This capability was first demonstrated by ATS-1 in 1966. More advanced synchronous satellites such as ATS-6 and SMS have brought about significant progress in this area. Future synchronous satellites such as STORMSAT and SEOS are expected to make a greater impact.

It is the purpose of this report to develop a rational approach which will lead to the establishment of the economic benefits which may result from the utilization of data obtained from new satellites such as STORMSAT and SEOS. Hence, the main emphasis of this report is on the medium and short-range weather phenomena rather than the long-term climatic variations. The weather events considered for this task are: thunderstorms, snowstorms, hurricanes, tornadoes, frost and temperature variations. Any effective improvement in the forecast of these weather events is expected to have a significant impact on various national industries and resource management functions. It should be noted at the very onset that the benefit estimation process is in terms of forecast capability and

not spacecraft sensor capability. As will be discussed later, it is extremely important to establish the relationship between sensor capability and forecast capability.

In order to estimate such impacts, a detailed analysis consisting of the following steps is proposed:

1. Industry Identification: Identification of the significant weather sensitive industries,
2. Resource Management Functions (RMF) Identification: Identification of the specific RMFS and the corresponding user groups within each industry that might be sensitive to weather forecast capability,
3. Weather Event Identification: Identification of the types of weather events that affect the various operations of the industries,
4. User Identification: Since all users that might realize benefits from weather forecasts do not necessarily use them, it is necessary to identify the fraction that regularly use weather forecast data as an input to operational decisions and the efficiency with which such utilizations are carried out,
5. Forecast Capability Identification: Identification of the sources and the types of weather forecast services that users avail themselves of. This includes the determination of the accuracy

of such existing forecasts by collecting the forecast data and the actual weather event occurrence data. For future systems utilizing data from STORMSAT or SEOS, it is necessary to estimate the forecast accuracy which results from the improved data collection capabilities.

6. Current Benefit Estimation: Preliminary estimation of the benefits associated with the current usage of existing weather forecast capabilities,

7. Current Potential Benefit Estimation: Estimation of the maximum benefits that might accrue if the current weather forecasts associated with the existing capabilities are used optimally by all relevant users,

8. Improved Capability Potential Benefit Estimation: Preliminary estimation of the additional potential benefits that would accrue if the improved forecasts associated with the improved data gathering capabilities of the future satellite systems are optimally used by all relevant users,

9. Detailed Benefit Estimation (Case Studies): Selection of several industries and RMFs, from the preliminary list, that show significant potential benefits for performing in-depth case studies. Establishment of

user contacts to understand the details of their operations, taking into account the various technical, economic, operational and legal constraints within which the user decisions have to be contained. If preliminary benefit estimates appear reasonable after user review, then it becomes necessary to perform detailed benefit calculations, including, as necessary, econometric and simulation modelling, taking into account all these realities, so as to supplement the preliminary benefit results obtained earlier. The case study results can then be extrapolated to the relevant industries and RMFs.

10. Experimental Validation of Case Study Results: Experimental validation consists of the design and performance of experiments utilizing existing and potentially available remotely sensed data and resulting forecasts. Objectives of these experiments are to facilitate technology transfer to the users and to experimentally validate the theoretical benefit estimates. The design and performance of experiments should intimately involve users and be based upon existing and potential user operations. The experiments should lead to the demonstration of the value of the improved forecasts by

comparing operations and costs with and without the utilization of improved weather forecasts.

Some progress has been made relative to the sequence of steps listed above and is discussed in Section 4.0. However, the overall task has only been started. For example, a list of significant weather sensitive industries has been compiled following the Standard Industrial Classification Manual (SIC) and the Dunn and Bradstreet Million Dollar Directory 1975, preliminary benefit studies of a number of industries have been carried out based on the forecast capabilities as supplied by the NASA Goddard Space Flight Center, and several detailed benefit studies have been conducted. User contacts have been established and some experimental data on forecast capabilities obtained which augment the data supplied by Goddard Space Flight Center on the technical (forecast) capabilities of the advanced systems considered. <u>However, no detailed case studies have yet been undertaken in collaboration with user groups</u>.

2.0 BACKGROUND

The National Weather Service (NWS), under the National Oceanic and Atmospheric Administration, has a vast operating program [Ref. 2]. In one year, about 3.5 million observations are taken and 1.9 million forecasts and warnings issued. The physical plant of NWS is valued at about $60 million. This includes hundreds of facilities and thousands of items of major equipment. In addition, facilities and equipment valued at millions of dollars, including the most advanced data processing equipment, are supplied by or leased from public and private agencies. Domestic and overseas operating locations are linked by an extensive international communications system.

The public and specialized meteorological forecast and service activities include:

1) Acquisition of raw data and the preparation of basic analyses and prognoses and other guidance material,

2) Refinement of guidance material into final products suitable for the public and for special user groups, and

3) Dissemination of the final products to the users.

As necessary, severe weather warnings are issued as far in advance as the present state of forecasting permits and are given widespread public dissemination by all possible media.

The basic meteorological organization of NWS is composed of three echelons as illustrated in Figure 2.1.

1) The first echelon consists of the National Meteorological Center (NMC), the National Severe Storms Forecast Center (NSSFC), the National Hurricane Center (NHC), the Hurricane Warning Centers at San Francisco and Honolulu, and the Regional Center for Tropical Meteorology (RCTM) at Miami. NMC is the backbone of the entire organization, and is responsible for the preparation of much of the synoptic scale guidance material and long-range forecasts used by the lower echelons. NSSFC provides a single source for severe local storm watches. NHC serves the same function for hurricane forecasts in the Atlantic and Gulf of Mexico, whereas San Francisco provides this service for the eastern Pacific, and Honolulu for the central Pacific. RCTM has a function similar to that of NMC for certain tropical areas.

2) The second echelon consists of the Weather Forecast Offices, numbering 52 including Alaska, Hawaii and Puerto Rico. These offices are responsible for warnings and forecasts for states, or large portions of the states, and assigned zones. Their state forecasts are issued twice

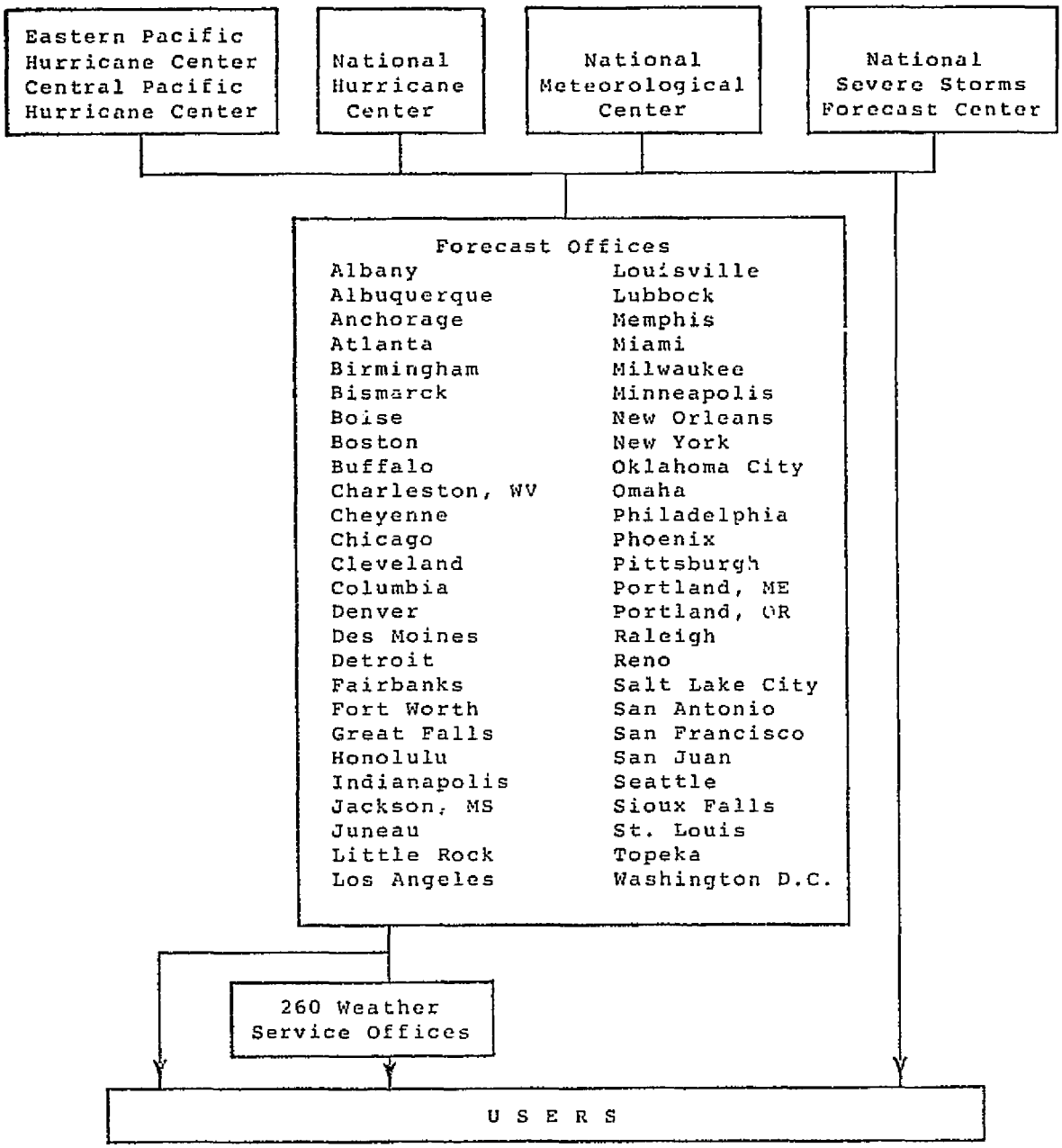

Figure 2.1 Basic Meteorological Organization of the NWS

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daily for a period of time out to 48 hours. This echelon provides the main field forecast support for the marine and aviation programs, as well as guidance for the agricultural and fire weather programs.

3) The third echelon consists of the Weather Service Offices. They issue local forecasts which are adaptations of the zone forecasts.

As mentioned earlier, the National Meteorological Center provides basic weather analysis and forecast guidance for use by lower echelons. It also provides an increasing number of meteorological end-products, such as wind forecasts for aviation and precipitation forecasts for hydrology and public services. In the course of one day, NMC receives the following observational reports from points around the world:

1) 14,000 synoptic and 25,000 hourly surface aviation
2) 2,500 synoptic ship
3) 2,500 atmospheric sounding
4) 3,500 aircraft
5) All available cloud and temperature data from weather satellites

The data are centrally processed and analyzed in a computer system, and the processed data are distributed widely. NMC makes 673 facsimile and 810 teletypewriter transmissions daily

to field offices. A few typical weather service programs that are, at present, in existence are listed below:

1) State forecast program,
2) Zone forecast program,
3) Local forecast program,
4) Community preparedness program,
5) Hurricane warning program,
6) Tornado and severe local storms warning program,
7) Coastal flood warning program,
8) Fruit-frost program,
9) Domestic aviation weather program,
10) International aviation weather program,
11) Service evaluation and safety investigation weather support program,
12) Urban air pollution weather service program,
13) Fire weather forecast and warning program,
14) Flash flood warning program,
15) Water management information program,
16) Tsunami warning system program,
17) High seas program,
18) Marine program for coastal and offshore waters, and
19) Marine program for great lakes.

With the introduction of satellite technology, it has been possible to take frequent and worldwide weather related

measurements, as mentioned in Section 1.0. This has led to improvements in the atmospheric models used for weather forecasting. NWS has, by now, processed data transmitted by ATS, SMS, GOES and the operational polar orbiting satellites. The SMS/GOES picture distribution system began operation in the summer of 1974 in order to move the pictures quickly from the satellite to the forecaster. Selected picture sectors are sent from a Central Data Distribution Facility (CDDF) via specially conditioned telephone lines to photorecorders located in NESS Satellite Field Services Stations and the WSFO/GOES facilities of the NWS. The forecasters receive the pictures within 25 minutes after they are taken by the satellite.

As mentioned in Section 3.0, "Methodology," the effectiveness of any of these programs can be expressed in terms of false alarm and miss probabilities, which are defined as follows:

1) False Alarm Probability: the conditional probability that an adverse weather event does not occur, given that a forecast was made for that adverse weather event, and
2) Miss Probability: given that an adverse weather event has occurred, the conditional probability that the forecast was for the adverse weather event not to occur.

With improvements in weather forecasting, it is expected that the values of the false alarm and miss probabilities will decrease. This, in turn, will give rise to certain economic benefits, as discussed in Section 3.0.

3.0 METHODOLOGY

Meteorology, as one of the environmental sciences, has been the beneficiary of many technological advances during recent years. These have included sophisticated tools such as meteorological satellites, electronic computers, and weather radar. However, not only has the development and use of these new devices required an expenditure of men, money, and material, but there is no indication that the need for these expenditures will decrease in the future. To a certain degree, these expenditures may be justified by the expanded scientific knowledge and other benefits that have been and will be accumulated. In the present environment, however, decisions regarding the approval of future programs require the consideration of the potential monetary returns that may result from government investments in research and technology programs. It is therefore important that an attempt be made to examine the economic benefits which may be expected from continuing investment and resulting progress in meteorology.

While many studies [References 3-24] have been made of the economic benefits and costs associated with current and improved weather forecasting capabilities, with but a few exceptions, these studies and resulting estimates have been made without user involvement. Therefore, the benefit estimates, for the most part, which have been made to date must be viewed

with a great deal of skepticism. Future benefit analyses must be undertaken with user involvement. A method for achieving this will be discussed in following paragraphs.

The government is currently funding research which, it is hoped, will ultimately lead to an improved understanding of weather phenomena and to improved weather forecasting capabilities. Within this context, it has been proposed to develop advanced capability satellites which will lead to improved forecasting of storms and other related meteorological phenomena. It is assumed that the government will provide the funds required for the research and development of this capability. If the research and development is successful, it is assumed that the government will implement an operational capability and that industries will capitalize at the appropriate time by incorporation into their operations the capabilities which have resulted from the government funding. The purpose of the government investment is the development of technology which will be of benefit to both industry (producers) and consumers. The magnitude of the economic benefits, increased profits for the producers and/or decreased prices for the consumers, is a measure of the value or desirability of the government investment. The government incentive in funding the R&D program is the perceived, estimated, or anticipated added benefits in the form of added consumer and producer surplus which will result from development of advanced technology. The added benefits

can only be achieved if industry utilizes the data and services that result in cost reductions. These benefits are maximized if the cost reductions are passed on to the consumer in the form of price reductions. It is assumed that producers will not capitalize on the advanced technology developments unless it is perceived, estimated, or anticipated that their operations will be improved. Following the above reasoning, it may be concluded that the government funded R&D program should pursue a course such that the added net benefits (benefits less costs) are maximized. This can only result if producer implementation takes place -- the sooner the implementation, the larger the benefits perceived by the government. Therefore, the government funded research should be oriented such that both the likelihood and the rate of producer implementation are maximized.

The orientation of and the results obtained from a research and development program can significantly influence the set of technologically and economically operational system alternatives and producers' options. It is therefore desirable to investigate the net social benefits that would result from the various implementation alternatives and to pursue an R&D program which will maximize the likelihood of achieving that capability which maximizes the net benefits.

In the discussions which follow, it is assumed that the R&D program will lead to an operational system, funded by the government, whose technology and level of capability are a direct consequence of the R&D program. It is further assumed

that the benefits result from data (i.e., meteorological forecasts) made possible by the operational system. The general pattern of costs and benefits is illustrated in Figure 3.1.

Within a specific technology, there are many different alternative technology development programs which can lead to a specific level of performance or capability. Capability, it should be noted, is normally a multidimensional parameter (for example, miss and false alarm probabilities* associated with different meteorological events). This is illustrated conceptually in Figure 3.2 where the present value of cost, of PVC, and of alternative technology programs is shown for achieving different performance or capability levels. For simplicity of illustration, capability is shown as a one dimensional parameter. It can be seen that for any desired level of performance a minimum present value of cost alternative can be selected, this normally being a long and difficult process. It can also be seen that the locus of minimum present value of cost approaches can be established in terms of performance level -- this being referred to as the "technology frontier." It must be emphasized that the phrase "technology alternative" encompasses both the government funded R&D program and the government funded operational system which is the direct result of the R&D program.

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*See Reference [3].

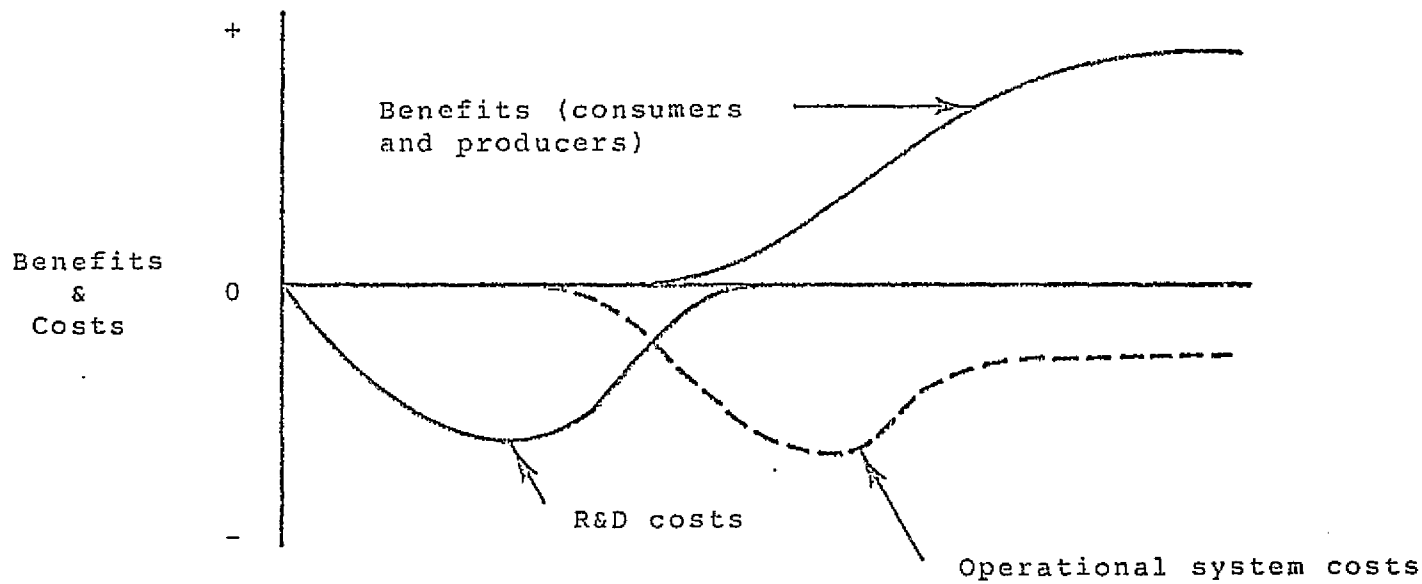

Figure 3.1 Time Flow of Costs and Benefits

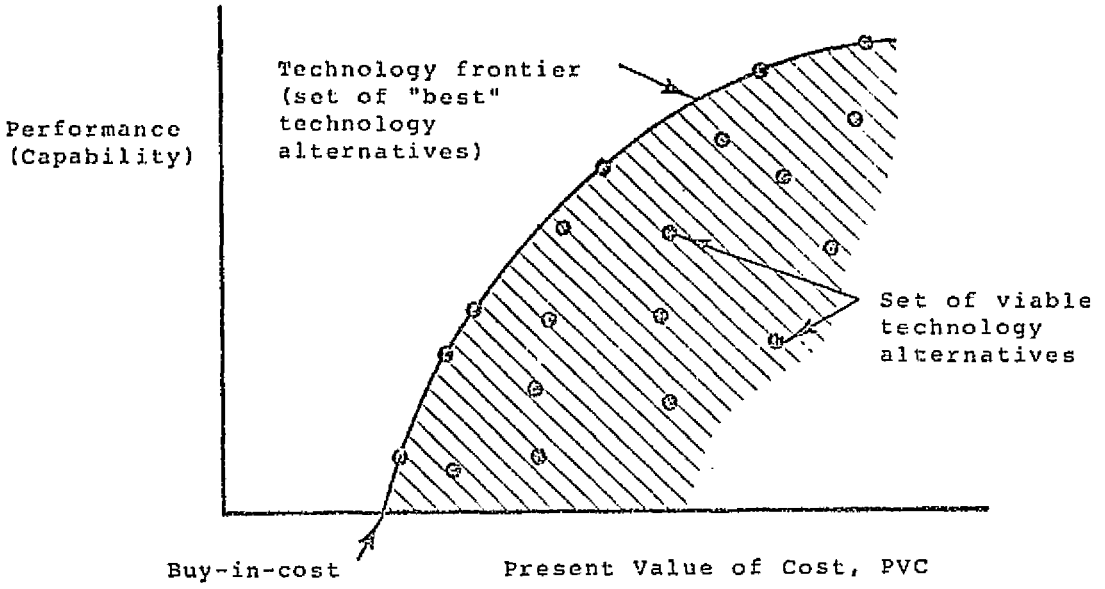

Figure 3.2 The Cost-Performance Technology Frontier

In general, different performance levels can be achieved with different technologies. This is illustrated in Figure 3.3 where each technology base is represented by its technology frontier in terms of performance vs. present value of cost. In general, the specific set of alternatives, that is, the technology frontier, which is most "efficient" is a function of performance level and is illustrated in Figure 3.3. Again, a technology frontier can be established which is the locus of the technology frontiers of each of the technology bases. This is the goal of R&D planning - to establish the best or most efficient (minimum present value of costs) technology alternatives in terms of performance or capability. The "best" technology base to be pursued as a function of

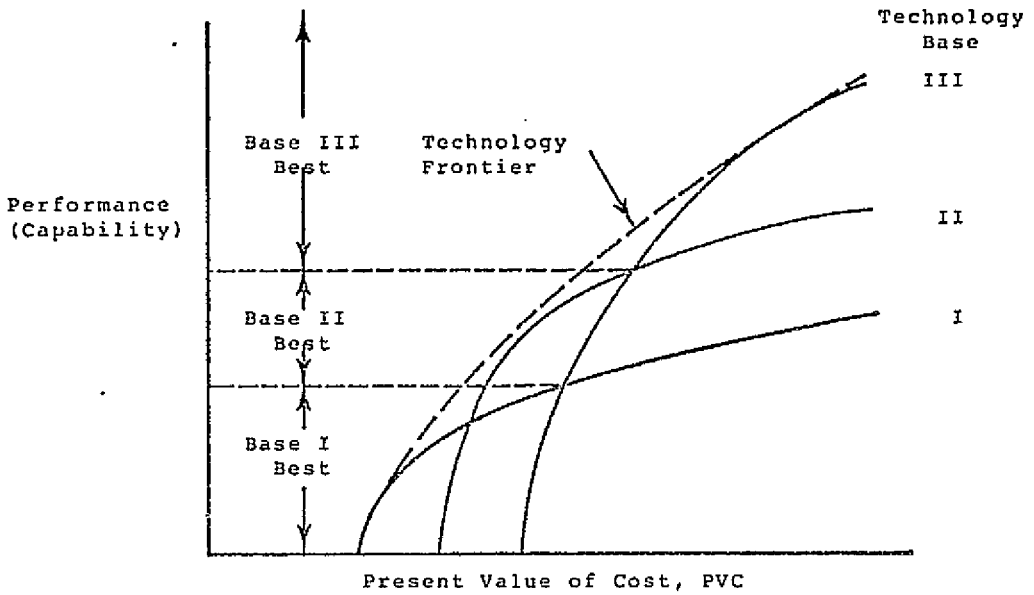

Figure 3.3 Most Efficient Technology Base as a Function of Performance (Capability)

capability is based, so far, only upon the consideration of the present value of cost of achieving the capability and is not based upon the benefits which might be obtained if indeed the performance or capability is achieved.

The effect of considering both the costs and benefits upon the determination of desired performance level and technology development alternative has already been discussed briefly in Section 1.0. However, for ready reference, it is illustrated in Figure 3.4. Figure 3.4 illustrates both the present value of costs and present value of benefits which are directly attributable to the alternatives on the technology frontier. The alternative and its performance level should be chosen such that the net present value,

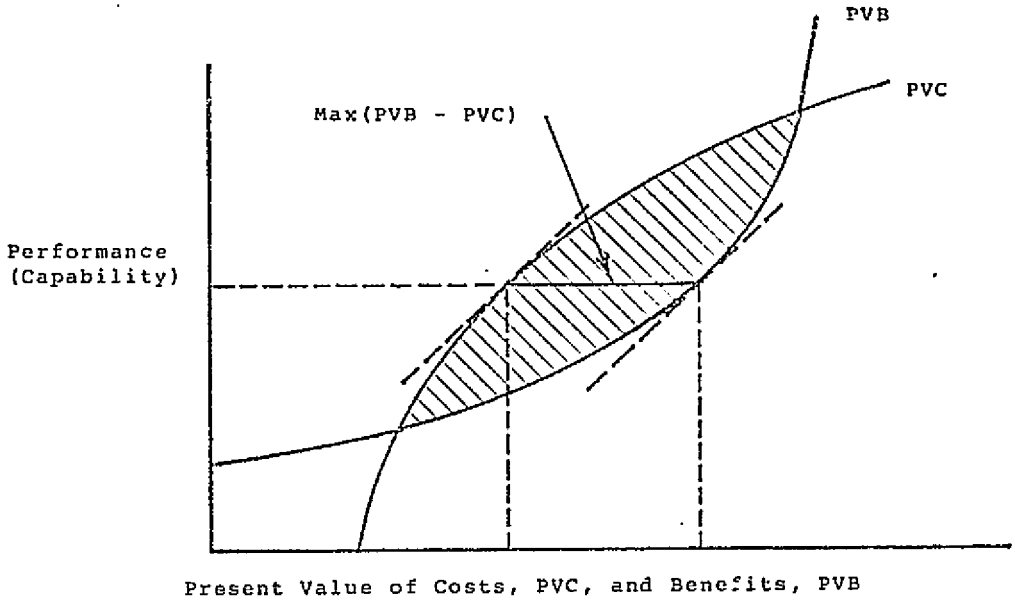

Figure 3.4 Present Value of Costs, PVC, and Benefits, PVB

that is the present value of benefits less the present value of cost (PVB-PVC), is maximized. This occurs at that performance level where the slopes of the benefit and cost curves are equal. It should be stated clearly that PVC is the present value of the cost of the research and development program and resulting operational system, i.e., the government investment to develop and implement the technology base, and PVB is the present value of the benefits which result from the producers' benefits which are derived from the efficient use of the data provided by the operational system. It is the purpose of this discussion to outline an approach which can be used to evaluate the economic desirability of alternative

technology implementations so that the most desirable R&D program may be pursued.

In the following paragraphs, a methodology is discussed for evaluating the benefits from the various possible meteorological technology implementation alternatives. Prior to this discussion it is worthwhile to consider several situations with regard to determining the desired performance level and also to discuss the specific meaning of benefits and how the benefits may be measured.

Consider program alternatives which result in technologies A and B as illustrated in Figure 3.5. Performance level K can be achieved with technology A and B at cost levels PVC_2 and PVC_1, respectively. It is clear that the development of technology B is preferred to A since, for an <u>equal capability</u>,

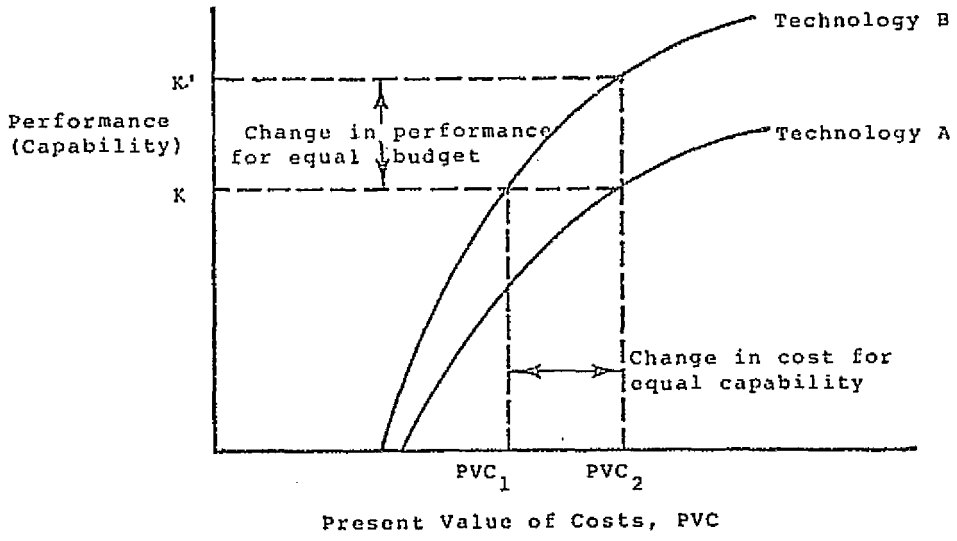

Figure 3.5 Concept of Equal Budget and Equal Capability

the present value of cost is minimized. On the other hand, it should be noted that at a cost PVC_2, technology B can be developed at a higher performance level than technology A (K' relative to K). This increase can be achieved at an <u>equal budget capability</u>. The value of technology B relative to technology A, at an equal capability level, is clearly $PVC_2 - PVC_1$. The value of technology B relative to technology A, at an equal budget level, can only be assessed by an analysis of the benefits which may result from the additional capability.

When comparing two different technology bases with costs PVC and PVC', several situations may arise as illustrated in Figures 3.6 and 3.7. In both figures, AB and A'B' represent the maximum net present value (benefits less costs) associated with technologies having present values of cost PVC and PVC', respectively. In Figures 3.6 and 3.7, it can be seen that A'B' is larger than AB and is achieved at a higher performance level. The increase in net present value in Figure 3.6 is achieved at a lower present value of cost (C'), (increased capability-decreased cost), whereas in Figure 3.7 the maximum net present value is achieved by pursuing technology B at an increased cost (C'), (increased capability-increased cost). The purpose of this example is to illustrate that it is not always desirable to pursue that technology development alternative which is associated with the minimum present value of costs. The selection of the economically best alternative, with its

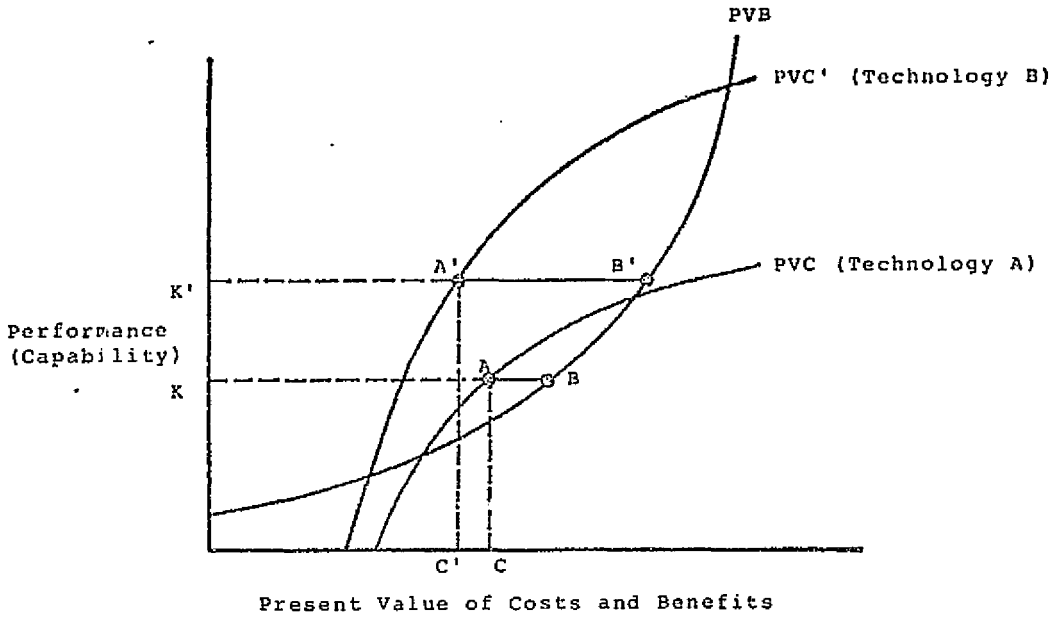

Figure 3.6 Impact of New Technology on Cost-Capability Relationship: Increased Capability - Decreased Cost

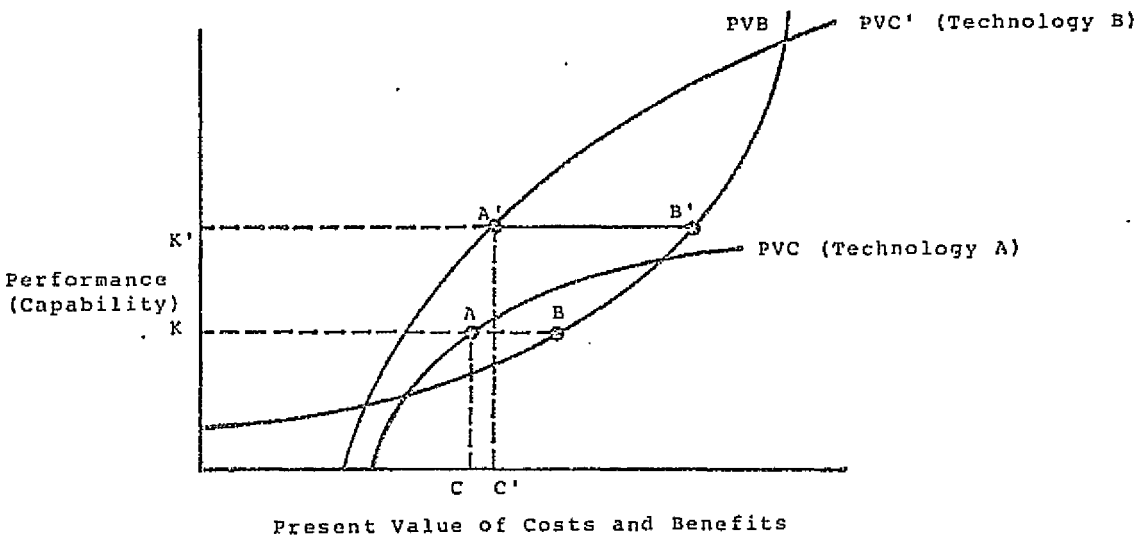

Figure 3.7 Impact of New Technology on Cost-Capability Relationship: Increased Capability - Increased Cost

associated costs and performance level, can only be determined by considering the benefits which may result at different performance levels and then comparing benefits and costs.

As discussed previously, the benefits of the government investment in meteorological research and development are assumed to result from the producers' utilization of data provided by an operational system which is a direct outgrowth of the R&D efforts. It is anticipated, at least in theory, that this will lead to a reduction in the price of related products and/or services. In order to compare alternatives, it is necessary to quantify these benefits. The analysis of the benefits resulting from a government expenditure, from the federal government's point of view, can be assessed by considering Figures 3.8 and 3.9. Figure 3.8 illustrates supply and demand

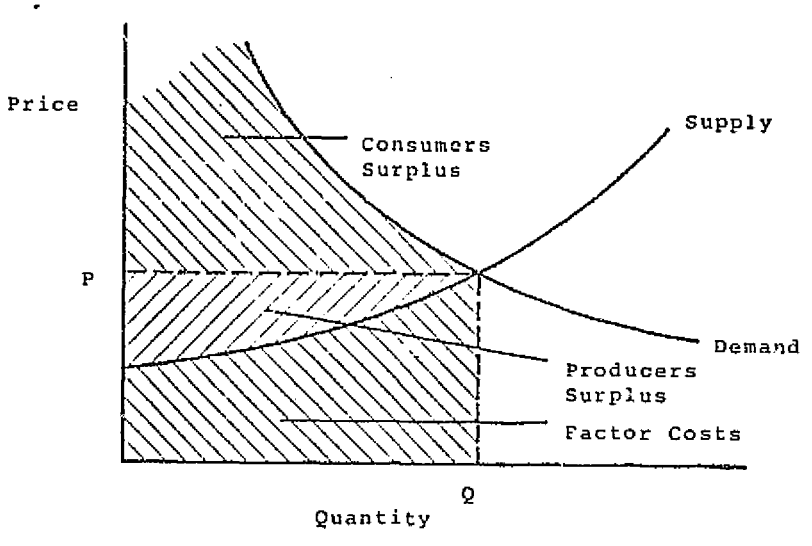

Figure 3.8 Supply/Demand/Benefit Relationship

curves in terms of price and quantity. With the indicated supply-demand curves, a quantity Q of a particular product or service will be sold at a price P. Three cross-hatched areas are shown, namely consumers' surplus, producers' surplus, and factor costs. The consumers' surplus represents the maximum sum of money a consumer would be willing to pay for a given amount of a good, less the amount he actually pays (P). The consumer surplus is the net benefit to consumers from consumption. The producers' surplus represents the net benefit or profit obtained by the suppliers. The factor costs represent payments made by the producers for materials and services and other expenses of production. The area under the demand curve out to the quantity Q (as determined from the supply-demand functions) consisting of consumer surplus and producers'

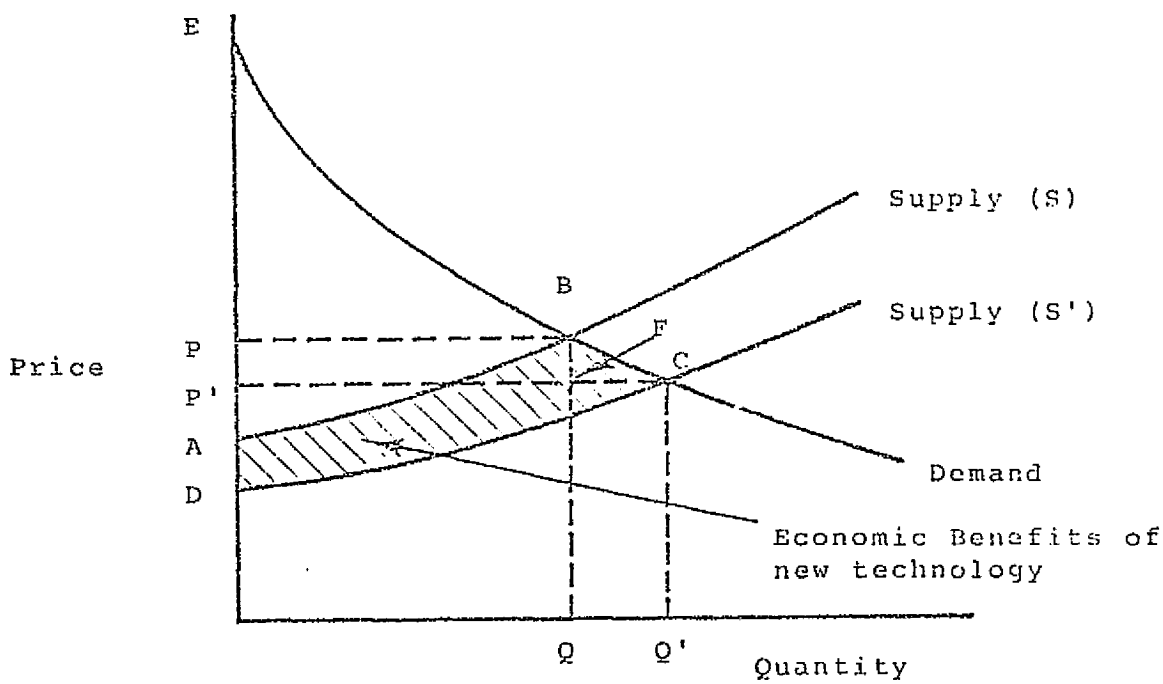

Figure 3.9 Impact of New Technology - Economic Benefits

surplus is a measure of the total public welfare or benefit associated with the product or service under consideration. The particular supply curve (S) represents the marginal cost of the product or service when conventional or current meteorological forecasting capability data are incorporated into the production process. This results in the product or service price P. If, because of government funding, a technology and operational capability are developed which, through improved meteorological forecasting capability, results in reduced factor costs and leads to supply curve S', assuming "ceteris paribus" conditions, then there is an associated decrease in product or service cost to P'. It should be noted that the reduction of the cost of a product or service is deemed to confer a benefit on society. The added public welfare or the economic benefits of the new technology can thus be measured by the cross-hatched area ABCD. This area depends upon the shape of the supply and demand curves and represents the change in consumers' and producers' surplus. Note that the benefits are obtained as a result of factor cost reductions. It is normally assumed that in the long term all displaced factors will seek and find their next best use.

Referring to Figure 3.9, it can be seen that the area ABCD, representing the increase in benefits, consists of the change in consumer surplus (PBCP' = ECP' - EBP) plus the change in producer surplus (P'CD - PBA). The change in consumer

surplus consists, in turn, of two parts that are referred to as the equal capability benefits given by (P - P') x Q and the added capability benefits as per the area BCF. Simply multiplying the quantity consumed by the price differential (P - P') yields a measure of the equal capability consumer surplus benefits; it does not include the added capability benefits and does not necessarily properly provide an accurate measure of the added public welfare resulting from the development of the new technology (because of the producers' surplus). When demand is inelastic, *i.e., $|\varepsilon| = 0$, there are no added capability benefits resulting from a price decrease. On the other extreme, when demand is perfectly elastic, i.e., $|\varepsilon| \to \infty$, the added capability benefits resulting from a price reduction become very large. Depending upon the values of ε and the shape of the supply curves, it is clear that the added public welfare may differ from the increase in equal capability consumer surplus by a non-negligible amount. The point is that a reduction in price confers a benefit on society and the magnitude of the reduction can be used to ordinally rank the order of desirability of alternative courses of action; the price reduction in itself may not be a reliable quantitative

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*Elasticity, ε, is defined as the percentage change in quantity divided by the percentage change in price:

$$\varepsilon = \frac{P}{Q}\frac{dQ}{dP} .$$

measure of the added public welfare and thus may provide little insight into the magnitude of the development program which is allowable in order to produce the price reductions.

In meteorological benefit analyses performed to date, a number of simplifying assumptions have been made. These are illustrated in Figure 3.10. The major assumption is that demand is inelastic, i.e., $|\varepsilon| = 0$, and therefore there are no added capability benefits resulting from price reductions. This is a conservative assumption which tends to lead to an understatement of benefits. The area ABCD represents the benefits attributable to the new technology (the shift in the supply curve from S to S'). As will be described in following paragraphs, the benefits result from improvements in scheduling brought about by the efficient utilization of improved meteorological forecasting data in the decision-making process.

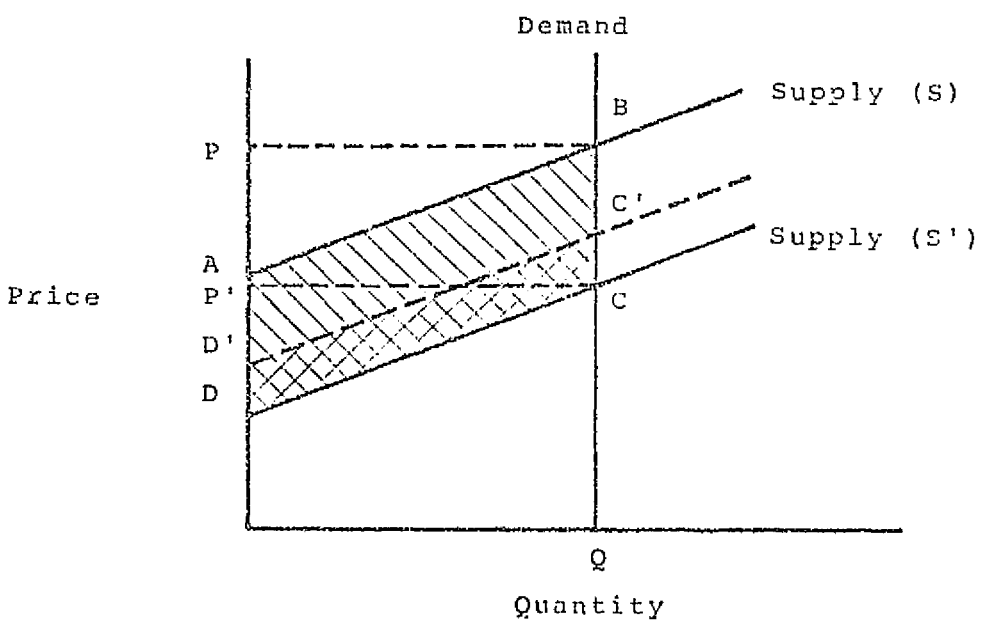

Figure 3.10 Supply/Demand Relationship Approximation

The scheduling improvements result in reductions in factor costs which may or may not be passed on to consumers; in either case, the benefits are given by the area ABCD. The assumption is that the factors which are no longer required will seek and find their next best use. This, however, may not necessarily be the case in the short term since part of the cost savings may occur from intermittent and essentially random labor work hour reductions. When this occurs, it may not be possible, in the short term, for the labor force to find its next best use. Thus, the situation may arise where part of the increase in producers' surplus occurs as a result of a dis-benefit to the workers. Again to be conservative, when this occurs the benefits are computed as the area ABC'D', with the true benefits (in the short term) being between the areas ABC'D' and ABCD. It might be argued, on the other hand, that workers so affected will ultimately renegotiate annual wage rates so as to earn the same annual wage (even though they are productively employed less) thus reducing the producers surplus to the area given by ABC'D'. It further might be argued that this added leisure time has an economic value with the area D'C'CD being an upper limit. In any event, to be on the conservative side, the area ABC'D' has, in most cases, been used as a measure of the economic benefits of improved meteorological forecasting.

The industry potential annual benefits may be defined as the cost reduction, i.e., the savings that would result from

the optimum utilization by the user community of meteorological forecasts of increased accuracy and reliability. Savings may be computed as the difference between the cost of performing a specified task or application when forecasts of level x are available and when forecasts of level y are available. It is assumed that the forecasts are used in such a manner that the user undertakes that course of action which, for a given forecast capability, minimizes cost.

Many applications which have been considered to date were found to be quite similar, particularly with respect to the utilization of meteorological forecast data. These are applications where a decision-maker must <u>choose between taking or not taking</u> some specific <u>protective action</u> against a future unfavorable weather condition: taking the protective action involves some cost with certainty; not taking the protective action involves escaping that cost, but incurring a certain loss if the unfavorable weather condition does in fact occur.

Thus, a newspaper distributor, who has a standard routine for distribution, can wrap his papers in plastic bags to protect them from rain. A storekeeper can tape his windows to protect them from a threatening hurricane. A construction company can delay pouring concrete and release employees from work when thunderstorms are forecast. A farmer can delay spraying his crops given a forecast for heavy rain. A citrus grower can light smudge pots to protect his fruit from frost.

Snow removal crews can be alerted and snow removal started earlier. Fishing fleets can be rescheduled when severe storms are forecast.

Consider the forecasts which might be provided to a decision-maker. For example, let y_1 and y_2 be forecasts of the occurrence or non-occurrence of a meteorological event; for example, storm or no storm. In the event that y_1 is forecast, the event w_1 and w_2 may actually be observed, for example, a storm or no storm is actually observed. This is shown in Figure 3.11, where a two-by-two contingency array is illustrated. Frequently, π_{21} is referred to as the false alarm probability and π_{12} is referred to as the probability of miss. The significance of these two terms will become apparent. Suffice it to say at this point that the economic benefits which may be achieved as a result of a new forecast capability are directly related to the probability of a false alarm and the probability of a miss. A false alarm occurs when, for example, clear weather occurs when a storm has been predicted. A miss occurs when, for example, a storm occurs when clear weather had been predicted.

A payoff function can now be defined as shown in Figure 3.12. The payoff function illustrates the cost of taking actions (pursuing strategies) a_1 and a_2 in terms of the weather forecast. Here a_1 represents the "protect" action and a_2 represents the "do not protect" action.

		FORECAST	
		Y_1	Y_2 (no rain)
OBSERVED	W_1 (rain)	π_{11}	π_{12}
	W_2 (no rain)	π_{21}	π_{22}
		π_1	π_2

π_1 = Probability of forecast y_1, the forecast of unfavorable weather (i.e. storm),

$\pi_2 = 1-\pi_1$ = Probability of forecast y_2, the forecast of favorable weather (i.e., no storm),

π_{11} = The conditional probability of unfavorable weather (w_1), given that forecast y_1 is made,

$\pi_{21} = 1-\pi_{11}$ = the conditional probability of favorable weather (w_2), given that forecast y_1 is made,

π_{12} = The conditional probability of unfavorable weather (w_1), given that forecast y_2 is made,

$\pi_{22} = 1-\pi_{12}$ = The conditional probability of favorable weather (w_2), given that forecast y_2 is made.

Figure 3.11 Two-by-Two Contingency Array

		WEATHER	
		Y_1 & W_1 (rain)	Y_2 & W_2 (no rain)
ACTION	a_1 (protect)	-C	-C ← cost of protection
	a_2 (no protect	-L ← loss	0

Figure 3.12 Payoff Function

The decision-maker's problem is to determine the best course of action given a forecast of y_1 or y_2. If the decision-maker receives forecast y_1, his expected cost if he chooses action a_1 is C, while his expected cost if he chooses a_2 is $\pi_{11}L$. Therefore, the choice of action given y_1 (i.e., $a(y_1)$) is

$$a(y_1) = \begin{cases} a_1 & \text{if} \quad C<\pi_{11}L \\ a_1 \text{ or } a_2 & \text{if} \quad C=\pi_{11}L \\ a_2 & \text{if} \quad C>\pi_{11}L \end{cases} \tag{3-1}$$

and the objective is to select that course of action depending upon the specific values of C, L, and π_{11}, such that

$$E(a|y_1) = \text{Min} \quad (C, \pi_{11}L) \tag{3-2}$$

where $E(a|y_1)$ is the expected cost given forecast y_1.

Similarly, when he receives forecast y_2, he chooses a_1 or a_2 depending on whether C or $\pi_{12}L$ is smaller. Therefore,

$$a(y_2) = \begin{cases} a_1 & \text{if} \quad C<\pi_{12}L \\ a_1 \text{ or } a_2 & \text{if} \quad C=\pi_{12}L \\ a_2 & \text{if} \quad C>\pi_{12}L \end{cases} \tag{3-3}$$

and

$$E(a|y_2) = \text{Min} \quad (C, \pi_{12}L) \tag{3-4}$$

The above equations determine the decision-maker's best decision rule, and the expected minimized cost for each of the two forecasts. The overall expected cost, E(C), under the best decision rule is given by

$$E(C) = \pi_1 \text{ Min } (C, \pi_{11}L) + \pi_2 \text{ Min } (C, \pi_{12}L) \quad (3\text{-}5)$$

potential saving, S, or industry benefit resulting from improved forecasts is therefore given by

$$S = \Delta E(C) = E_A(C) - E_B(C) \quad (3\text{-}6)$$

where $E_A(C)$ and $E_B(C)$ are the specific values of minimum expected cost resulting from system alternatives A and B where each alternative has associated with it different values of the π_{ij} terms in the contingency array.

Equations 3-5 and 3-6 yield the industry expected costs and potential industry benefits, respectively, resulting from the best decision rule for a given capability level of forecast.* The social benefits may differ since, in general, at least a portion of the industry savings will occur as the

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*Note that in previous studies forecasts are assumed to be stated as certainty equivalent events. In reality, forecasts can be probabilistic (i.e., there is an 80% chance of rain, etc.). Future analyses should investigate the industry decision rules and resulting benefits given probabilistic forecasts.

result of a loss to some other sector of the economy (for example, industry savings which result from wage reductions are offset by labor's loss of wages, assuming that labor cannot recoup, at least in the short term, the lost wages by some other productive means or wages are renegotiated so as to maintain near or the same annual wage as before the introduction of the new technology).

To establish the expected social cost, E'(C), under the best industry decision rule, Equation 3-5 can be restated as

$$E'(C) = \pi_1[\mathrm{Min}(C, \pi_{11}L)+K_1] + \pi_2[\mathrm{Min}(C, \pi_{12}L)+K_2] \quad (3\text{-}5A)$$

where

$K_1 = C'$	when	$C \leq \pi_{11}L$
$K_1 = \pi_{11}L'$	when	$C > \pi_{11}L$
$K_2 = C'$	when	$C \leq \pi_{12}L$
$K_2 = \pi_{12}L'$	when	$C > \pi_{12}L$.

C' and L' are the losses or costs which are incurred by other segments of the economy when the optimum industry policy is pursued.

The expected potential social benefits are given by

$$E(B) = B = \Delta E'(C) = E'_A(C) - E'_B(C) \quad (3\text{-}6A)$$

where $E'_A(C)$ and $E'_B(C)$ are the specific values of expected social costs resulting from system alternatives A and B.

It should be noted that in previous meteorological benefit analyses no consideration has been given to supply-demand-price relationships and their consequences in the determination of benefits. This omission has been a necessary limitation imposed by the magnitude of effort constraint. Future benefit analyses should consider, when applicable, the elimination of this omission. It should also be noted that in previous benefit analyses various weather events have been treated independently. In fact, there is a high degree of correlation between different types of weather events. Future analyses should take into account the statistical relationships between the pertinent events.

In general, the annual costs or expenses associated with weather phenomena can be considered in three parts, namely (1) expenses incurred on false alarm days; (2) expenses incurred on miss days; and (3) expenses incurred on correctly forecast days. A <u>false alarm day</u> signifies a day when a forecast for a storm (or frost) is made which, in reality, turns out to be a clear day. A <u>miss day</u> signifies a day when a forecast is made for clear weather which, in reality, turns out to be a stormy (or frost) day. A <u>correctly forecast day</u> is one where the event forecast actually occurs. It should be noted that when the forecast capability is perfect the total expense is associated with correctly forecast days. As the forecast capability degrades the expenses associated with false alarm and

miss days increase, whereas those associated with correctly forecast days decrease. This is illustrated by the following equations.

$$\beta = N\pi'_{12} \tag{3-7}$$

$$\gamma = N - \beta \tag{3-8}$$

$$\alpha = \eta - \gamma = \gamma\left(\frac{1}{\pi_{11}} - 1\right) \tag{3-9}$$

where

β = Number of miss days,

N = Number of storm days which occur per year,

π'_{12} = Probability of clear weather forecast, given that storm is to occur in reality,

γ = Number of days of storm occurrence which are forecast correctly,

α = Number of false alarm days,

n = Number of days that storm is forecast, and

π_{11} = Probability of storm occurrence, given a storm forecast.

Note that π'_{12} differs from π_{12} which was previously defined as the probability of a storm occurrence, given a clear weather forecast. This modification is necessary because data are available on the number of storm occurrences in a year rather than on the total number of annual clear weather forecasts.

This basic methodology has been employed in the evaluation of many of the benefit areas discussed in References [3], [8] and [24]. Specific values of the π_{ij} terms in the contingency array have been estimated by NASA and others based upon several different remote sensing systems. Values of π_{ij} have also been estimated as a function of the time of forecast.

It was the intent of the rather extensive discussion presented in the previous pages to illustrate several points pertaining to the economic merits of continued meteorology-related research and development. First, <u>both benefits</u> (in terms of user cost reductions) <u>and costs</u> (government R & D and operational system implementation and operations including data processing and data distribution) must be considered so that the net present value of benefits can be established. Both the benefits and the costs should be established in terms of forecasting capability so that the desired forecast capability can be established (i.e., that forecast capability which maximizes the net present value of benefits). Second, the benefits and costs are in terms of meteorological event forecast capability and not sensor measurement capability. Therefore, it is necessary to establish the "transfer function" from measured data to meteorological event forecast capability. This will make it possible to establish the benefits and costs of improved meteorological forecasting in terms of sensor mix and capability. Third, and perhaps most importantly, it is

necessary to evaluate the economic benefits of improved meteorological forecasting with a complete and thorough understanding of meteorological forecast data users' operations, costs and constraints and the potential impact of meteorological forecasts on user operations. The thorough understanding of user operations will lead to a determination of required forecast capability and data products and data distribution requirements.

Lastly, since economic benefits are primarily dependent upon the use of meteorological forecasts by producers, it will, in many cases, be necessary to convince the users that economic benefits can be achieved if meteorological forecasts are correctly incorporated into their decision-making processes. Thus, it will be important to perform benefit demonstrations with direct and extensive user involvement. These user demonstrations will affect both the total achieved benefits and the rate at which the benefits will be achieved (i.e., rate of user implementation).

The benefit analyses performed to date have provided answers to some questions but have left many questions unanswered and have raised many new issues requiring analysis. To a large extent the anslyses to date have served to convert "unknown unknowns" into "known unknowns," thus increasing rather than perhaps decreasing the need for further meteorology-related analyses.

In order to establish meaningful direction to future analyses, it is first necessary to state the goals toward which the efforts should be directed. The additional study/analysis areas outlined in the following paragraphs are directed toward the following goals:

- Provide justification of R&D expenditures,
- Determination of "best" operational system and R&D program combination (see Figure 3-4), and
- Assist in determining the configuration of the R&D and operational spacecraft and time phasing capability.

Within these broad goals, work to date indicates that additional studies and analyses need to be performed in the following broad areas:

- Meteorological Modeling,
- Cost Modeling, and
- Benefit Analyses.

The details will be discussed in Section 5.0.

4.0 A REVIEW OF RECENT BENEFIT STUDIES RELATED TO THE RECOMMENDED METHODOLOGY

A thorough study of benefits which might result from the improvement in weather forecasting capability is a substantial effort. This is evident from the procedural steps outlined at the end of Section 1.0. Several benefit studies have been undertaken in this area as a positive step toward the establishment of reliable benefit estimates. To indicate the extent of the task already completed and the credibility level of the preliminary results, the ten above mentioned steps are considered, one at a time. Under each step, the relevant recent studies are indicated. From this, the remaining tasks that need to be undertaken become evident.

1. Industry Identification

For the purpose of making an accurate identification of all branches of U.S. industry that are weather sensitive, U.S. industries have been categorized according to the Standard Industrial Classification Manual (SIC). This manual assigns so-called SIC numbers to each of the branches of U.S. industry. These numbers are numerical categories established by the U.S. Department of Commerce to cover all industries - manufacturing and non-manufacturing. Every corporation and type of business activity is assigned an SIC number. When a corporation is

enga in more than one activity, the dominant activity prevails in determining the corporate SIC number assigned. A preliminary survey has been made of the industries and subindustries following the SIC classification. Many companies have been contacted by telephone so as to obtain a preliminary estimate as to whether their operations are weather sensitive. Out of the weather sensitive industries, the significant ones have been chosen in accordance with their sales volume as published in the Statistical Abstract of the U.S. (1974), and the Dunn and Bradstreet Million Dollar Directory of 1975. Appendix A provides a list of these significant industries that are, on a first look, sensitive to weather.

2. RMF Indentification

The categorization of significant weather sensitive industries, as done under Step 1, does not, by itself, depict the complete picture of the various weather sensitive operations. This is due to the fact that not all operations within an industry are necessarily weather sensitive. For this purpose, a preliminary list of weather sensitive RMFs has been compiled as illustrated in Appendix B.

3. Weather Event Identification

The weather events that have an impact on various industries and RMFs have been identified as:

- Thunderstorms
- Heavy rain
- Snowstorms
- Hurricanes
- Tornadoes
- Frost
- Hail, and
- Temperature variations.

Recent studies [Ref. 3-24] have considered the benefits resulting from improvements in the forecasting of a number of the above events. To date, these events have been considered independently. Since there is a great deal of correlation between the different events, this must be considered in future analyses.

4. User Identification

Recent benefit studies have not been aimed at specific user identification primarily because of the magnitude of the undertaking and the preliminary nature of the analyses. A rather sizable effort is required to determine the fraction of potential users that actually use weather forecast data in the scheduling of their day-to-day operations. No readily available information seems to occur in existing literature. The task calls for a survey of users following a careful sampling scheme. A questionnaire may be used for this survey and

should be designed to aim at a quantitative description of three types of users: (1) those that do not pay heed to weather forecasts, (2) those that make decisions based on weather forecast data but whose decisions are not optimal due to lack of thorough understanding of the economics involved, and (3) those that follow an optimal course of action, taking into account the specific probabilities associated with the forecasts and the cost of protection and the loss due to lack of protection in adverse weather. This has been discussed in detail in Section 3.0. Figure 4.1 illustrates the various costs and losses as a function of forecast error. As the forecast error increases, it is expected that there will be an increase in the number of misses and false alarms, and a

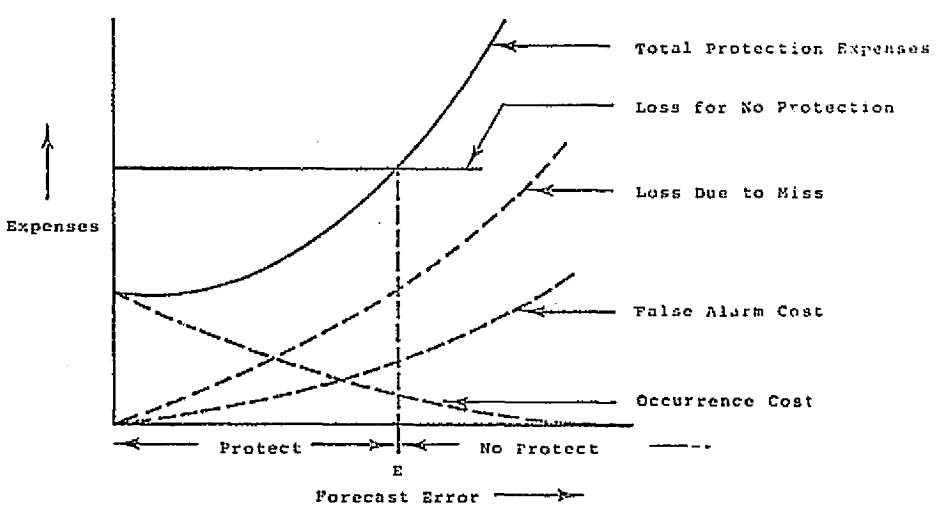

Figure 4.1 Expenses vs. Forecast Error

decrease in the number of correctly forecast days. Thus, if the policy is to protect under adverse weather forecasts, the total expenses of protection increase as the forecast service deteriorates. On the other hand, if a policy of ignoring the weather forecast is followed, the loss obviously remains constant, i.e., independent of weather forecast. Thus, as indicated in Figure 4.1, if the forecast error is less than E, it pays to protect in the face of adverse weather forecasts. But, if the forecast error is greater than E, it pays to ignore the forecast, because the forecast is, more often than not, misleading.

Thus, in order to survey the users' actions, it is also necessary to obtain the proper cost and loss figures that are needed to calculate the optimal course of action under a given forecast capability. Up till now, a few contacts have been established to obtain a rough idea as to how responsive various user groups are to weather forecasts. In industries or activities such as air transportation, electric power generation and distribution, and highway snow removal, it has been observed that the managements of these industries are highly responsive to weather forecasts, and any improvement in the forecast will probably be promptly incorporated into their day-to-day operational decisions. Some of these industries currently employ private consulting firms in addition to the

National Weather Service Forecasts available to them, in order to obtain the needed specialized forecasts. On the other hand, there are certain other industries like construction, where the forecast data are not always utilized to the best advantage of the industry. Moreover, in several cases, due to extraneous reasons, it is not possible to take any corrective action because the forecast does not allow sufficient lead time. For example, the field crop harvesting operation is highly sensitive to heavy rain and thunderstorms. But, for many crops, this is usually scheduled weeks in advance, so that, on a short notice, it is not usually possible to reschedule the harvesting operation. In short, a significant amount of work has yet to be performed to obtain reliable results on the amount of usage of weather forecast information by users who might benefit from it

5. Forecast Capability Identification

Recent benefit analyses [Ref. 3, 4, 8] have considered several different levels of forecast capability; namely:

1) CONV: This is the conventional system and refers to the existing forecast capability as described in Chapter 2.0, with the existing operational satellites. (SMS has not been considered fully operational as yet),

2) SMS: This denotes the forecast capability which, it is estimated, will be realizable with an operational SMS in conjunction with the CONV system,

3) STORMSAT: This refers to the forecast capability which, it is estimated, will be realizable with a satellite like STORMSAT working in conjunction with the SMS and the CONV system, and,

4) SEOS: This refers to the forecasting capability which, it is estimated, will be realizable with a satellite like SEOS working in conjunction with SMS and CONV.

The estimation of a system capability is an involved task that has to take into account not only the spatial resolution of the satellite, but also factors such as the number of satellites that constitute the system, signal handling capacity, traffic overload, system reliability, the functional relationship between measured data and forecast, etc. These factors have not yet been considered explicitly in the benefit analyses in deciding upon the four different levels of system capabilities. In other words, none of the capabilities have been deduced from fundamental descriptions of the hardware and software systems nor from the detailed physical models of the atmosphere relating to weather forecasting. They have been provided by the Goddard Space Flight Center based upon preliminary analyses and intuitive judgment, and are illustrated in Figures 4.2 and 4.6. These are the capabilities that have been

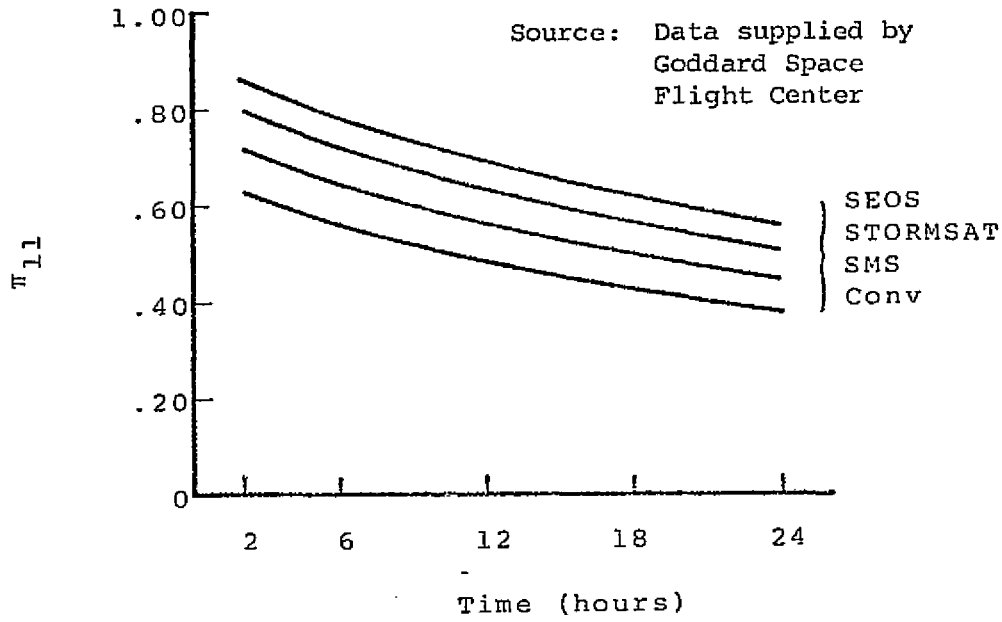

Figure 4.2 Probability of a Thunderstorm Occurrence Given a Thunderstorm Forecast

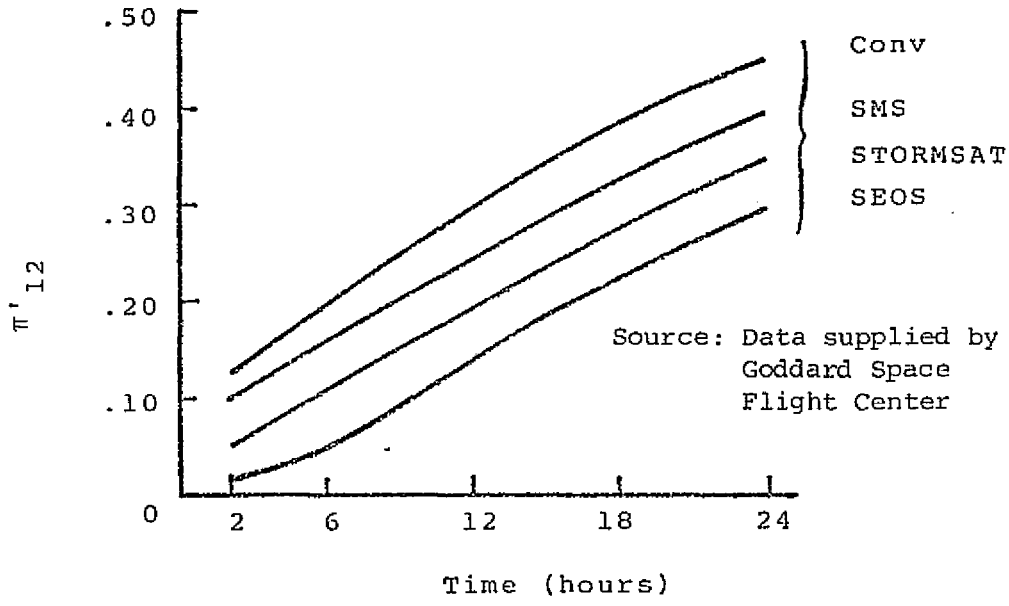

Figure 4.3 Probability of a Clear Weather Forecast Given a Thunderstorm Occurrence

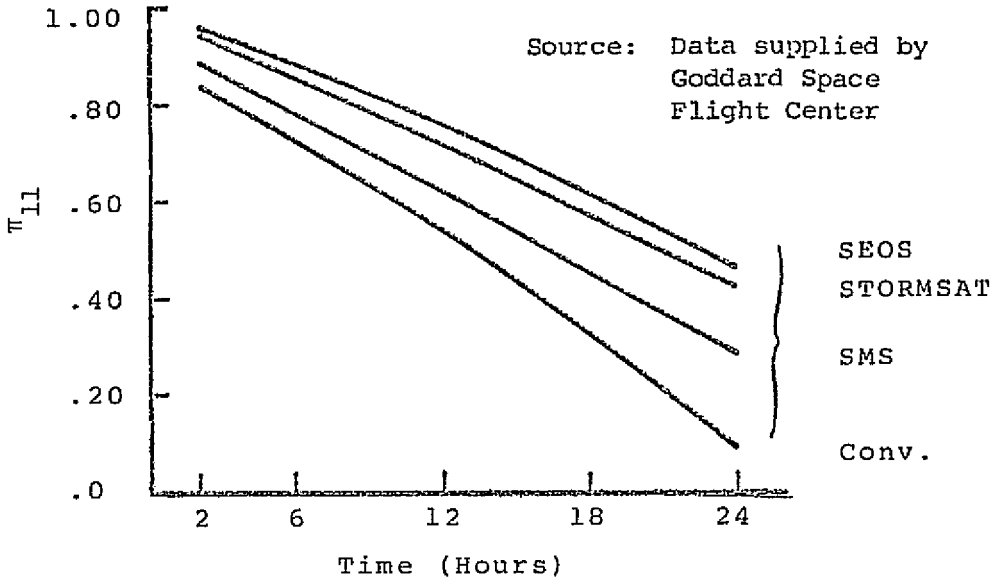

Figure 4.4 Probability of Snowstorm Occurrence, Given a Snowstorm Forecast ($1.6 \times 10^5 km^2$ area)

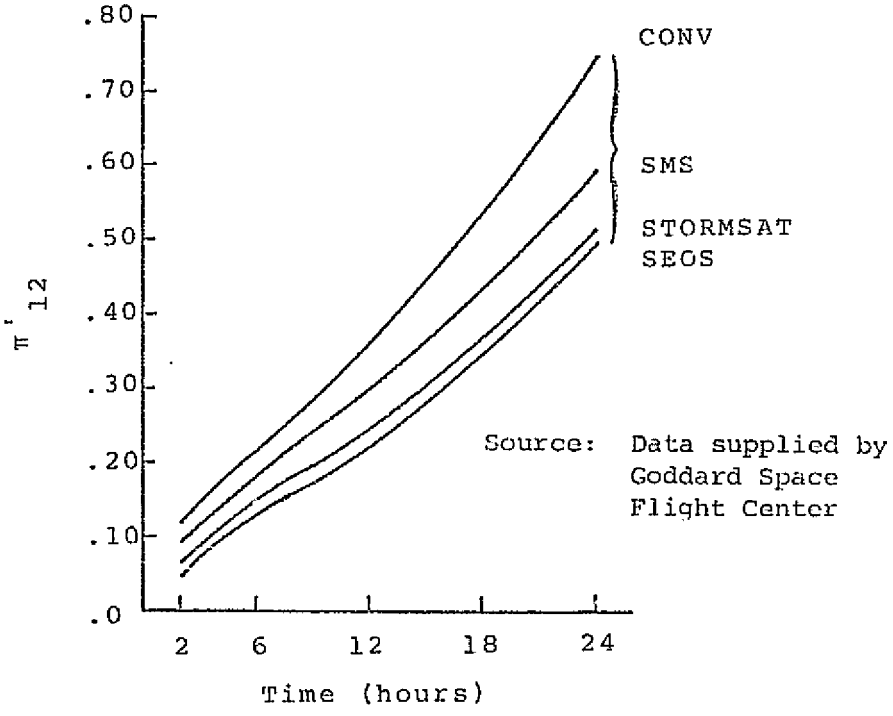

Figure 4.5 Probability of a Clear Weather Forecast Given a Snowstorm Occurrence (1.6×10^5 km^2 area)

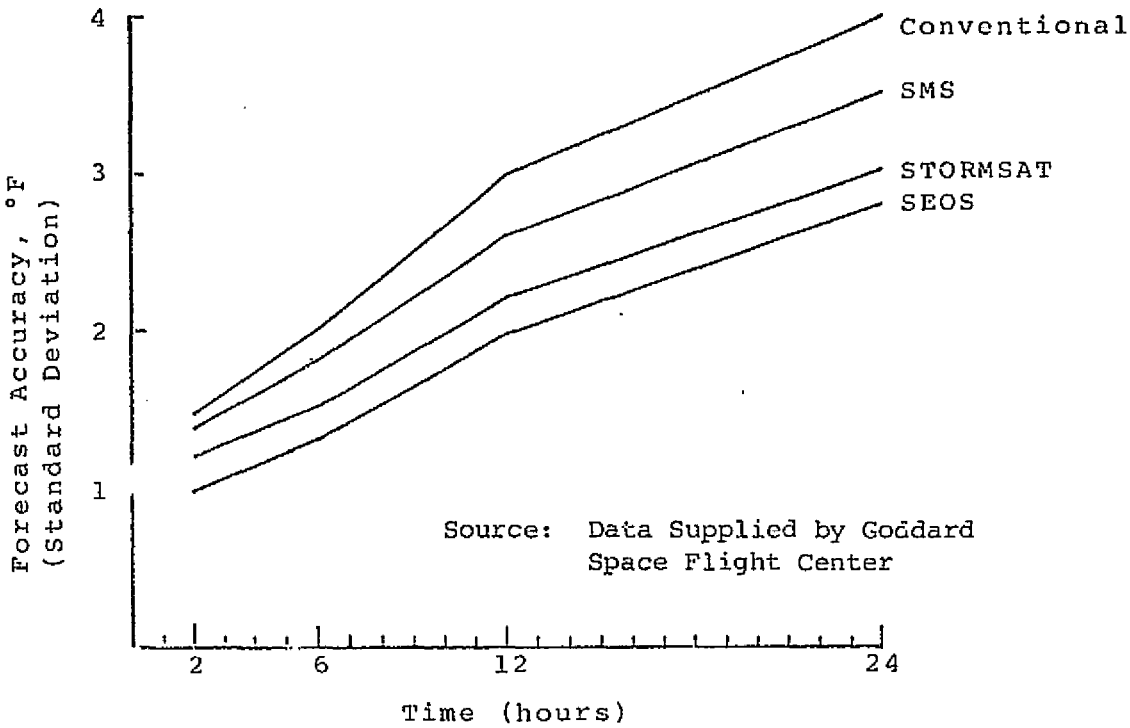

Figure 4.6 Temperature Forecast Accuracy

used in most of the recent benefit calculations. Primary emphasis has been placed upon the 2 to 6 hour forecasts. Though the numerical values shown in Figures 4.2 and 4.6 are the best descriptions of the corresponding capabilities available at this time, these are only rough estimates. There are two important factors that may drastically change these curves, and consequently may impact the results of the benefit calculations. First, the values of false alarm and miss probabilities are expressed over a rather large area (1.6×10^5 km^2). Many user-oriented forecasts should be constrained to much smaller areas. For example, for a construction company, it is important to find out what the weather will be at the site - not an

average forecast over a large area. As the area of forecast changes, both the false alarm and miss rates will also change. Secondly, there is no unique definition of false alarm or miss, but rather it depends on what level of adverseness of weather is considered to be really adverse by the user. For example, for a highway snow removal operation, the situation (in some municipal areas) starts getting critical only if the precipitation exceeds half an inch. Thus, any precipitation less than half an inch is not considered by the snow removal agencies to be an adverse event calling for preventive actions. But, on the other hand, it may turn out that even a fraction of an inch of snow precipitation may be crucial for some horticultural industries. Thus, if a snowstorm is forecast, upon which the highway snow removal management and the horticultural industry both take precautionary measures, and if this forecast is followed by half an inch of snow, the snow removal industry will call its precautionary measure a wastage due to false alarm, while the horticultural industry may be thankful to the forecast service. It is obvious from this that, even for the same forecast system, a snow removal industry and a horticultural industry working at the same place may report entirely different rates of false alarm and miss statistics for the same forecast.

Thus, the forecast capabilities illustrated in Figures 4.2 to 4.6 should be considered as rather approximate descriptions, perhaps good enough for preliminary benefit analyses,

but requiring in-depth experimental verification for detailed benefit analyses. This verification has been done only in one case, viz., the detailed benefit study of the highway snow removal operation [Ref. 8]. It has been observed that the percentage of miss, as illustrated in Figure 4.5, is more or less in conformity with actual field data. However, the percentage of false alarm as deduced [Ref. 8] from Figures 4.4 and 4.5 is approximately 17% for a CONV two-hour forecast, while actual data indicate that the false alarm rate in Washington D.C. has been close to 60%. The two reasons for this discrepancy have been explained above. Since the final results of a benefit analysis based upon a specified forecast capability depends heavily on the numerical description of that capability, it is of utmost importance to establish user contacts, to understand precisely how the critical levels of adverse weather phenomena are defined by them, and then to collect data at various sites of operation and over a reasonable period of time of both the forecasts and the actual occurrences. This will lead to the establishment of the forecast capability of the conventional system. These data, in turn, will help the development of superior weather models to estimate the capabilities of the improved systems of the future. As mentioned earlier, data pertaining to the experimental verification of the conventional forecast

capability have been obtained for only one case, viz., the highway snow removal operation, and indicates that the relationships graph illustrated in Figures 4.2 to 4.6 are only rough approximations, though they are perhaps the best available at the moment.

6. & 7. Estimation of Realized Benefits and Potential Benefits of the Conventional Forecast System

Benefits have been estimated based on the assumption that, had there been no weather forecast service available, every unfavorable weather event would have been met with unpreparedness with consequent losses, whereas, with the availability of the current forecast facilities, a given percentage of users do pay heed to the forecast. As a result, on the one hand, the user avoids some loss because of preparedness for adverse weather conditions, but, on the other hand, they incur some unnecessary expenditure in wasteful preparation on a false alarm day. If the cost for avoidance of loss is greater than the added false alarm expenditure, the user benefits from the forecast. This, of course, is the potential benefit, because it assumes that all users will use the forecast in an optimal fashion. It should be emphasized that the assumption regarding the no-forecast situation is rather simple-minded. It is not necessarily true that, if no forecast service is available, a user is going to stop using his common sense. As for example, a boatman will not take his boat out when the sky is dark with

clouds and the wind has reached a rather high velocity. For this reason, the results obtained for the potential benefit of the conventional system are on the high side. They should be considered as an upper bound. Also, due to the reasons explained in item 5, the results are not conclusive.

To calculate the fraction of the potential benefits that are actually being achieved, one ought to know what percentage of users use the information optimally, what percentage use it nonoptimally, and what percentage do not use it at all. Due to the shortcomings discussed under item 4 above, the results obtained should be viewed as preliminary. No elaborate user statistics have been obtained. Only a few contacts have been established. The results of these benefit analyses are illustrated in Table 4.1. The boxes drawn around the two benefit areas, viz., Electric Power and Highways, indicate that preliminary user contacts have been established in these two areas.

8. Improved Capability Potential Benefit Estimation

The estimation of potential benefits resulting from improved capability is the same as the calculation of the potential benefits associated with the conventional forecast system. The improved capabilities associated with SMS, STORMSAT and SEOS are obtained from Figures 4.2 to 4.6. The incremental potential benefits of each system relative to the conventional system are illustrated in Table 4.1. The details of these computations are described in References [3], [4], [8] and [9]. The results shown in Table 4.1 should not be

Table 4.1 Preliminary Estimates of Annual Benefits ($ million)

Benefit Areas	CONV Relative to No Forecast	CONV Potential Relative to No Forecast	SHS Relative to CONV	STORMSAT Relative to CONV	SEOS Relative to CONV
Agriculture					
• Agricultural Scheduling	275	1,200*	116	230	350
• Timber Management	3-15	11-40*	9-14	15-20	20-25
• Livestock Raising	NQ	NQ	NQ	NQ	NQ
Heavy Industry					
• Construction	100-500	400-1500	655*	920*	1,200*
• Electric Power	NQ**	NQ**	2	5	8
• Gas Line Management	NQ**	NQ**	1	2	3
• Communication	Small	Small	0.3	0.6	1
• Mining	3-15	10-50	0-20	0-30	0-40
Coastal Resources					
• Ocean Fishing	15	25	6	10	15
• Ocean Plant Harvesting	0	0	0	0	0
• Off-Shore Drilling	5-15	5-15	1-6	3-8	5-10
Transportation					
• Coastal Shipping	25	25	8	14	20
• Dock-Side Loading	1-2	2-5	1	2	3
• Deep Sea Port Mgt.	0	0	0	0	0
• Inland Waterway	NQ	NQ	NQ	NQ	NQ
• Air Transportation	500	500	20	34	46
• Railroads	Small	Small	0	0	0
• Highways	500	500	113	180	250
Recreation					
• Boating	40	40	2	4	6
• Skiing	NQ	NQ	NQ	NQ	NQ
• Outdoor Sports	Small	Small	1	1-2	1-5
Disaster Control					
• Flood	20	20	17	29	30
• Forest Fire	30	30	24	40	50
• Coastal Disaster	10	10	1-2	2-3	2-6

NQ: Not quantified.

*: Not achievable due to operational constraints.

**: Since benefit is due to improved temperature forecast, a no-forecast situation cannot be described by any specific event.

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considered as firm numbers because of the lack of detailed user involvement and, as discussed above, because the capabilities of SMS, STORMSAT and SEOS used in these calculations are based upon very preliminary forecast data illustrated in Figures 4.2 to 4.6.

9. Detailed Benefit Estimation

Based on the results of the preliminary benefit analyses discussed in items 6, 7 and 8, two specific benefit areas were selected for detailed studies. They are: (1) Highway Transportation and (2) Electric Power Industry. User contacts were established, and various cost figures obtained. The user-provided data were studied to compute the false alarm and miss percentages of the current forecast capabilities. These percentages, as indicated in item 5, were found to differ from the preliminary forecast capabilities shown in Figures 4.4 and 4.5. The reasons for these discrepancies have already been discussed. The results of these case studies are shown in Table 4.1 with boxes drawn around them. These benefit figures are considered to be firmer than the rest of the numbers shown in Table 4.1. These studies are described in detail in Reference [8].

10. Design of Case Studies

Detailed benefit case studies with significant user involvement have not yet been undertaken. Table 4.1 indicates

that there are a few potential candidates that offer the possibility of large potential benefits compared to others and are therefore candidates for case studies. They are: (1) Agricultural Scheduling, (2) Construction, (3) Air Transportation, (4) Highway Transportation, (5) Flood Control, and (6) Forest Fire Control. It should be noted that, because of the preliminary nature of the benefit analyses performed to date, it is entirely possible that benefits in other areas have been grossly understated, whereas others may have been overstated. The overstatement leads to some additional, and in the long run unnecessary, work whereas there is a danger that those that have been understated will be overlooked.

5.0 STATEMENT OF WORK

There are two main economic considerations associated with the planning of a future satellite system. One is the cost, and the other is the benefit. The benefit picture without the associated cost data does not provide the full story. As illustrated in Figure 1.1, one of the guidelines for future system planning is the present worth of the net incremental benefit which is defined as the present worth of the incremental benefit minus the present worth of the incremental cost. The estimation of the cost of developing a complicated satellite system from the conceptual to the operational stage is complicated in itself. The costs to be considered for establishing the net benefits are the total life cycle costs and include those associated with system research, development, implementation, and operation. In other words all nonrecurring and recurring costs must be considered.

5.1 Previous Assumptions and Approximations

The review of the recent benefit analyses, as presented in Section 4.0, indicates that results obtained thus far should not be considered as conclusive. The reasons for this are as follows:

1. The forecast capabilities of the various systems used in these analyses are only

preliminary estimates. In one case of detailed study, viz., Highway Transportation, these estimates were compared against experimental data, and it was found that a forecast capability, to a certain extent, is determined by the intensity of the weather event that is considered to be adverse by the user concerned. (See Section 4.0 for a detailed discussion.) Thus, a general description of forecast capabilities over large geographical areas appears to be of insufficient accuracy for detailed case studies.

2. The assumption that all users can obtain relevant data on demand may be too idealistic. Any system has signal flow constraints, traffic overload constraints, and reliability constraints. For example, if the system relies on only one SEOS satellite, it may be difficult to simultaneously monitor a tornado in Florida and a forest fire in California and obtain a continuous stream of meteorological data required for thunderstorm forecasting upon which users have learned to rely.

3. The assumption that all potential users will optimally use the available data is rather utopian in nature. Without a detailed user

survey, it is not possible to accurately estimate the actual level of conscious effort on the part of the user to make optimal use of such data.

4. <u>There may be various operational and legal constraints that might deter a user from using such data</u>. For example, a twenty-four-hour forecast will not help a farmer to reschedule his harvesting which is usually fixed weeks in advance. Similarly, a snowstorm may prevent a builder from laying foundations, but will not prevent him from painting the inside of a house. It is not possible to provide firm results on the achievable benefits due to improved forecasts without first developing detailed mathematical models to describe the sequential operation scheme and their flexibilities under existing constraints.

5. <u>In many instances, analytical results cannot be considered conclusive unless verified by experimental evidence</u>. As such, without concrete case studies and user demonstrations, a degree of uncertainty will always remain.

5.2 Suggested Guidelines for Future Work

The above-mentioned factors to a large extent provide guidelines for future efforts directed toward establishing meaningful benefit estimates. The suggested efforts are as follows:

1. Development of mathematical models to relate sensor measurement capabilities with forecast capabilities. The benefit analyses are based on various weather events as forecast and observed, and not on the raw data as gathered by sensors. Further, the benefit estimates depend rather heavily on the numerical values assigned to the various forecast capabilities. Thus, it is important to establish the relationships between the measurement capabilities of sensors and the consequent forecast capabilities. A mathematical model should be developed which can bridge this gap. Further, the model should have enough flexibility to answer the two following questions:

   a. Given a certain measurement capability, what is the forecast capability expressed as a function of the area over which the forecasts are being made? and,

   b. Given a certain measurement capability,

what is the forecast capability for a certain weather event, where the event is characterized not only by the type (e.g., thunderstorm, snowstorm, etc.), but by its intensity as well (e.g., a snowstorm with precipitation equal to one inch or more, a thunderstorm with precipitation equal to two inches or more, etc.)?

Answers to these questions will make the benefit analyses more meaningful for two reasons. First, many users are interested in weather events at their particular site of operation, and not over a large area. Secondly, without any knowledge about the intensity of a weather event, it is impossible to determine whether that event is considered adverse or not by a given user group. As a matter of fact, different user groups have different levels of tolerance depending upon the operational details. Experimental data on current forecasts and actual occurrences of weather events can provide a testing ground for this model. If the existing data can be satisfactorily correlated, extrapolation can be made for the improved capabilities of the future.

2. <u>Detailed benefit studies of the existing forecast systems with user involvement</u>. Preliminary benefit studies have indicated the possibility of very significant benefits to be achieved if the existing forecast capabilities are utilized to the best advantage of users. From Table 4.1, agricultural scheduling and construction scheduling seem to be prime candidates. However, these benefit figures are rather preliminary because of the lack of user involvement in their determination. Further, in-depth studies have not been conducted which take into account detailed operations and constraints. At this stage, it is necessary to perform additional in-depth benefit studies with user involvement. In a number of instances, it will be necessary to demonstrate the validity of results. For these cases, the studies should include the design of experiments aimed at demonstrating the benefits. The details of operating and accounting procedures, etc., should be taken into account. The goal is four-fold, viz., (1) to determine what percentage of users make conscious efforts to utilize the existing data optimally, (2) to

obtain more detailed understanding of user requirements, operations, and restrictions, (3) to obtain more credible benefit estimates, and (4) to get users involved to the point where they may become spokesmen for the need of improvement in forecasts by using future satellites like STORMSAT and SEOS.

3. Benefit studies of improved forecast systems with user involvement. Table 4.1 indicates that agricultural scheduling, construction, and highway transportation are at least three areas where significant additional benefits can be achieved as a result of improvements in forecasting capabilities. If an accurate description of the improved capabilities (i.e., STORMSAT and SEOS) can be obtained by using the mathematical model described previously, this task can run simultaneously with the previous task of benefit studies of the existing forecast systems with user involvement. The results of this study, if positive, will provide added impetus for users to become spokesmen for the need of achieving improved meteorological forecasting capabilities.

4. Benefit demonstrations with user involvement. Analyses culminating in demonstrations of potential benefits should be undertaken with direct and extensive user involvement. These demonstrations should be based upon mathematical modeling, simulation techniques, utilization of conventional observation and forecast data, utilization of improved forecast data, and combinations of these. It should be noted that mathematical modeling and simulation, augmented by actual experiments, can be utilized very effectively to cover a broad range of applications and forecast capabilities without incurring exorbitant costs.

5. Analysis of spacecraft and sensor costs in terms of sensor capabilities. These costs need to be developed on a parametric basis as a function of sensor capability. Both point design and cost estimating relationships should be utilized as appropriate.

6. Spacecraft configuration analyses in terms of maximization of net benefits. As the transformation of sensor measurements to phenomena observation and forecast capability is developed, cost models developed and benefit analyses performed, it is necessary to develop the methodology and capability of putting all the pieces together.

A systems analysis capability should be developed which would, making use of benefits in terms of forecast capability, cost in terms of sensor measurement capability, and the functional relationships between sensor measurement and phenomena observation and forecast capability, make possible the following:

- determination of the desired mix and capability of sensors,
- determination of operational use strategies,
- determination of mix and number of spacecraft, and
- determination of time phasing of capability for both the R&D phase and operational system.

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APPENDIX A

SIGNIFICANT WEATHER SENSITIVE INDUSTRIES

(According to SIC classification)

		1973 income in millions of dollars
Division A:	Agriculture, Forestry & Fishery	
01:	Agricultural Production - crops	38,172
02:	Agricultural Production - livestock	45,277
07:	Agricultural Services	7,076
08:	Forestry	470
09:	Fishery	704
Division B:	Mining	
10:	Metal Mining	3,487
11:	Anthracite Mining	1,560
12:	Bituminous Coal & Lignite	5,329
13:	Oil & Gas	23,866
14:	Nonmetal Minerals (except fuel)	3,651
Division C:	Construction	
15:	Building Construction	65,434
16:	Construction other than Building	31,837
17:	Construction - special trade contractors	57,306

		1973 income in millions of dollars
Division E:	Transportation, Communication, Electric, Gas & Utility	
40:	Railroad Transportation	14,352
41:	Local & Public Transit, Highway Mass Transportation	10,205
42:	Motor Freight Transportation	18,700
43:	U.S. Postal Service	8,339
44:	Water Transportation	3,204
45:	Air Transportation	2,284
46:	Pipelines (except natural gas)	1,338
47:	Transportation Services (travel agencies)	329,438
48:	Communication	
	I Telephone (domestic)	22,405
	II Telegraph	660
	III Bell Telephone	24,072
	IV Independent Telephones	3,661
	V Broadcast	3,770
49:	Electric & Gas	
	I Electric Power	31,700
	II Gas	19,747
Division H:	Services	
70:	Hotels, Motels, etc.	60,542
73:	Miscellaneous Business Services	22,595
78:	Motion Pictures	3,476

		1973 income in millions of dollars
79:	Amusement & Recreation (except motion picture)	4,827
80:	Educational Services	
	I Elementary, secondary. public	44,511
	II Higher Education	23,879

APPENDIX B

WEATHER SENSITIVE RESOURCE MANAGEMENT FUNCTIONS

1. Intensive Use of Living Resources: Agriculture

    1.1 Optimization of planting schedules

    1.2 Optimization of harvesting schedules

    1.3 Improvement in crop irrigation

    1.4 Reduction of frost damage

2. Extensive Use of Living Resources: Forestry, Wildlife, and Rangeland

    2.1 Timber harvest management

    2.2 Rangeland management

    2.3 Forest fire control and early warning

3. Inland Water Resources

    3.1 Water supply management

    3.2 Water impoundment systems management

    3.3 Flood control and early warning

    3.4 Optimization of shipping routes on the Great Lakes

4. Nonreplenishable Natural Resources

    4.1 Optimization of open mine operation

5. Atmosphere

    5.1 Early warning for thunderstorms, snowstorms, hailstorms, hurricanes, tornadoes, and frosts

6. Oceans

6.1 Optimization of ocean fisheries management

6.2 Optimization of ocean plant food management

6.3 Improvement of coastal zone management

6.4 Deep-sea port management

6.5 Dock-side loading and unloading

6.6 Optimization of ship routing

6.7 Off-shore drilling for oil and gas

7. Industries

7.1 Construction industry management

7.2 Transportation management

7.3 Electric power industry management

7.4 Gas line management

7.5 Communication systems management

7.6 Recreation management
(boating, skiing, sports)