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SOME ECONOMIC BENEFITS OF A SYNCHRONOUS EARTH OBSERVATORY SATELLITE

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16. Abstract

An analysis has been made of the economic benefits which might be derived from reduced forecasting errors made possible by data obtained from a synchronous satellite system which can collect earth observation and meteorological data continuously and on demand. The costs of establishing and maintaining such systems are not considered, but certain user costs directly associated with achieving benefits are included.

In the analysis, benefits have been evaluated which might be obtained as a result of improved thunderstorm forecasting, frost warning, and grain harvest forecasting capabilities. The analysis for the benefits in these areas have not been concerned with details of the satellite configuration or operational methods, but the anticipated system capabilities have been used to arrive at realistic estimates of system performance on which to base the benefit analysis. The major emphasis of the analyses has been on the benefits which result from system forecasting accuracies.

Benefits from improved thunderstorm forecasts are indicated for the construction, air transportation and agricultural industries. The effects of improved frost warning capability on the citrus crop are determined. The benefits from improved grain forecasting capability are evaluated in terms of both U.S. benefits resulting from domestic grain distribution and U.S. benefits from international grain distribution.

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PREFACE

This report summarizes the activity conducted during a four-month study under Contract NAS5-20021 to evaluate the potential economic benefits of several representative applications of synchronous earth observatory satellite. These applications were selected from earth resources applications identified in a previous ERIM study under Contract NAS5-21937 and from meteorological applications identified in a parallel study (also for NASA/GSFC) conducted by the Space Science and Engineering Center of the University of Wisconsin.

The work was performed jointly by the Environmental Research Institute of Michigan and ECON, Incorporated, with ERIM as the prime contractor. Mr. Donald S. Lowe acted as Principal Investigator and Mr. Irvin J. Sattinger participated as Project Engineer. For ECON, Mr. Joel S. Greenberg was Project Director and Dr. Ranendra K. Bhattacharyya was Principal Investigator. Dr. Louis Walter, Goddard Space Flight Center was Technical Officer for the project, which was directed by Mr. Laurence T. Hogarth, Systems Analysis Office.

ERIM concentrated its effort on evaluation and estimation of remote sensing capabilities and on specifying methods of applying these capabilities to the economic activities under study. ECON was fully responsible for development and application of the economic methodology used to estimate potential benefits of the applications. ERIM did not participate to any significant extent in the thunderstorm warning application; the complete study effort for this application was undertaken by ECON.

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1.0 INTRODUCTION

Low altitude meteorological and earth observation satellites have been providing important data for many years. These satellites, because of their limited number and their low altitude orbits, provide information on a rather discontinuous basis. The single ERTS satellite, for example, provides repetitive observations (in the absence of cloud cover) at intervals up to eighteen days.

Attention is now focusing on high resolution synchronous equatorial meteorological satellites (as exemplified by the recently launched SMS) and earth observation satellites. Because of its orbital characteristics, this type of satellite has a capability for observation of a specified point on or above the earth's surface which approaches being available continuously or on demand. This capability is limited only by satellite performance (i.e., instantaneous field of view, scan time, resolution, etc.) and cloud cover. The continuous and on-demand capability would make possible the observation and forecasting of short-lived phenomena such as thunderstorms and tornadoes. It would also make possible the repeated observation of varying phenomena of longer duration, such as crop maturation. It is therefore anticipated that high resolution data provided on a continuous or demand basis will lead to a reduction of forecasting errors that will result in substantial economic benefits.

In this report, the term SEOS (synchronous earth observatory satellite) is used to refer to this general type of satellite. The use of the term does not imply the present existence of a specific design for such a satellite, but refers instead to a satellite operating in a synchronous orbit and capable of continuous or on-demand data collection at a given spatial resolution and feature recognition and classification capability. The value of identical information collected on demand is, of course, independent of the particular details of the collection system. While this study was carried out to identify potential benefits from SEOS, the methodology and results apply to any earth observatory satellite system capable of collecting data on demand.

Since this project could not undertake the analysis of benefits to be derived from all of the potential uses for SEOS, three representative applications were selected for detailed study. In selecting these applications, we looked for those which seemed likely to show substantial benefits in a variety of economic sectors, which appeared to be technically feasible with moderate research and development effort, and which took advantage of both the meteorological capability and the earth resources capability of SEOS. In addition, the applications were confined to those which could be assisted by a synchronous satellite located above the Western Hemisphere.

The use of this type of satellite for improved forecasting of thunderstorms was adopted as one of the meteorological applications because it seemed likely to offer a high level of benefits both in dollars and in lives for a variety of economic activities. Potential annual savings of about 1400 million dollars were identified in the construction area alone.

As a closely parallel study of a meteorological application of smaller scope, we also undertook the analysis of benefits to be derived in providing improved weather forecasting for protection against frost damage to the citrus fruit industry. This application lends itself to detailed and clear-cut analysis of the manner in which improved data from SEOS can specifically improve an economically-significant operation. Annual savings just in heater operation costs (fuel and labor) in citrus groves were estimated to be 7.8 million dollars.

The third application was that of grain distribution. This application takes advantage of the earth resources capability of SEOS as distinguished from its meteorological capability. Previous work performed at ECON, Inc. on economic models of grain distribution indicated that the improved knowledge derived from SEOS could show major economic benefits for worldwide performance of food distribution. The economic benefit study concentrated on the distribution of wheat, which has the greatest production value among all the staple crops of the world. By reducing the U.S. production forecast error by 50%, an annual savings exceeding 36 million dollars can materialize.

Since the study was limited in scope, not all of the potential benefits even within the three study areas could be considered exhaustively. Other applications offer many possibilities for demonstrating additional economic and social benefits of SEOS applications.

This report summarizes the results of the survey of current and anticipated future capabilities of satellite systems for collecting earth resources and meteorological data needed for the three selected applications. It also summarizes the analysis conducted by ECON, Inc. of the economic benefits which might be derived from resulting reductions in forecasting errors. Appendix A discusses methods of using SEOS data and other space-acquired data for reducing grain forecasting errors.

The use of synchronous satellite data is only one of a number of possible methods for improving performance for the applications studied. No attempt has been made to compare the cost-effectiveness of SEOS with these other methods for performance improvement. Instead, the objective has been to estimate as accurately as possible from available research data the potential benefits to be derived from adding SEOS technology to existing methods of weather or crop forecasting.

The benefits resulting from improved forecast capabilities are incremental in nature, always being relative to existing or anticipated capabilities. The benefits are attributable to the system or systems which make possible the increased forecast capability. Since this study has not been concerned with the mix of systems which are necessary to achieve a forecast capability, great care must be exercised in assigning these benefits to any particular system.

Note that all benefits have been evaluated relative to conventional or presently available forecasting capabilities. The effect of ERTS type systems, as they might impact or modify the conventional forecasting capability, have not been considered. It must be cautioned that any increase in the level of the conventional capability through enhancement with ERTS or other satellite data, with which forecast capabilities based upon systems providing continuous and on demand data are compared, will result in reduced benefits attributable to continuous and on demand data.

Three types of weather forecasts are considered and are denoted as Conventional, Level 1 and Level 2. Levels 1 and 2 imply continuous and on demand capability. The accuracy of the forecasts differ. The Level 1 forecast is based upon the accuracy (anticipated by NASA) of a system utilizing SMS technology and the Level 2 forecast is based upon the projected capability of a SEOS-type system. The Conventional forecast is based upon current forecasting capabilities.

It has been assumed in this study that a system will exist such that forecast data will be available when and where required. This implies that the satellite system collects the data as and when required, the data are processed as and when required and the forecasts are communicated to the potential users as and when required. Therefore, the analysis is based on the assumption that data collection, data processing, and data communication systems of the desired capability will exist. The <u>costs of establishing and maintaining such systems are not considered</u>. As will be described later, user costs associated with achieving benefits are included.

The analysis of benefits have not been concerned with the details of satellite configuration, sensors, resolution, etc. The analyses have been concerned only with the benefits which result from estimated system forecasting capabilities. It should be noted that the benefit estimation methodology which will be described in the following pages can be used to assess the incremental value of the various satellite sensors, resolution capability, etc., <u>if</u> these capabilities can be expressed in terms of the system forecasting accuracies.

The benefit analyses are predicated on a change in forecast capability. The forecast capability is a function of basic measurements and observations and system constraints imposed on these measurements and observations. In general, it is necessary to observe or measure certain basic parameters (i.e., reflected radiance in various spectral bands, temperature, etc.) and transform these basic observables or measurables into more meaningful derived data forms (for example, observed wheat acreage). This transformation process must consider the errors in the measurables and the resulting errors associated with the derived data forms. In order to forecast the future, it is further necessary to combine or transform the derived data forms, along with their associated errors, obtained from different sources such as satellites, aircraft, ground observations, etc., into the desired forecast parameters taking into account the uncertainties in the knowledge of the transformation process. The result of these two transformation processes is that basic measurements and observations are converted into a forecast which must be treated as probabilistic in nature (for example, expressed as the expected number of bushels of wheat and an associated standard deviation).

To the extent that theoretical or experimental information has been available, we have attempted to assess the system performance occurring through these data transformations. We estimated what improvements in forecasting performance relative to existing forecasting systems might be anticipated from the use of information systems which make use of synchronous satellite data. NASA estimates were utilized for thunderstorm forecasting capabilities.

Once conclusions have been reached concerning anticipated improvements in forecasting capability, a final transformation is necessary to convert the estimated forecast capabilities into economic benefits. The results shown in this report are based primarily on analyses of the final transformation, i.e., forecast capability to benefits. The starting point for these benefit analyses has therefore been at the level of forecast capability.

The basic approach used to evaluate the benefits from improved forecasting due to continuous and on demand data is illustrated in Figure 1.1. Each of the three benefit areas are considered. Several different applications are considered for thunderstorm and frost warnings. For each application (for example, the construction industry), a user model has been established. Because of the limited duration of the study, simplistic though meaningful user models have been developed. In the case of grain forecasting, a comprehensive economic model, developed for NASA under contract NASW-2558, has been utilized. Using such models, the possible actions, costs, and consequences resulting from the utilization of forecast information have been determined. A decision model is then utilized which establishes the best course of user action, interms of the postulated or estimated forecast accuracy of current systems. The cost of operations is thus determined based upon current forecast capability and on assumed optimum choice of user action based on the forecast capability. This same approach is then repeated using the improved forecasting capability resulting from the continuous and on demand data. As necessary, new models are created and the cost of operations determined based upon the improved forecasting capability. The difference in the costs, properly adjusted to take into account their effect on other segments of the economy, represents the potential annual savings or potential annual societal benefits which might be achieved as the result of improved forecasting capability assuming an optimum choice of user action. <u>These are potential benefits in the sense that they may be achieved if the total user community believes in and therefore uses the improved forecasting data in pursuing their optimum course of action</u>.

Not all users will utilize the improved forecast data, nor, if they do rely on the improved data, will they necessarily pursue the optimum course of action strategy. Nor will all users who will utilize the improved forecast data in determining their course of action utilize such data as soon as they become available. There will undoubtedly be a learning or wait-and-see phase. Thus, the estimated actual benefits will differ from the potential benefits as illustrated in Figure 1.2. It is anticipated that the estimated actual benefits will approach a level which is equal to or less than the potential benefits and that the rate of growth to this level will follow an "s"-shaped learning curve typical of new product or service introductions.

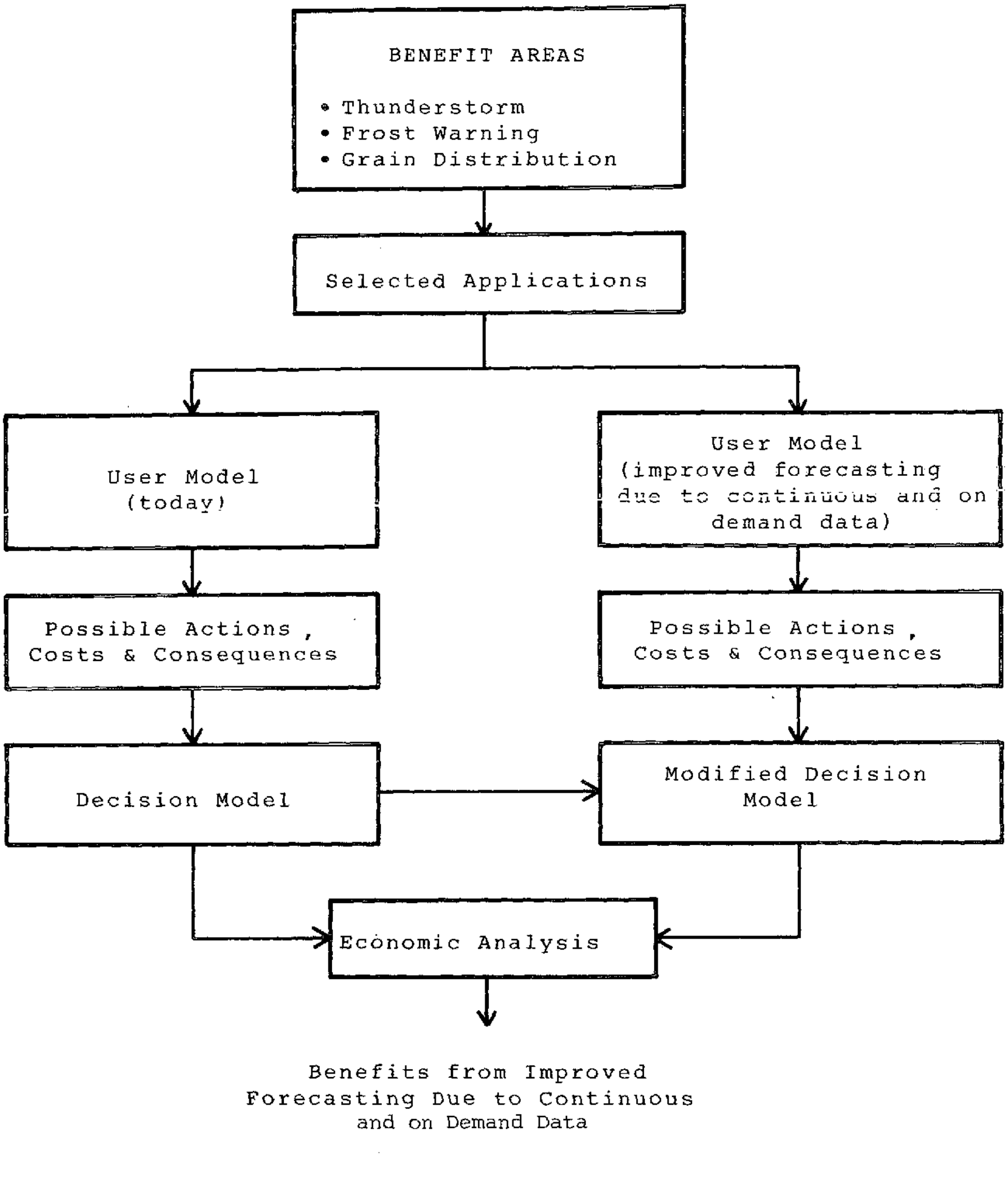

Figure 1.1 Basic Approach for Evaluating Benefits from Improved Forecasting Due to Continuous and On Demand Data

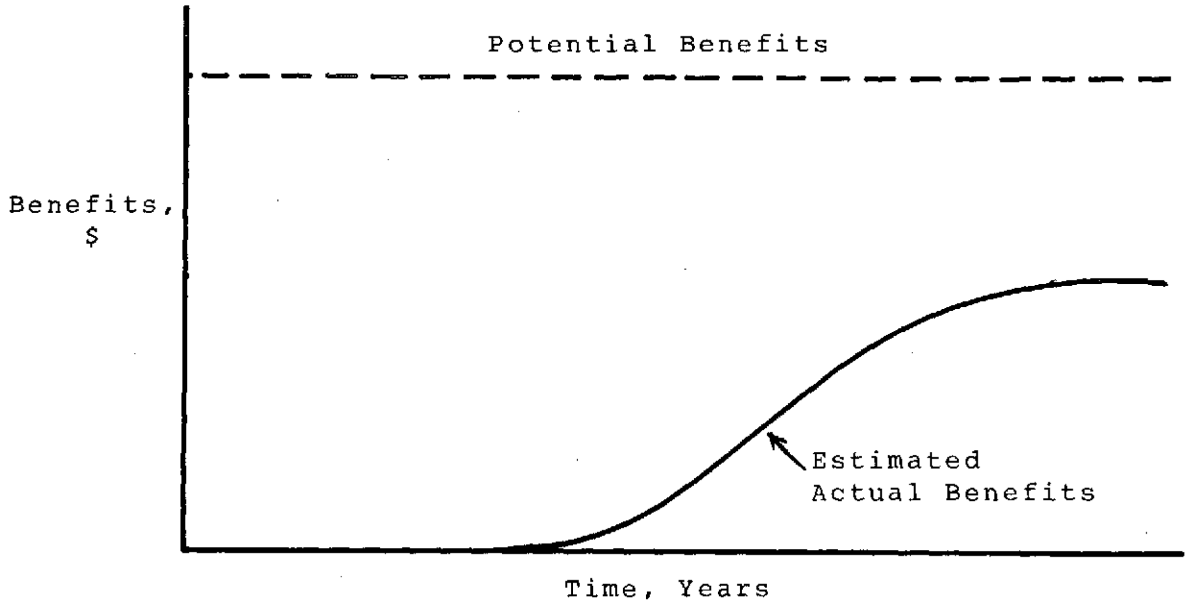

Figure 1.2 Benefits as a Function of Time

When the benefit pattern has been expressed as a function of time, the present worth or value of the benefit stream, PVB, can be expressed as

$$PVB = \sum_{i=1}^{\infty} \frac{B_i}{(1+r/100)^i} \tag{1-1}$$

where B_i is the estimated actual benefit in the i^{th} year and r is the discount rate.

The methodology used for estimating the benefits is described in detail in Section 2.0. The estimation of benefits due to better thunderstorm warning, frost warning, and grain forecasting are described in Sections 3.0, 4.0, and 5.0 respectively.

2.0 ECONOMIC METHODOLOGY

The economic methodology is concerned with evaluating, in quantitative terms, the potential benefits which might result from improved forecasts made possible by remote observation systems which can provide continuous and on demand data.

2.1 Thunderstorm and Frost Warning

Thunderstorms and frost are considered to be short-lived phenomena. In order to observe or forecast their presence, it is necessary to look at the correct place at the correct time. It is assumed in the following that the system design is such that observation can be made where and when required.

The basic methodology for evaluating savings from better forecasting of short-lived phenomena assumes that

a. there exists a choice between taking or not taking specific protective action,

b. taking protective action involves incurring some cost with certainty, and

c. not taking action involves escaping the cost of taking an action if the forecasted weather condition does not occur, but incurring a certain loss if the forecasted unfavorable weather condition does occur.

In order to illustrate the basic concept involved, consider the newspaper boy's dilemna (this is presented in a simplified and idealized form). The newspaper boy receives a quantity of papers which he is to deliver in the near future. It is cloudy and a forecast has been made for rain. The newspaper boy has two alternative courses of action, namely, (1) wrap each newspaper in a plastic bag which he has to purchase so that, in the event of rain, the newspapers will not get wet, or (2) do not wrap the newspapers in plastic bags; in the event of rain, the papers will get wet and he will have to purchase and deliver additional papers. Which alternative course of action should he follow? The former course of action involves incurring a cost with certainty, i.e., the cost of the plastic bags, whether it does or does not rain. The latter course of action involves incurring a loss, i.e., the cost of new papers if rain occurs. It should be obvious in this action (protect with plastic bags) and no-action (do not protect) situation, which is typical of the benefit areas to be considered for storm and frost warning forecasts, that there is an optimum strategy which should be followed if rain is forecast and if rain is not forecast. It should also be obvious that the optimum strategy depends upon the following factors:

a. the cost of action (i.e., the cost of the plastic bags),
b. the loss resulting from no action (i.e., the cost of buying and delivering additional newspapers),
c. the probability of rain given a rain forecast, and
d. the probability of rain given a no-rain forecast.

These basic concepts are placed into mathematical formulation in the following paragraphs. It should be noted that the potential benefits from improved forecasting is the difference in the cost associated with following the optimum strategy with and without the improved forecast data.

2.1.1 Potential Annual Benefits

In the private sector, potential annual benefits may be characterized as cost savings which may result from an investment. In the public sector, the societal potential annual benefits are defined as the change which might occur in gross national product (GNP) as a result of an expenditure of public or private funds. In the analyses that follow, both the private and public sectors must be considered. A public investment is being considered (i.e., the development of a new forecast capability) which will result in benefits to the private sector. A course of action will, it is assumed, be followed by the private sector (for example, the construction industry) which will result in a maximization of the cost reductions or cost savings of that sector. The firms which comprise an industry sector are motivated by maximizing their benefits and not societal benefits. Therefore, the computation of potential annual benefits consists of the following two parts, (a) determination of the industry potential annual benefits assuming optimum utilization of thunderstorm and frost forecasts of increased accuracy and reliability, and (b) determination of societal potential annual benefits given the optimum industry course of action as determined by maximizing industry potential annual benefits.

The industry potential annual benefits are defined as the cost reduction, i.e., the savings that would result from the optimum utilization by the user community of thunderstorm and frost forecasts of increased accuracy and reliability. Savings are 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 a manner such that the user undertakes that course of action which, for a given forecast capability, minimizes cost.

The applications considered in the thunderstorm and frost warning areas are similar. They are applications where a decision-maker must choose between taking or not taking some specific protective action 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.

Consider the forecasts which might be provided to a decision-maker.* Let these forecasts be y_1 and y_2, for example, forecast of storm or no storm. In the event that y_1 is forecast, the events w_1 and w_2 may actually be observed, for example, storm or no storm is actually observed. This is shown in Figure 2.1 where a two-by-two contingency array is illustrated.

		Forecast State	
		y_1	y_2
Observed State	w_1	π_{11}	π_{12}
	w_2	π_{21}	π_{22}
		π_1	π_2

Figure 2.1 Two-By-Two Contingency Array

* The following discussion is based upon results presented in Reference 1.

The following notation has been used.

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

π_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,

π_{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,

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

In the above definitions of the π_{ij}'s, the first subscript refers to the weather state (actually observed) while the second subscript refers to the forecast. Frequently, <u>π_{21} is referred to as the false alarm probability and π_{12} is referred to as the probability of miss.</u>

A payoff function can now be defined as shown in Figure 2.2. The payoff function illustrates the cost of taking actions (pursuing strategies) a_1 and a_2 in terms of the weather forecast. a_1 represents the "protect" action and a_2 represents the "do not protect" action.

Forecast State	y_1		y_2	
Observed State	w_1	w_2	w_1	w_2
Action				
a_1 (protect)	C	C	C	C
a_2 (do not protect)	L	O	L	O

Figure 2.2 Payoff Function (the cost associated with the "protect" and "do not protect" strategies)

C is the cost of protection and L is the loss incurred if adverse weather occurs and no protective action is taken.

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

$$a\ (y_1) = \begin{cases} a_1 & \text{if} \quad C<\pi_{11}L \\ a_1 \text{ or } a_2 & \text{if} \quad C=\pi_{11}L \\ a_2 & \text{if} \quad C>\pi_{11}L \end{cases} \tag{2-1}$$

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

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

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,

$$a\ (y_2) = \begin{cases} a_1 & \text{if} \quad C<\pi_{12}L \\ a_1 \text{ or } a_2 & \text{if} \quad C=\pi_{12}L \\ a_2 & \text{if} \quad C>\pi_{12}L \end{cases} \tag{2-3}$$

and

$$E\ (a|y_2) = \text{Min}\ (C,\ \pi_{12}L) \tag{2-4}$$

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

$$E(C) = \pi_1 \text{ Min } (C, \pi_{11}L) + \pi_2 \text{ Min } (C, \pi_{12}L) \quad (2\text{-}5)$$

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

$$S = \Delta E(C) = E_A(C) - E_B(C) \quad (2\text{-}6)$$

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 2-5 and 2-6 yield the industry expected cost and potential industry benefits, respectively, resulting from the best decision rule for a given capability level of forecast. The societal benefits will differ since, in general, at least a portion of the industry savings will occur as the result of a loss to some other sector of the economy (for example, industry savings which result from wage reductions are offset by labors' loss of wages assuming that labor cannot recoup the lost wages by some other productive means).

To establish the societal expected cost $E'(C)$, under the best industry decision rule, Equation 2-5 can be restated as

$$E'(C) = \pi_1[\text{Min}(C,\pi_{11}L)+K_1] + \pi_2[\text{Min}(C,\pi_{12}L)+K_2] \quad (2\text{-}5A)$$

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 societal benefits are given by

$$E(B) = B = \Delta E'(C) = E_A'(C) - E_B'(C) \qquad (2\text{-}6A)$$

where $E_A'(C)$ and $E_B'(C)$ are the specific values of expected societal cost resulting from system alternatives A and B.

It should be noted that 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.

Specific values of the π_{ij} terms in the contingency array have been estimated by NASA based upon several different remote sensing systems. Values of π_{ij} have also been estimated as a function of the time of forecast. These specific values and their consequences are discussed in detail in Sections 3.0 and 4.0.

2.1.2 Economic Benefits

The previous Section has been concerned with estimating the potential annual benefits which might be realized if all of the user community pursued these optimum courses of action. The potential annual benefits, in the form of societal savings, must be converted into the annual benefit stream which may result from the improved forecasts so that the present worth of this benefit stream can be established. The annual benefits, B_i, are given by

$$B_i = \eta_i E(B) \qquad (2\text{-}7)$$

where η_i is the probability of implementation by users. In other words, η_i represents the fraction of the total projected long term savings that will be achieved as a function of time since not all users will incorporate the improved forecast data into their decision-making process. A typical growth pattern of B_i is illustrated in Figure 1.2 and indicates the relationship of B_i to $E(B)$. Once B_i is determined, the present worth of the benefit stream, PVB, can be computed (Equation 1-1).

2.2 Grain Distribution

Grain distribution benefits arise from the smoothing out of the flow of product, from grower to user, resulting from improved forecasts. Both U.S. benefits resulting from domestic grain distribution and U.S. benefits resulting from international grain distribution are considered. These benefits are not totally additive. All that can be said at present is that the grain distribution benefits lie between the larger of the two and their sum. Methodologies have been developed and are discussed below, for evaluating both of these U.S. benefits. In the latter case the methodology is general in the sense that internatioinal grain forecasts (resulting from remote sensing earth observation data) can be considered. For the current analysis, however, only U.S. earth observation and hence U.S. grain forecasts, are considered. The specific results obtained from employing these methodologies are described in Section 5.0.

The methodology employed to evaluate the benefit which may result from a more accurate crop forecast is somewhat different from the benefit evaluation methodology associated with improved weather forecasting and discussed previously. This is due to the fact that, in the case of weather forecasts, benefits accrue from making judicious decisions regarding whether to carry out or not carry out certain operations in the face of a probabilistic storm forecast, while in the case of crop forecasting, the market (both domestic as well as international) responds to a crop forecast in a rather spontaneous way over which, in a free society, there is hardly any control. The price fluctuation, in a free market, is dependent on the estimated demand-supply situation, which, in turn depends on the forecast. Figure 2.3 illustrates this phenomenon in the context of the Hayami Peterson Economic Model [2]. Assume OQ^* to be the true production of a crop, which is associated with the price P^*Q^*. If the forecast has an error of $+\varepsilon$, then the forecasted quantity is OQ_2, where Q^*Q_2 corresponds to ε. This corresponds to the price P_2Q_2, and the benefit due to the lowering of price is given by the area $P^*Q^*Q_2P_2$. However, since the actual quantity produced is OQ^* rather than OQ_2, the erroneous market price P_2Q_2 results in a shortage in the next period, when the quantity available in the market becomes OQ_1 instead of OQ^* (where $Q_1Q^* = Q^*Q_2$). The corresponding price becomes P_1Q_1 with a resulting disbenefit represented by the area $P_1Q_1Q^*P^*$. Hence the

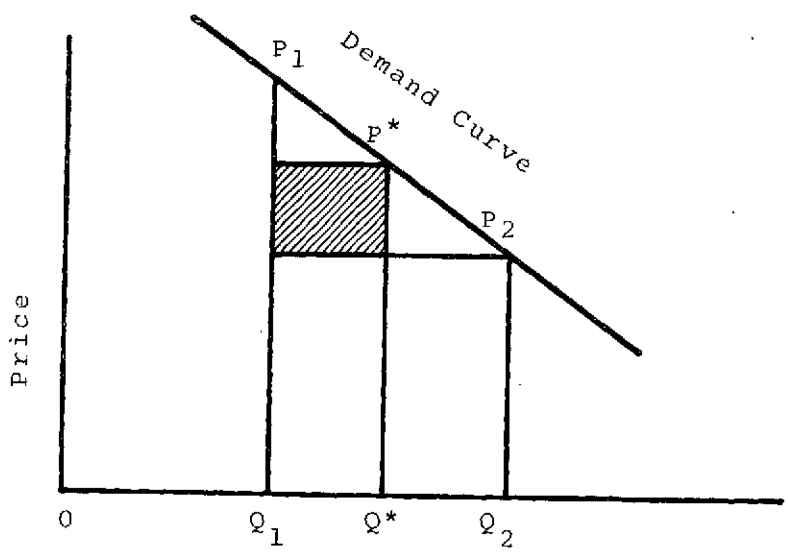

Figure 2.3 Benefits Due to Improved Forecasting of Quantity Through Price-Quantity-Demand Relationship

resultant disbenefit is the difference between the two areas which is represented by the shaded rectangle. This result is symmetric with respect to the sign of the forecast error. In other words, if the forecast has an error $-\varepsilon$ instead of $+\varepsilon$, it can be easily seen that the disbenefit turns out to be the same shaded rectangle. The benefit resulting from improved forecasting is the difference in the size of the shaded rectangle which results with and without the improved forecast. It should, however, be noted that the demand curve in Figure 2.3 has been drawn as a straight line for the sake of simplicity. In actual calculation, a hyperbolic demand curve has been used which corresponds to a constant elasticity of demand.

The physical interpretation of this benefit calculation is that with a more accurate foreknowledge about forthcoming crops, it is possible to make a better allocation of the consumption of commodities over time, thus ensuring a smoother flow. A smooth flow of commodities is more beneficial than an irregular flow, because the value of increments to consumption is not constant. It decreases as the quantity consumed increases. As an illustration, the value of an additional bushel of tomatoes in the presence of a large crop in August is much smaller than the value of the same bushel of tomatoes in the middle of winter when few are available. This concept of benefit due to smoother flow will now be developed - first in the international market, and then in the domestic market.

The International Market

The international market of an agricultural commodity can be simplistically defined by the commodity flow among various nations along with their corresponding prices. For this simplistic approach the various nations comprising the international market have been grouped into three classes:

Class 1: U.S.A. (which is predominantly an exporting nation)

Class 2: All other exporting nations of the world

Class 3: All importing nations

Accordingly, the commodity flow matrix can be represented as:

$$\overline{Q} \equiv \begin{bmatrix} Q_1 & 0 & Q_2 & Q_3 \\ 0 & Q_4 & Q_5 & Q_6 \\ 0 & 0 & Q_7 & 0 \end{bmatrix} \tag{2.8}$$

where:

Q_1 is the domestic consumption of class 1

Q_2 is the export of class 1 to class 3

Q_3 is the inventory of class 1

Q_4 is the domestic consumption of class 2

Q_5 is the export of class 2 to class 3

Q_6 is the inventory of class 2

Q_7 is the total production of class 3

Note that a row in the $\overline{Q}$ matrix corresponds to total production plus initial inventory for each class. Each of the first three columns corresponds to the consumption of each class.

The zero terms in the matrix are the result of the following assumptions:

1. There is no export from class 1 to class 2
2. There is no export from class 2 to class 1

3. There is no export from class 3 to either class 1 or class 2
4. There is no carry over inventory associated with class 3.

It directly follows from Equation 2.8 that for class 1, the total production in a particular year plus the previous years carry-over inventory is given by the summation of the terms in the first row.

Thus

$$T_1 \equiv Q_1 + Q_2 + Q_3 \tag{2.9}$$

Similarly,

$$T_2 \equiv Q_4 + Q_5 + Q_6 \tag{2.10}$$

Further, the domestic consumption of class 3 is given by the summation of the terms in the third column.

Thus

$$T_5 \equiv Q_2 + Q_5 + Q_7 \tag{2.11}$$

The terms T_1, T_2, Q_7, Q_4 and T_5 are assumed in this model to be exogenous variables. For the sake of symmetry, Q_7 and Q_4 will be referred to as T_3 and T_4, respectively. The endogenous variables that are relevant for calculating the benefit of the United States are the quantities Q_1 and Q_2 and the associated prices P_1 and P_2. The relationship between the various flow terms and their corresponding prices are assumed to be expressed by demand Equation 2.12.

$$Q_i = K_i + \sum_{j=1}^{5} a_{ij} P_j \tag{2.12}$$

where i goes from 1 to 7, K_i is a constant and the a_{ij} terms are the coefficients or slopes of the price-quantity relationships. The values of K_i and a_{ij} for all values of i and j can be estimated from historical data (i.e., values of Q's and P's of previous years) as will be discussed later.

The exogenous variables can be expressed by regrouping Equation 2.12 for various values of i. Thus,

$$T_1 = \sum_{i=1}^{3} Q_i = R_1 + \sum_{j=1}^{5} S_{1j} P_j \tag{2.13}$$

where $$R_1 = \sum_{i=1}^{3} K_i$$

and $$S_{1j} = \sum_{i=1}^{3} a_{ij}$$

Similarly,

$$T_2 = \sum_{i=4}^{6} a_{ij} = R_2 + \sum_{j=1}^{5} S_{2j} P_j \tag{2.14}$$

where $$R_2 = \sum_{i=4}^{6} K_i$$

and $$S_{2j} = \sum_{i=4}^{6} a_{ij}$$

These two examples are enough to illustrate how the T_i, R_i and S_{ij} terms are calculated from the Q_i, K_i and a_{ij} terms respectively.

Thus the exogenous variables can be expressed as:

$$\begin{bmatrix} T_1 - R_1 \\ T_2 - R_2 \\ T_3 - R_3 \\ T_4 - R_4 \\ T_5 - R_5 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} & \cdots & S_{15} \\ S_{21} & S_{22} & & S_{25} \\ \vdots & \vdots & & \vdots \\ S_{51} & S_{52} & & S_{55} \end{bmatrix} \begin{bmatrix} P_1 \\ P_2 \\ \vdots \\ P_5 \end{bmatrix} \tag{2.15}$$

From Equation 2.15, the vector $\overline{P}$ can be calculated as

$$\overline{P} = [\ S\ ]^{-1}\ [\ \overline{T-R}\ ] \qquad (2.16)$$

Equation (2.16) gives the various domestic prices as well as the import-export prices corresponding to a given set of exogenous variables T_i (as i goes from 1 to 5). These prices are now inserted in Equation 2.12, to compute Q_i as i goes from 1 to 7. Thus the flow matrix of Equation 2.8 is determined in terms K_i and a_{ij}. As mentioned earlier, these coefficients are estimated from the historical values of Q's and P's. Let $Q_i(n)$ and $P_i(n)$ represent the historical values of the year n where $1 \leq n \leq N$. The least square estimates [3] of the coefficients are given by:

$$\begin{bmatrix} K_i \\ a_{i1} \\ a_{i2} \\ a_{i3} \\ a_{i4} \\ a_{i5} \end{bmatrix} = \begin{bmatrix} D^T\ D \end{bmatrix}^{-1} D^T \begin{bmatrix} Q_i(1) \\ Q_i(2) \\ \cdot \\ \cdot \\ \cdot \\ Q_i(N) \end{bmatrix} \qquad (2.17)$$

where the matrix D is given by

$$D \equiv \begin{bmatrix} 1 & P_1(1) & P_2(1) & \cdots & P_5(1) \\ 1 & P_1(2) & P_2(2) & \cdots & P_5(2) \\ \cdot & & & & \\ \cdot & & & & \\ \cdot & & & & \\ 1 & P_1(N) & P_2(N) & \cdots & P_5(N) \end{bmatrix} \qquad (2.18)$$

and D^T is the transpose of the D matrix. The estimated values of the coefficients, as expressed in Equation (2.17), are used to determine the D, R, and S terms as defined in Equations (2.13) and (2.14) which, in turn, are inserted in Equation (2.16) along with the exogenous variables T_i in order to find the various prices. As mentioned earlier, these prices are inserted in Equation (2.12) to compute the terms of the flow matrix. The terms Q_1, and Q_2 are of specific importance because they pertain to the United States. Since their values depend on the exogenous variables T_i $(1 \leq i \leq 5)$, the errors in forecasting the T_i terms get reflected in the evaluation of the Q's. Let the magnitudes of the errors associated with the production forecast of the three classes of countries be denoted by ε_1, ε_2, and ε_3. Under such circumstances, if the true future productions are T_1, T_2, and T_3, the upper and lower bounds of forecasted productions become $T_1 \pm\varepsilon_1$, $T_2 \pm\varepsilon_2$ and $T_3 \pm\varepsilon_3$ respectively. Since the Demand Equation (2.12) is linear, therefore the upper bounds on Q_1 and Q_2 will occur at some combinations of $T_1 \pm\varepsilon_1$, $T_2 \pm\varepsilon_2$ and $T_3 \pm\varepsilon_3$ instead of occurring at some point in between the extrema of the T's. The number of possible combinations of the three extrema is eight. For each such combination, the corresponding values of Q_1 and Q_2 are computed. Let Q_1^{max} and Q_1^{min} be the upper and lower bounds of the computed value of Q_1. Now, the demand curve of Figure 2.3 can be used to compute the disbenefit, W, in the domestic market that is associated with the forecast error. Alternatively, the demand curve can be generated by using Equation (2.19)

$$Q = a P^b \tag{2.19}$$

where Q is the quantity,

P is the price,

a is a constant, and

b is the elasticity of demand which is assumed* to be -0.1

It is assumed that the effect of utilizing a synchronous earth observation satellite system which is capable of providing continuous and on demand information pertaining to U. S. crop production is to reduce the error ε_1 in forecasting the domestic production. Let this reduced error be defined as ε_1'.

Since the satellite observation system is restricted to the observation of the United States only, the errors ε_2 and ε_3 remain unchanged. Thus, the new upper and lower bounds of the forecasted productions become $T_1 \pm\varepsilon_1'$, $T_2 \pm\varepsilon_2$ and $T_3 \pm\varepsilon_3$. The same procedure can be followed to obtain the upper and lower bounds of Q_1, and a new disbenefit, W', can be calculated. Thus the benefit associated with the continuous data gathering system over the conventional system is [W - W']. It should be noted that the benefit of a perfect forecast all over the world as compared to the conventional forecast capability is given by W. However, such a capability assumes that a worldwide data gathering system is implemented and that forecasting techniques using these data are made flawless all over the world.

The Domestic Market

Up till now, the domestic benefit accruing from better U. S. forecast in the perspective of international flow of the commodity has been considered. The other aspect of benefit is realized from a better regulation of the domestic market by the process of smoothing the domestic inventory. This problem has been discussed in detail in Reference 4.

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* Based upon previous detailed ECON analyses.

In this approach, the money equivalent to an amount S of consumption is defined, as before, as the area under the demand curve from zero to S. Thus,

$$V(S) = \int_{0}^{S} p(x)\,dx \tag{2-20}$$

Now assume $S_t, S_{t+1}, S_{t+2}, \ldots\ldots$ as a series of consumptions over consecutive time periods, starting at the present time t. The present value, at time t, of this series of consumptions is given by:

$$V^t(S_t, S_{t+1}, \ldots) = \sum_{i=t}^{\infty} \frac{1}{(1+r)^{i-t}} \int_{0}^{S_i} p(x)\,dx \tag{2-21}$$

where r is the discount factor. Let Q_t represent the quantity of grain placed in the inventory in period t in order to hold over until period $t+1$, and let $C(Q_t)$ be the cost incurred in period t to perform this storage. A certain amount of grain is usually lost through deterioration in storage, and so, assume that $(1-\delta)Q_t$ is actually carried forward from period t to period $(t+1)$ where δ is a positive quantity. Let G_t represent the grain harvest in time period t. Then the consumption in period t is equal to the grain harvested in that period plus inheritance from the previous period less the inventory held over to period $t+1$. Thus,

$$S_t = G_t + (1-\delta)Q_{t-1} - Q_t \tag{2-22}$$

The welfare measured in period t is given by:

$$W^t = V^t(S_t, S_{t+1}, \ldots) - \sum_{i=t}^{\infty} \frac{C(Q_i)}{(1+r)^{i-t}} \tag{2-23}$$

where:

V^t is as defined by equation 2-21,

S_t, S_{t+1} ... conform to equation 2-22, and

$C(Q_i)$, as mentioned earlier, is the cost to the inventory holder in carrying an inventory of Q_i.

Note that the G_t's are exogenous variables specified by nature, while Q_t's are determined by profit maximizing inventory holders. The values of the Q_t's which, under a certain crop forecast will maximize the expected profits of the inventory holders can be found by the method of dynamic programming [4]. These, when inserted in Equation 2-23 determine the value of W^t. By introducing improved forecast information, the choices of the inventory holders are affected, with the resulting effect on W^t. The difference between the two values of W^t under the conventional forecast system and the improved forecast system defines the benefit of one with respect to the other.

The total benefit derived from the domestic market as well as from the international market lies between the larger of these two benefits and their sum. Equation 1-1 can now be used to determine the present worth of the bounds of the total benefit.

3.0 THUNDERSTORM WARNING

This section deals with the evaluation of some of the potential economic benefits that might be derived from such improvements in forecasting thunderstorms as might be realized by a satellite system collecting meteorological data on a continuous basis and providing this information as demanded by a user. The benefit areas described in this Section are, by no means, all exhaustive. Rather, these constitute typical examples based upon several different commerce and industry aplications which are affected by thunderstorms, and where some cost saving action (or no action, as the case may be) can be taken on a day-to-day basis based on thunderstorm warnings. Hence, the more accurate the forecast, the more effective the cost saving decision. An effort has been made to evaluate the potential cost saving, and to estimate the probable benefit that might accrue as a result of the implementation of such cost saving plans, keeping in mind that the implementation of a plan seldom attains 100% of its potential.

3.1 Definition of Thunderstorm

Meteorological terms are apt to be subject to multiple interpretations depending on the agencies preparing weather forecasts. However, for the purpose of this study, the following definitions, as provided by NASA, are used.

Thunderstorm: A storm associated with lightning and thunder, and characterized by the following:

1. wind gusts less than 50 knots, and
2. hail, if any, less than 3/4 inch in diameter at the surface of the earth.

Severe Thunderstorm: A thunderstorm with wind gusts in excess of 50 knots, or with hail of 3/4 inch, or larger, diameter at the surface of the earth, or both.

Tornado: A violently rotating column of air which forms a pendant, usually from a cumulonimbus cloud, and touches the ground. It nearly always starts as a funnel cloud and is accompanied by a loud roaring noise.

3.2 Benefit Areas

The following application or benefit areas have been considered:

1. Construction Industry
2. Air Transportation Industry
3. Agricultural Industry

As pointed out earlier, the list does not exhaust all the areas where potential benefits can be achieved through the use of forecasts of thunderstorms. However, these are typical examples and provide a feel for the magnitude of potential benefits.

3.2.1 Construction Industry

In 1964, the total expenses of the U.S. construction industry were approximately $88 billion [5,6] in 1964 dollars. This constituted more than 10% of the gross national product. Based upon the assumption that the expenses of the construction industry maintain a constant relationship with the nominal GNP, the estimated expense figures in the 1980's, when expressed in 1974 dollars*, are expected to be at least double those of 1964. It should be noted that the annual expenses have been assumed (a degree of conservatism) to remain constant during the period of the benefit computation.

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* All value figures in this report are expressed in current 1974 dollars unless otherwise mentioned.

The business volume of the construction industry can be broadly classified into the following segments: [7,9]

1. Heavy Construction: airport, dam, sewage, power lines, utilities, etc,
2. General Building: industrial, institutional, high-rise, apartment complex, etc.
3. Single Family Residential
4. Highways and Bridges
5. Repair and Maintenance

References 6 and 8 indicate that, out of the total volume of construction business, 14.2% is related to heavy construction, 33.75% to general building, 19.55% to single family residential, 7.5% to highways and bridges, and 25% to repair and maintenance. It should be noted that these five segments of construction are not equally sensitive to bad weather. Heavy construction and highway construction are naturally much more weather sensitive than single family residential construction. Figure 3.1 illustrates the weather sensitivity of the five segments. The numerical values have been obtained by extrapolating, in proportion with nominal GNP, the 1964 data given in Reference 8. References 7 and 8 provide a detailed breakdown of the various construction activities and their respective degrees of sensitiveness with respect to weather. This is summarized in Table 3.1. From the activities listed in Table 3.1, it follows that losses due to weather can be divided into four categories.

1. Perishable material,
2. Wages,
3. Equipment, and
4. Overhead and profit.

Table 3.2 indicates the breakdown of the <u>weather sensitive</u> volume of the construction industry of 1980 into these four

Table 3.1 Critical Limits of Weather Elements Having Significant Influence on Construction Operations (from References 7 and 8)

Surveying	L*	Waterproofing	M
Demolition and clearing	M	Backfilling	M
Temporary site work	M	Erecting structural steel	L
Delivery of materials	M	Exterior carpentry	L
Material stockpiling	L	Exterior masonry	L
Site grading	M	External cladding	L
Excavation	M	Installing metal siding	L
Pile driving	M	Fireproofing	L
Dredging	M	Roofing	L
Erection of coffer dams	M	Cutting concrete pavement	M
Forming	M	Trenching, installing pipe	M
Emplacing reinforcing steel	M	Bituminous concrete pouring	L
Quarrying	M	Installing windows and doors, glazing	L
Delivery of pre-mixed concrete	M	Exterior painting	L
Pouring concrete	M	Installation of culverts and incidental drainage	M
Stripping and curing concrete	M	Landscaping	M
Installing underground plumbing	M	Traffic protections	M
		Paving	L
		Fencing	M

*L indicates light; M indicates moderate

Table 3.2 Estimated Volume of '80 Construction (Billion Dollars)

Category	Volume	Weather Sensitive Portion: Perishable	Wages	Equipment	Overhead and Profit	Total Sensitive Volume
Residential	34.4	1.92	3.24	.14	4.28	9.58 (27.9%)
General	59.4	3.85	8.16	.44	5.34	17.79 (30%)
Highway etc.	13.2	3.33	3.26	1.55	1.45	9.59 (72.7%)
Heavy	25.0	3.75	6.25	5.0	5.0	20.00 (80%)
Repair and Maintenance	44.0	5.35	7.99	2.77	6.28	22.39 (50.9%)
Total	176.0	18.2	28.9	9.9	22.35	73.35 (45%)

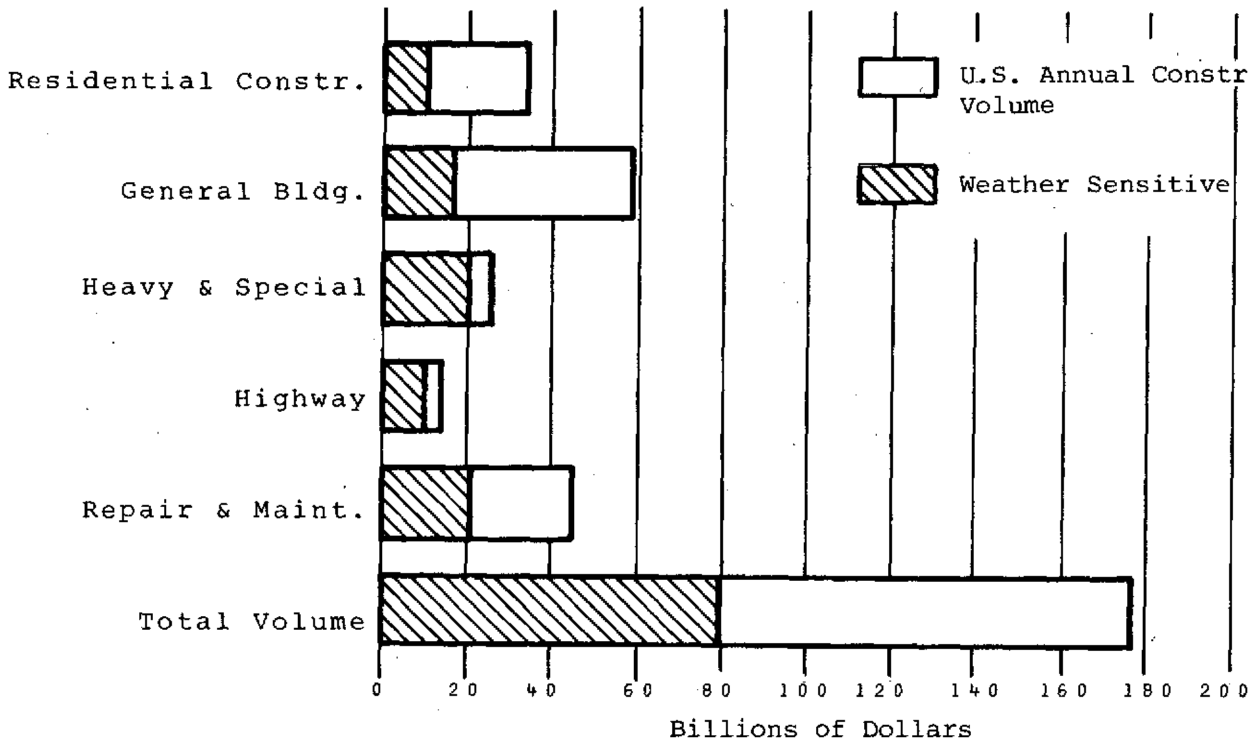

Figure 3.1 Construction Losses Due to The Weather (extrapolation of data given in Reference 8)

categories. The numerical values are obtained by the same extrapolation method previously referred to.

The annual expenditure due to bad weather depends upon the frequency of the bad weather, the forecast accuracy, and the construction policy regarding bad weather. These factors will be discussed in some detail in the following pages and the annual expenditure due to bad weather determined for optimal construction industry policies in terms of different weather forecast accuracies. These annual expenditures are converted into potential savings resulting from improved forecast accuracies. The potential savings are thence converted into a time varying stream of annual benefits and the present worth of benefits established. Both the benefits associated with the construction industry, in the narrow sense, and societal benefits, in the broad sense, are considered.

Only three types of bad weather are considered in the present study, viz., thunderstorm, severe thunderstorm, and tornado and have been defined previously. Most construction work cannot progress in any of the three cases of bad weather. Therefore, if the destruction caused by tornadoes is neglected, the construction expenses caused by a storm remain the same irrespective of whether it is a regular or severe thunderstorm or a tornado. Further, the number of tornadoes and severe thunderstorms is negligible compared to the number of regular thunderstorms. Hence, the expenses which are the result of severe storms and tornadoes can be neglected in comparison with the expenses which are the result of regular thunderstorms as long as concern is focused on the expenditure due to non-optimal construction scheduling. Since the weather throughout the United States is not uniform, it is necessary to consider equi-thunderstorm zones and evaluate the construction expenses in each zone separately. Figure 3.2 illustrates the distribution of yearly thunderstorm activity over the United States excluding Alaska and Hawaii [19]. The characteristics of these zones are summarized in Table 3.3. The thunderstorm-related expenses of each zone are calculated separately as discussed in the following paragraphs, and then aggregated to obtain the national picture.

Three types of weather forecasts are considered: Conventional, Level 1, and Level 2. Levels 1 and 2 imply continuous and on demand capability. The accuracy of the forecasts differ. <u>The Level 1 forecast is based upon the anticipated (by NASA) accuracy of a system based upon SMS technology and the Level 2 forecast is based upon the</u>

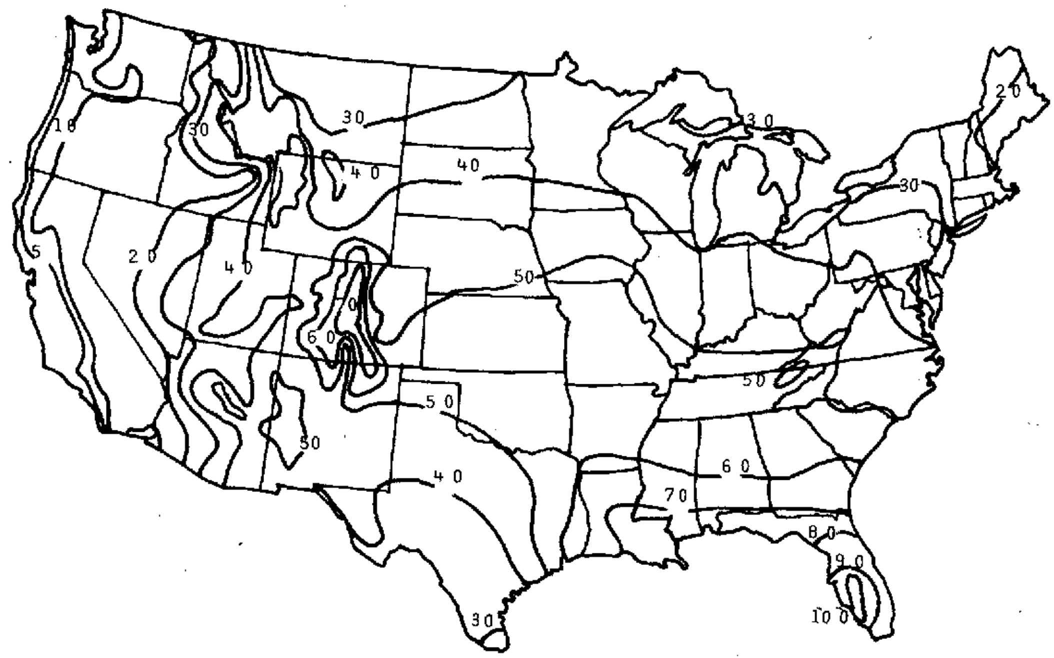

Figure 3.2 Geographical Distribution of Thunderstorms in Terms of Mean Annual Number of Storm Days (from Reference 10)

Table 3.3 Geographical Distribution of Miss & False Alarm (Six Hour Forecast)							
# Of Days of Thunderstorm Occurrence	Area (Square Miles)	# of Miss Days			# of False Alarm Days		
		Conv	Level 1	Level 2	Conv	Level 1	Level 2
100	4,151	5.00	3.00	2.00	51.15	32.33	17.29
90	8,302	4.50	2.70	1.80	46.04	29.10	15.56
80	20,755	4.00	2.40	1.60	40.92	25.87	13.84
70	58,114	3.50	2.10	1.40	35.81	22.63	12.11
60	99,624	3.00	1.80	1.20	30.69	19.40	10.38
50	581,140	2.50	1.50	1.00	25.58	16.17	8.65
40	747,180	2.00	1.20	0.80	20.46	12.93	6.92
30	547,932	1.50	0.90	0.60	15.35	9.70	5.19
20	249,060	1.00	0.60	0.40	10.23	6.47	3.46
10	282,268	0.50	0.30	0.20	5.12	3.23	1.73
5	66,416	0.25	0.15	0.10	2.56	1.62	0.86

projected capability of a SEOS-type system.* The accuracy of each forecast can be expressed in terms of "False Alarm" and "Miss" days. A false alarm day signifies a forecast for a storm which, in reality, turns out to be a clear day. A miss day signifies a forecast for clear weather which, in reality, turns out to be a stormy day. Clearly, the percentages of false alarm and miss for each type of forecast will depend on the lead time associated with the forecast. The incidence of false alarm and miss will, in general, be higher for a twenty-four hour forecast than for a two-hour forecast, and since the construction schedule for a day can be drawn up in the morning, the six-hour forecast is the most relevant piece of weather information for the construction industry. Equations (3.1), (3.2), and (3.3) are used to determine the miss days, the number of correctly forecasted storm days, and the false alarm days, respectively. The conditional probabilities used in these equations have been provided by NASA (Goddard Space Flight Center) and are shown in Figures 3.3 and 3.4. The conditional probabilities obtained from these figures for the six-hour forecast are inserted in the following equations:

$$\beta = N\,\pi'_{12} \tag{3.1}$$

$$\gamma = N - \beta \tag{3.2}$$

$$\alpha = [n-\gamma] = \gamma\left[\frac{1}{\pi_{11}} - 1\right] \tag{3.3}$$

where β = Number of miss days

N = Number of days storms occur in a year

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* Again, it must be emphasized that costs of implementation and operation of the systems have not been considered. No consideration has been given to the number of satellites and their on-board equipment required to achieve the continuous and on demand capability.

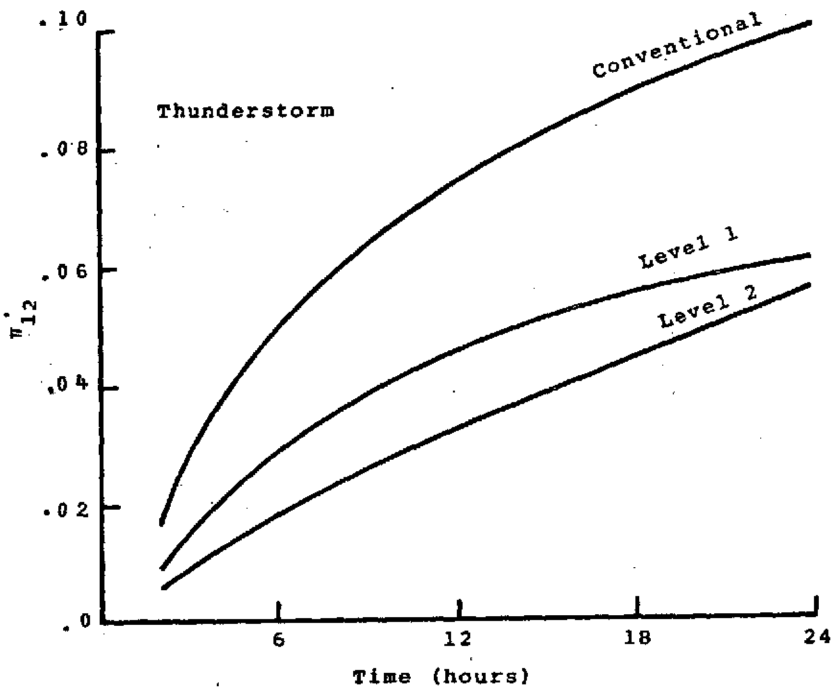

Figure 3.3 Probability That Forecast Was For Clear Weather Given That Storm Occurred (Data Supplied by NASA)

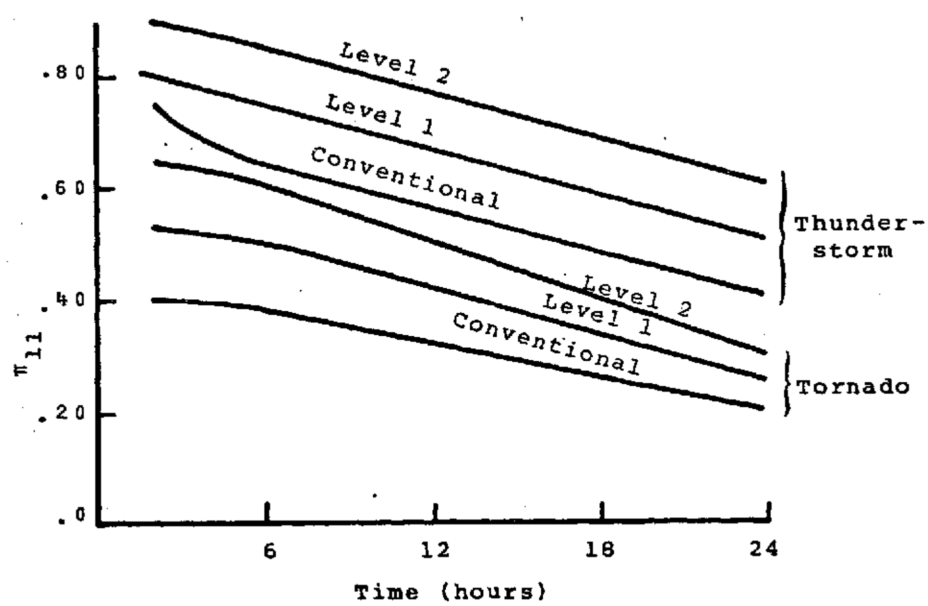

Figure 3.4 Probability of Storm Occurrence Given A Storm Forecast (over large area) (Data Supplied by NASA)

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

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

The geographic distributions of α and β for the three forecasts considered are shown in Table 3.3. The construction expenses associated with α, β, and γ are, in general, different. Further, they depend on the nature of the construction policy regarding work/no work decisions. This aspect of the problem is treated in detail in the following paragraphs.

The expenses of the construction industry under various conditions are shown in Figure 3.5. To understand the expense functions, consider a hypothetical case where a construction company starts the day's work with a capital of X dollars. On a regular construction day with a forecast for no storm, and with no storm occurring, the company spends the following:

a. (M+S) dollars for raw material, where S constitutes that portion of raw material which would be wasted if a storm occurred, and M is the remaining portion of raw material unaffected by the storm,

b. E dollars for equipment rental, and

c. W dollars for wages.

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* Note that π'_{12} is different from π_{12} which has previously been defined as the probability of 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.

By the end of the day, the company markets the day's work and makes a net profit of P dollars. Thus, the market value of the day's construction must be (M+S+E+W+P) dollars, so that the capital the company owns at the end of the day is (X+P) dollars. On a false alarm day (thunderstorm forecast, but no storm occurs), if the decision is to work, the profit picture remains the same, i.e., the capital by the end of the day becomes (X+P) dollars.

However, if the decision is to work in spite of a storm forecast, and if the storm does strike as predicted, the company spends (M+S+E+W) dollars of the X dollars it started with. (S+E+W) dollars of this is wastage. Further, since the work cannot be completed for marketing, no profit can be made. Hence, at the end of the day, the company is left with a capital of (X-S-E-W) dollars. This, compared with a regular working day, is equivalent to a loss of (X+P)-(X-S-E-W) or (S+E+W+P) dollars. This profit/loss picture remains the same for a day when the forecast is for clear weather, and a storm occurs unexpectedly, i.e., for a miss day.

Now consider the situation when, due to a storm forecast, the decision is made not to work. Since there is no work, there is no profit. Also, the equipment rental will have to be paid because such rentals are usually prearranged. However, with proper precaution, the perishable raw material can be saved. Further, adjustments can be made to the company's benefit regarding the wages of the workers. The company would, obviously, like to achieve a "no work, no pay" policy, which worker's unions may not always accept. Various construction companies have been contacted relative to this issue, and it has been found that there are no fixed rules regarding union contracts. However, the two bounds within which a settlement is usually reached are (a) no pay for the afternoon, and (b) two hours' wages for the afternoon if the decision is taken to call off the afternoon's work due to storm apprehension. Thus, at the end of a no-work day, the company is left with a capital of (X-E-W') dollars where W' varies from zero to two hours' wages. The expense due to such a decision, in comparison with a normal working day, is (X+P)-(X-E-W') or (P+E+W') dollars. The picture remains the same as long as there is no work, irrespective of whether a storm does or does not occur.

The various combinations shown in Figure 3.5 can be expressed as a matrix of expense functions as shown in Table 3.4. The numerical values used in this table are calculated as follows.

From Table 3.2, it follows that the total amount of perishable material used per year (approximately 250 working days of construction) throughout the United States (approximately 3,022 thousand square miles) is 18.2 billion dollars. Assuming uniformity in construction throughout the country, the amount of perishable material used per half a day (since thunderstorms usually occur in the afternoon) per square mile becomes 12.045 dollars. The remainder of the numbers are calculated in the same fashion. It should be noted that construction activities have been assumed to be uniform throughout the country.

In order to decide upon the optimal policy for the construction company, the expected cost associated with the decision to work in the face of a thunderstorm forecast has to be compared with the decision to stop work. It is clear from Table 3.4 that, for the three levels of forecasts considered,

$$[P+E+W'] < \pi_{11}\ [S+E+W+P] \qquad (3.4)$$

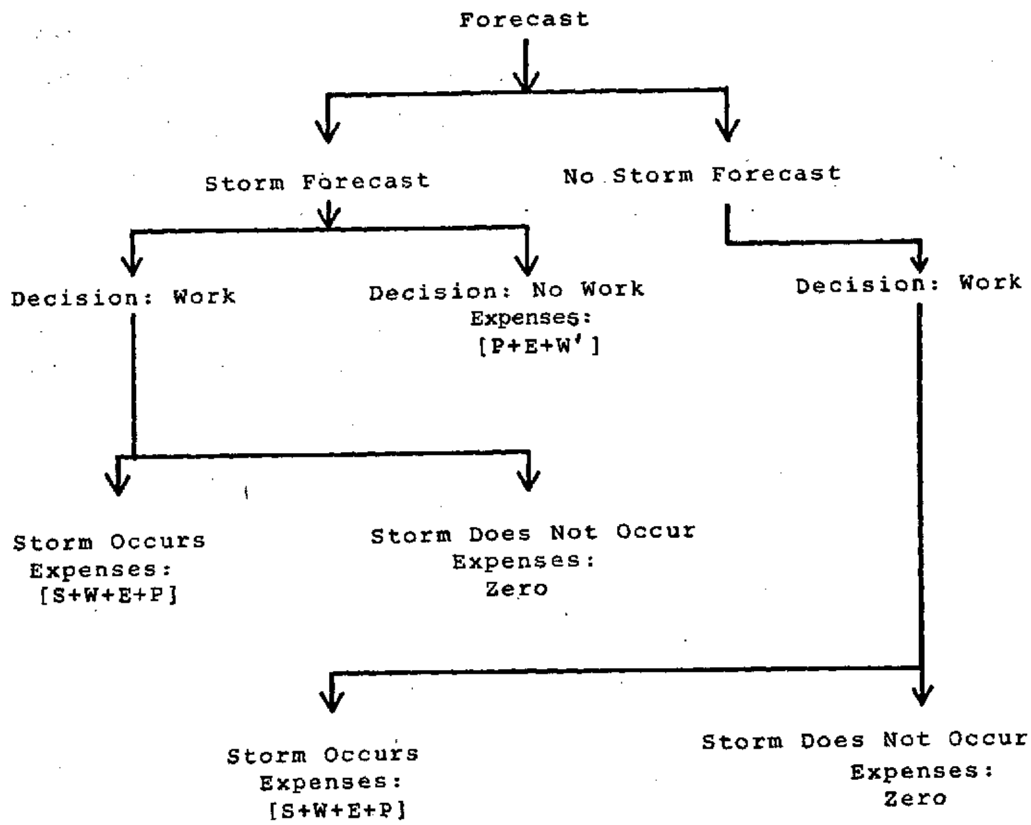


Figure 3.5 Expenses of the Construction Industry

Table 3.4 Expense Function of Construction Industry Per Square Mile Per Afternoon of Storm Forecast (Dollars)

Policy	Storm	No Storm
Work	S+E+W+P	0
No Work	P+E+W'	P+E+W'

$S = 12.045$, $E = 6.552$, $W = 19.126$, $P = 14.792$
$0 \leq W' \leq 9.563$

Hence, the optimal policy for a construction company should be to stop work in the afternoon if an afternoon thunderstorm had been forecast in the morning. (It should be noted that, when the cost function is defined as the national or societal loss rather than the expenses of the construction industry, the optimal decision need not be the same, as will be evident later in this Section.)

The potential saving of one forecast capability with respect to another is the difference between the expenses incurred due to thunderstorms when using the forecasts of the two systems under the assumption that the respective optimal policy on construction schedule has been followed in each case. These optimal policies, given a storm forecast as described above, are listed in Table 3.5.

Combining Tables 3.3 and 3.4, it is possible to find the expenses incurred under various forecast systems on (1) a miss day, (2) a false alarm day, and (3) a storm day that has been correctly forecast. These are shown in Tables 3.6, 3.7, and 3.8, respectively, in terms of frequency of thunderstorm occurrence. Table 3.9 gives the aggregate of all these expenses for the different forecast capabilities considered, and Table 3.10 gives comparative figures on the potential savings.

In the previous paragraphs, construction industry benefits have been estimated based upon a policy of <u>industry cost minimization</u>. The cost minimization, it should be noted, occurs at the expense of reduced wages paid to construction workers when following a policy of "no work" when a forecast is given for thunderstorms. This possible reduction in wages may be viewed as a "disbenefit" to the construction workers and the estimation of societal expenses and benefits should take this into account. It might be argued, however, that the

Table 3.5 Optimal Policy for Construction Industry Given A Storm Forecast	
Type of Forecast	Policy
1. Perfect	Stop Work
2. Conventional*	Stop Work
3. Level 1 *	Stop Work
4. Level 2 *	Stop Work
5. No Forecast Facility	Work

* As per forecast accuracies given in Figures 3.3 and 3.4.

reduction in wages is a normal result of the functioning of supply and demand in a free economy and that the wages plus the leisure time value provide the necessary compensation to labor. In this case, the construction industry benefits correspond to the societal benefits. On the other extreme are the societal benefits which take into account the loss of workers' wages. This "disbenefit" approach is now considered.

This societal expense function can be established in a manner similar to that of the construction industry where a capital of X dollars is avilable at the start of a day. At the end of a regular day (no storm and no storm forecast), the capital in the hands of industry and construction workers is*

* Start with X dollars. Industry spends S+W+E. Total earned by industry and workers (and equipment rentors) is S+W+E+P and W+E, respectively. Total money available to industry and workers at day's end is therefore X-(S+W+E)+(S+W+E+P)+(W+E)= X+W+E+P.

Table 3.6 Annual Expenses Due to Miss For Construction Industry						
# of Days of Thunderstorm Occurrence	Area (square miles)	Miss Expenses in Million $				
		No Forecast	Conv	Level 1	Level 2	Perfect
100	4,151	21.80	1.09	0.65	0.44	0
90	8,302	39.24	1.96	1.18	0.78	0
80	20,755	87.20	4.36	2.61	1.74	0
70	58,114	213.63	10.68	6.40	4.27	0
60	99,624	313.90	15.70	9.42	6.28	0
50	581,140	1529.93	76.30	45.78	30.52	0
40	747,180	1569.53	78.47	47.09	31.39	0
30	547,932	863.24	43.16	25.90	17.26	0
20	249,060	261.59	13.08	7.85	5.23	0
10	282,268	148.23	7.41	4.45	2.96	0
5	66,416	17.44	8.72	0.52	0.35	0
	TOTAL (Billion $)	5.062	0.261	0.152	0.101	0

Table 3.7 Upper Bound of Annual Expenses of Construction Industry Due to False Alarm (W' = 9.563)						
# of Days of Thunderstorm Occurrence	Area (square miles)	False Alarm Expenses in million $				
		No Forecast	Conv	Level 1	Level 2	Perfect
100	4,151	0	6.56	4.15	2.22	0
90	8,302	0	11.81	7.47	3.99	0
80	20,755	0	26.25	16.59	8.88	0
70	58,114	0	65.32	40.65	21.75	0
60	99,624	0	94.50	59.73	31.96	0
50	581,140	0	459.45	290.43	155.37	0
40	747,180	0	472.48	298.59	159.80	0
30	547,932	0	259.95	164.27	87.89	0
20	249,060	0	78.75	49.80	26.63	0
10	282,268	0	44.67	28.18	15.09	0
5	66,416	0	5.25	3.33	1.77	0
	TOTAL (Billion $)	0	1.525	0.963	0.515	0

Table 3.8 Upper Bound of Annual Expenses of Construction Industry Due to Storm days Correctly Forecast (W' = 9.563)

# of Days of Thunderstorm Occurrence	Area (square miles)	Expenses Due to Storm Correctly Forecast (million $)				
		No Forecast	Conv	Level 1	Level 2	Perfect
100	4,151	0	12.19	12.44	12.57	12.83
90	8,302	0	21.94	22.40	22.63	23.09
80	20,755	0	48.75	49.78	50.29	51.32
70	58,114	0	119.44	121.96	123.21	125.73
60	99,624	0	175.51	179.20	181.05	184.74
50	581,140	0	853.16	871.12	880.10	898.06
40	747,180	0	877.54	896.01	905.25	923.72
30	547,932	0	482.65	492.81	497.89	508.05
20	249,060	0	146.26	149.34	150.87	153.95
10	282,268	0	82.88	84.62	85.50	87.24
5	66,416	0	9.75	9.96	10.06	10.26
	TOTAL (Billion $)	0	2.830	2.890	2.919	2.979

Table 3.9 Aggregate Annual Expenses of Construction Industry Due to Thunderstorms (in Billion $)

Type of Forecast	Correctly Forecasted Storm		False Alarm		Miss	Total	
	Upper Bound	Lower Bound	Upper Bound	Lower Bound		Upper Bound	Lower Bound
No Forecast	0.0	0.0	0.0	0.0	5.062	5.062	5.062
Conv	2.830	1.954	1.525	1.053	0.261	4.616	3.268
Level 1	2.890	1.996	0.963	0.665	0.152	4.005	2.813
Level 2	2.919	2.016	0.515	0.365	0.101	3.535	2.979
Perfect	2.979	2.057	0	0	0	2.979	2.057

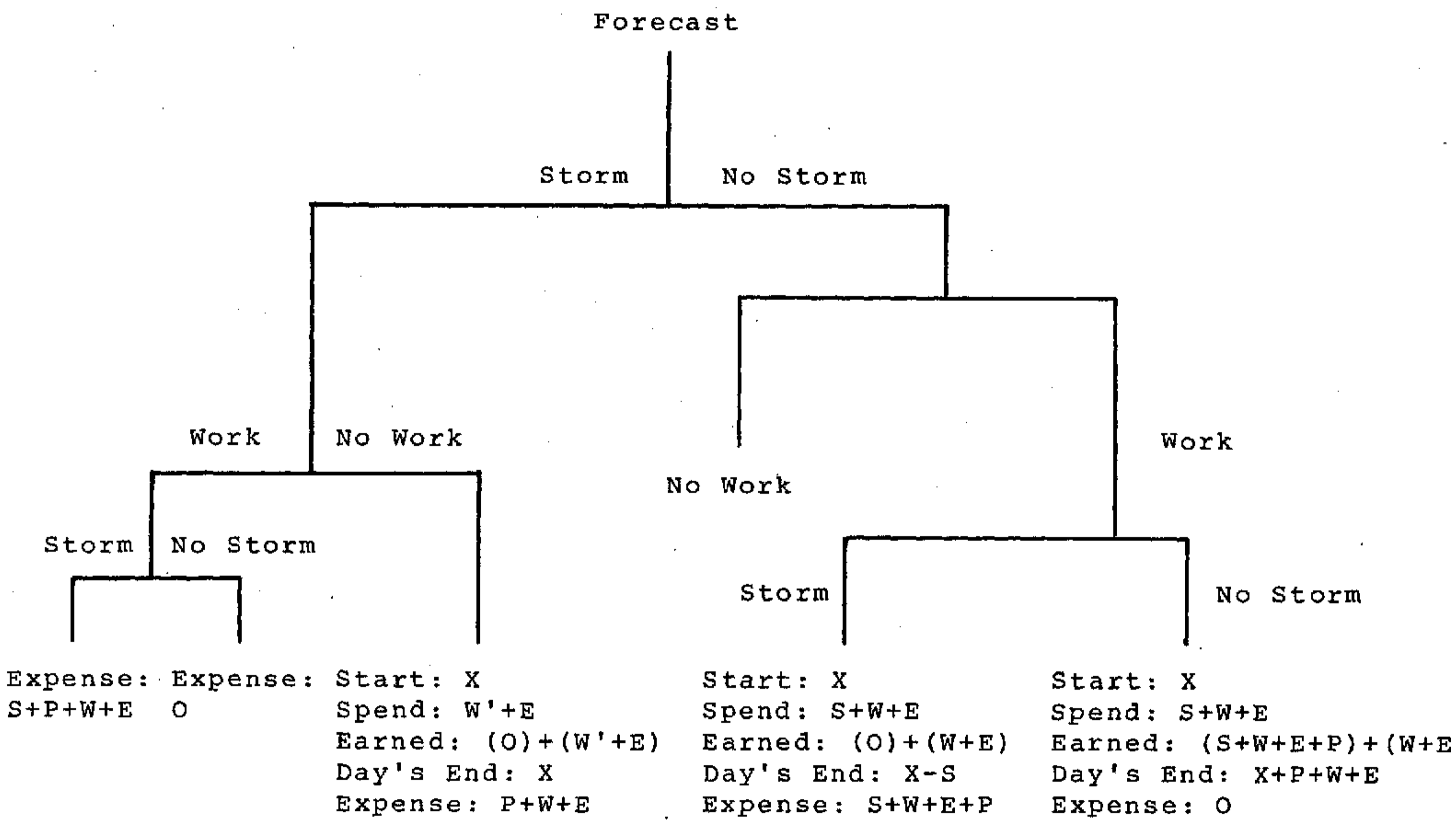
Note: The upper and lower bounds are based upon W'=0 and W'=9.563 dollars, respectively.

Table 3.10 Comparative Savings for Construction Industry (in Billion $)

Levels Compared	Upper Bound	Lower Bound
Level 1 over Conv	0.61	0.45
Level 2 over Level 1	0.47	0.34
Level 2 over Conv	1.08	0.79

X+P+W+E. It should be noted that the interaction of the construction industry with other industries has not been taken into account. This would require an input/output-type analysis which is well beyond the scope of the current efforts.

The expense function under the various combinations of storm-no-storm forecasts and work-no-work policies are given in Figure 3.6. It should be noted that the only change relative to the construction industry cost minimization policy as illustrated in Figure 3.5 is in the branch which illustrates the no-work policy given a storm forecast; i.e., the societal expense function is P+W+E, whereas the construction industry expense function is P+W'+E. This difference in expense functions is taken into account and summarized in Tables 3.11 and 3.12 for the expenses incurred as a result of false alarms and correct storm forecasts, respectively. The effect of misses is summarized in Table 3.6 where it should be noted the construction industry and societal expenses are the same. Table 3.13 presents the aggregate or total societal expenses on annual construction due to thunderstorms. Several points should be noted, namely, (a) the societal expenses are



<u>Note</u>: "Earned" includes both construction industry and construction workers

Figure 3.6 Societal Expenses

Table 3.11 Societal Expenses On Construction Incurred On False Alarm Days						
# Of Days Of Thunderstorm Occurrence	Area (square miles)	False Alarm Expenses in Million $				
		No Forecast	Conv	Level 1	Level 2	Perfect
100	4,151	0	8.59	5.43	2.91	0
90	8,302	0	15.46	9.78	5.22	0
80	20,755	0	34.37	21.72	11.63	0
70	58,114	0	85.53	53.23	28.48	0
60	99,624	0	123.74	78.21	41.85	0
50	581,140	0	601.61	380.29	203.44	0
40	747,180	0	618.67	390.98	209.24	0
30	547,932	0	340.38	215.10	115.08	0
20	249,060	0	103.12	65.21	34.87	0
10	282,268	0	58.49	36.90	19.76	0
5	66,416	0	6.87	4.36	2.32	0
	TOTAL (Billion $)	0	1.997	1.261	0.674	0

Table 3.12 Societal Expenses On Construction Incurred On Storm Days Correctly Forecast						
# of Days of Thunderstorm Occurrence	Area (square miles)	Expenses Due To Storm Correctly Forecast In Million $				
		No Forecast	Conv	Level 1	Level 2	Perfect
100	4,151	0	15.96	16.29	16.46	16.80
90	8,302	0	28.73	29.33	29.63	30.23
80	20,755	0	63.83	65.18	65.85	67.20
70	58,114	0	156.40	159.70	161.33	164.63
60	99,624	0	229.81	234.65	237.07	241.90
50	581,140	0	1117.14	1140.65	1152.41	1175.93
40	747,180	0	1149.06	1173.25	1185.35	1209.53
30	547,932	0	631.99	645.29	651.94	665.25
20	249,060	0	191.51	195.55	197.55	201.58
10	282,268	0	108.52	110.80	111.95	114.23
5	66,416	0	12.77	13.04	13.17	13.43
	TOTAL (Billion $)	0	3.706	3.784	3.823	3.901

greater, as would be expected, than those of the construction industry alone as given in Table 3.13, (b) the societal expense function, and hence savings and benefits, is independent of w' and dependent upon W. The reason for this, is that a reduction in wages paid by the construction industry results in a change in the industry expense function which is cancelled out by a corresponding change in the workers' expense function and, (c) the total societal expenses, as indicated in Table 3.13, are less when there is no forecast data utilized. The reason for this is that, when no forecast data is utilized, the optimum societal policy coincides with that of the construction industry (i.e., work unless there is a storm), whereas, in all other cases, the optimal societal policy does not correspond with the optimal policy followed by the construction industry.

A comparison of societal savings which may result from achieving different forecast levels is presented in Table 3.14. It should be noted that these savings are greater than the savings that result when considering only the construction industry (i.e., not considering societal benefits). The reason for the increase in potential savings is that an optimum societal policy (work/no-work) is not being followed and improved forecast capability can reduce the disbenefit as seen by the workers. In other words, the burden placed on the workers (in terms of wages, foregone) is reduced as forecast capability is increased when the construction industry persues its optimum course of action.

The present worth or value of the benefit stream that might accrue as a result of these savings will now be discussed. The present worth of the benefits depends on the following factors:

Table 3.13 Aggregate Societal Expenses On Annual Construction Due To Thunderstorms (Billion $)

Type of Forecast	Correctly Forecast Storm	False Alarm	Miss	Total
No Forecast	0.0	0.0	5.062	5.062
Conv	3.706	1.997	0.261	5.964
Level 1	3.784	1.261	0.152	5.197
Level 2	3.823	0.674	0.101	4.598
Perfect	3.901	0.0	0.0	3.901

Table 3.14 Comparison Of Societal Savings In Annual Construction (Billion $)

Levels Compared	Amount of Saving
Level 1 over Conv	.767
Level 2 over Conv	1.366
Level 2 over Level 1	.599

1. Magnitude of potential cost saving,
2. The fraction of the potential cost saving which may be realized in practice through user implementation,
3. The date when the implementation program begins,
4. The shape of the implementation curve during the transitional period, and
5. The factor by which the future benefits are to be discounted to calculate the present worth.

Up till now, only point (1), i.e., the magnitude of the potential cost saving, has been discussed. The other factors are considered below.

As a result of contacting a number of construction companies (viz-Bechtel, Turner, Lummus, Parsons, Ebaska, Austin, etc.), it has been found that utilization of weather forecast information varies considerably from company to company. On one extreme is the case where a company schedules its daily work completely disregarding the weather forecast. On the other extreme is the case where a weather forecast available in the previous evening as well as the morning forecast for the afternoon are meticulously accommodated in the construction schedule. With such a wide variance, the average value usually loses its significance. However, considering the volume of business of various construction companies and their respective sensitiveness to weather forecasts, it appears that approximately 30% of the potential cost saving associated with today's available forecast information is achieved through proper implementation. The validity of this estimate of the achieved utilization of weather forecast data can only be verified by a statistically significant sampling of the firms in the construction industry and a detailed analysis of the operations and costs of a number of construction firms. The remaining 70% unachieved is partly due to the traditional ways of running the construction business and partly due to the diffident attitude towards weather forecasts because of the inherent inexactitude of the present forecasting system. However, it can be assumed that with improvements in weather forecasts, this diffidence can be gradually overcome, and that with gradual refinements in construction policies, companies will be more prone to utilize weather information in scheduling work. Thus, 30% seems to be a conservative estimate of the implementability of potential benefits for the future.

Regarding the date of implementation of an operational forecasting system which will provide continuous and on demand data and the user implementation curve, it should be noted that the launching of a satellite along with the development of an operational system usually takes place in two phases. The first phase is experimental during which scientific knowledge is gathered and the potential capabilities demonstrated. This is followed by the second phase which is the development of the operational system during which the majority of the potential benefits are realized. For example, ATS-3, launched in 1967, demonstrated the capability of color photography [11] from a synchronous orbit, using a multi-color spin-scan camera. The operational descendant of ATS-3 is GOES with its launching in 1974. It is expected that the operational system for data reception and interpretation associated with GOES will be fully established by 1979 [12]. Thus, the time interval between launching an experimental satellite and its operational descendent (in the case of ATS-3 and GOES) has been seven years. The economic benefits can be achieved starting with the launch of the operational satellites. However, it is expected to take another five years to reach the steady state value, i.e., complete system implementation and maximum implementation of system capabilities into user operations. The implementation curve (for ATS-3-GOES) is assumed to be S-shaped, as shown in Figure 1.2, and is extended over the period 1967 to 1979, with zero value from 1967 to 1974, followed by a transitional increment till it reaches the final level at 1979. The S-shaped curve can be approximated by the Normal Distribution Function (cummulative) and can be specified in terms of the expected value (year during which 50% of the final level of implementation is achieved) and standard deviation of the implementation time.

Assuming that the experimental SEOS will be launched in the year x, where x is in the range of 1980 to 1985, the operational descendent may be expected to be launched in the year x + 7, and the benefit is expected to reach its full value in the year x + 12. Accordingly, the equation for the user implementation curve is given by:

$$B_i = \frac{\delta B}{\sqrt{2\pi}\sigma} \int^{i} \exp \left[-(t-x-m)^2/2\sigma^2\right] dt \tag{3.5}$$

for $i > x + 7$

and $$B_i = o \tag{3.6}$$

for $i \leq x + 7$

where

B_i is the benefit achieved in the year i

X is the calender during which the experimental satellite is launched (beginning of year assumed)

B is the steady state value of the benefit

σ is 1.67 based upon an assumed 5 year build up of benefits

m is the year, relative to experimental satellite launch date, during which 50% of the final level of implementation is achieved

δ fraction of benefits achieved through proper implementation (estimated as 0.3)

The present worth of the benefits calculated for 1974, discounted at the rate of 10% is:

$$PVB = \sum_{i=x+8}^{\infty} \frac{B_i}{(1+r)^{i-1974}} \tag{3.7}$$

where $r = 0.1$

Note that a discount rate of 10% has been utilized. The discount rate is the effective discount rate and as such includes the effects of inflation. The effective discount rate, r,, is related to the social rate of return, R, and the inflation rate, I, by

$$(1+r)=(1+R)/(1+I)$$

Therefore, the choice of r=10% implies either no inflation or a value of R in excess of 10%. The use of a lower value of R or an inflation rate greater than zero has the effect of reducing r and increasing the estimated present worth of benefits. Therefore, it is felt that the choice of r=10% leads to conservative results.

The summation of the infinite series in Equation (3.7) and the normal distribution function of Equation (3.5) yields approximately:

$$PVB = 1.34B/(1.1)^{x-1974} \tag{3.8}$$

Equation (3.8) is used to calculate the present worth of the benefits resulting from the different forecast systems. The difference of the present worth represents the present worth of one forecast system relative to the other. A comparison of the present worth is illustrated in Figure 3.7 for values of x (i.e., the launch date of the experimental satellite) varying between 1980 and 1985. The high and low values, as discussed previously, correspond to two hours' wages and no afternoon wages, respectively, when afternoon work is called off due to thunderstorm forecasts.

Also illustrated is the present worth of societal benefits. Since societal savings, for any specified forecast capability are independent of w' it follows that PVB is independent of w' and only a single curve of PVB vs. year of experimental launching is necessary. This is contrasted to the dependence of PVB upon w' when only construction industry benefits, are considered. For PVB of the construction industry, $0 \leq w' \leq 9.563$ where the upper bound is for 2 hours wages. It should be noted that if this upper bound approached 4 hours wages (i.e., a full afternoon's pay) the upper curve of the construction industry becomes coincident with the curve of PVB for the societal benefits.

3.2.2 Air Transportation

The air transportation industry can be dividen into the following three categories [9]:

1. General Aviation: personal, recreational, instructional, etc.
2. Commercial Aviation: both domestic and international flights by carriers owned by American companies to and from U. S. terminals on both scheduled as well as non-scheduled flights.

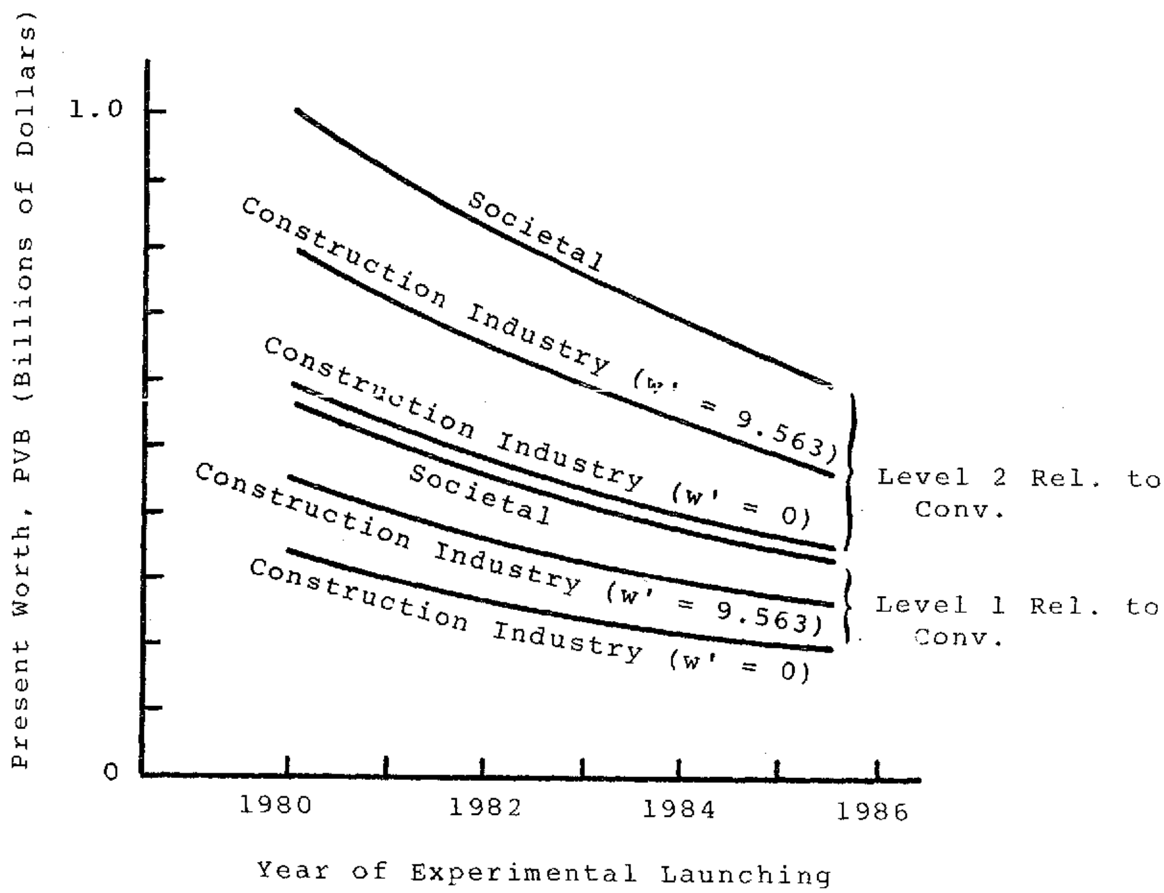


Figure 3.7 Present Worth of Construction Industry and Societal Benefits

3. Military: both domestic and overseas flights operated by the U. S. Military Airlift Command.

The major portion of the air transportation industry falls into the commercial aviation category. The commercial airlines industry may be classified as being capital intensive with fixed costs being between 68% and 88% of operation expenses [13]. These figures are calculated on the basis of 1965 price levels. They may be somewhat different after the recent boost of gasoline price. However, assuming that these figures still hold and will continue to hold in the future, the cost avoidance due to a cancelled flight is between 12% and 32% of the total cost (including the fixed costs) associated with that flight. The revenue associated with a flight is completely lost if the flight is cancelled. Stormy weather produces flight delays and cancellations. A delayed arrival due to stormy weather, however, is a more prevalent phenomenon than a complete flight cancellation. A flight delay results in increased operational costs. Further, there are other costs associated with flight delays, such as board and lodging expenses of stranded passengers, and the hidden cost associated with the inconvenience, missed appointments, lost contracts, etc. suffered by such passengers. Thus, the improvement of thunderstorm forecast capability will yield cost reduction opportunities to commercial airlines resulting from reductions in flight delays and flight cancellations. Specifically, the improvement of thunderstorm forecast capability will:

a. reduce the probability of being caught in an unexpected thunderstorm, i.e., the probability of a miss (as had been defined previously) will be reduced. This, in turn, will improve the delay situation, and,

b. reduce the number of false alarms, i.e., forecasts for storms which in reality do not occur. A storm alarm compels airline companies to cancel flights or to take alternate routes of transportation which are more expensive, and usually associated with delayed arrivals. Thus, there are savings associated with improvements in the false alarm situation.

It is, in general, not true that improved storm forecasts will reduce the accident rate of commercial airlines since commercial airlines rarely have accidents that are weather related [14]. The same holds for military aircraft as well. However, this is reversed in the case of "general aviation" -- as preveiously defined. Most of the general aviation aircraft are small, with limited range, and without sophisticated and automated instrumentation facilities. As a result, the cost which results from accidents far outweighs the cost which results from delays and flight cancellations [14].

The method used to compute the benefits of improved thunderstorm forecast capability to the three categories of air transportation is similar to that described in connection with the construction industry except for the following two main distinctions:

a. the average, flight times are relatively short being, on the average less than two hours. Therefore, the most relevant piece of weather information for the air transporation industry is the two hour forecast rather than the six hour forecast as is the case for the construction industry.

b. Since the question of human life is involved, the decision in the face of a storm forecast has been assumed to be one of always circumventing the area where the storm is forecast. This may not be an optimal decision in the strict economic sense (as has been discussed previously for the construction industry where the objective was that of minimizing the cost of the construction industry and pursuing a policy of action and no-action which would achieve that objective). However, it has been found that the general practice of the air transportation industry is to be on the conservative side and avoid a storm forecast region rather than to take chances. It is believed that this practice is not going to change within the foreseeable future.

General Aviation

As mentioned earlier, the principal cause of weather related loss in general aviation is accidents. Out of a total of 22,151 general aviation accidents between 1964 and 1967 (both inclusive), there were 1,536 that were due to bad weather and 25 of these were due to faulty forecasts [9]. A question arises as to why only 1.6% of the weather related accidents are due to faulty forecasts. It is felt that the remaining 98.4% of the weather related accidents are due to the fact that people are so used to false alarm situations that they tend to treat a storm forecast rather lightly. Consequently, if they run into trouble due to a storm, the weather forecasting agencies can claim that indeed there was a storm forecast. Thus, with improved thunderstorm forecasts, benefits should accrue in two areas:

a. As the miss rate decreases, there will be less accidents due to faulty forecasts.

b. As the false alarm rate decreases, thunderstorm forecasts will be taken more seriously. Hence, there will be fewer weather related accidents that are not directly due to faulty forecasts.

The 25 accidents which occurred between 1964 and 1967 that were due to faulty forecasts essentially constitute the miss expenses associated with a conventional forecast system. This is equivalent to 6.25 accidents, on the average, per year. For 1974 and through the 1980's, this, most probably, is a conservative figure. However, assuming this figure to hold through the 1980's and assuming that the average price of such an aircraft is ten thousand dollars, the yearly miss expense associated with the conventional forecast system is 62,500 dollars neglecting the loss of human lives (which is about 12 per year [9]). In order to find the corresponding loss associated with different forecast capabilities it is necessary to compute the respective miss rates as compared to the conventional system. The conditional probabilities, as provided by NASA, for two hour forecasts are shown in Figures 3.3 and 3.4. These, when inserted in Equations 3.1 and 3.3 result in Table 3.15, where the geographical distribution of storm areas is reproduced from Figure 3.2.

Table 3.15 Geographical Distribution of Miss & False Alarm Days (Two Hour Forecast)

# of Days of Thunderstorm Occurrence	Area (Square Miles)	# of Miss Days			# of False Alarm Days		
		Conv	Level 1	Level 2	Conv	Level 1	Level 2
100	4,151	2.00	1.00	0.50	32.63	24.75	13.51
90	8,302	1.80	0.90	0.45	29.37	22.27	12.21
80	20,755	1.60	0.80	0.40	26.11	19.80	10.85
70	58,114	1.40	0.70	0.35	23.31	17.32	9.50
60	99,624	1.20	0.60	0.30	19.58	14.85	8.14
50	581,140	1.00	0.50	0.25	16.32	12.37	6.78
40	747,180	0.80	0.40	0.20	13.05	9.9	5.42
30	547,932	0.60	0.30	0.15	9.79	7.42	4.07
20	249,060	0.40	0.20	0.10	6.53	4.95	2.71
10	282,268	0.20	0.10	0.05	3.26	2.47	1.36
5	66,416	0.10	0.05	0.03	1.63	1.24	0.68

Assuming that the number of forecast related accidents is proportional to the miss percentage, it follows directly from Table 3.15 that the expected annual loss due to forecast related accidents with a Level 1 forecast capability is 31,250 dollars and six lives, and the same with a Level 2 forecast capability is 15,625 dollars and 3 lives. These are listed in Table 3.16.

As mentioned earlier, the expenses in general aviation due to false alarms are associated with accidents that occur because fliers often take chances in the face of a storm forecast on the assumption that it would turn out to be a false alarm. Reference 9 states that the total weather related accidents during a four year period was 1,536, out of which 25 were due to incorrect forecasts. Thus, 1,511 accidents took place during periods of time during which bad weather was forecast. Assuming that the thunderstorm season encompasses six months per year, approximately 190 accidents per year can be attributed to thunderstorms and tornadoes which were correctly forecast but not paid heed to. This

Table 3.16 Expenses of Air Transportation Industry Which Are Due to Thunderstorms (Million $)

	General Aviation			Commercial Aviation		
	Conv	Level 1	Level 2	Conv	Level 1	Level 2
Miss	.063 + 12 lives / 1.26	.031 + 6 lives / .63	.016 + 3 lives / .32	9.40	4.70	2.35
False Alarm	1.90 + 375 lives / 39.4	1.43 + 275 lives / 28.93	.78 + 150 lives / 15.78	12.35	9.34	5.12
Total	1.96 + 387 lives / 40.66	1.46 + 281 lives / 29.56	.80 + 153 lives / 16.10	21.75	14.04	7.47

corresponds to 1.90 million dollars and approximately 375 lives. From Table 3.15, it directly follows that 5.79% of the entire area of the United States is, on the average, under the spell of false alarm days during the six months of the storm season. For the Level 1 and the Level 2 forecast capabilities, the corresponding figures are 4.38% and 2.40%, respectively. Assuming a linear relationship between the false alarm accidents and the percentages of false alarm, the expenses given a Level 1 forecast capability become 1.43 million dollars and approximately 275 lives. The corresponding expenses given a Level 2 forecast capability become 0.78 million dollars and approximately 150 lives. These are listed in Table 3.16. The assumed linear relationship between false alarm accidents and false alarm percentages is justified to the extent that if the false alarm percentage becomes zero, the false alarm accidents also will tend to zero. This follows since complete faith will then be placed in the storm forecast, and fliers will not take a chance when the forecast is for bad weather, except possibly those few with whom danger happens to be the breath of life.

The economic value of a life may be expressed as the present worth of the expected future earning stream of an individual. Assuming an average working life of 30 years and an average income level of $20,000 (for those who fly), an economic value of approximately 0.2 million dollars is obtained at a discount rate of 10%. If it is assumed that the average working life expectancy for those involved in accidents is 1/2 their average working life, the economic value of a life is estimated to be on the order of 0.1 million dollars. The "lives" indicated in Table 3.16 have been converted to their economic equivalent and included in the indicated totals.

Commercial Aviation

As mentioned previously the primary expenditures of commercial airlines due to thunderstorms are the result of delays and flight deviations from the optimal flight path. Part of these expenditures can never be recovered because thunderstorms do occur in reality. However, with improved thunderstorm forecasts, that portion of the expenditures which are the result of false alarms and missed storms can be decreased. A miss, i.e., an unexpected storm, creates, among other things, a landing problem and as a result aircraft are delayed in flight. If cautioned beforehand, alternate flight and landing arrangements can be made, though at a certain cost. A false alarm compels the airlines to take alternate routes in order to avoid the storm forecast area, thus incurring additional expenditures which can be avoided with an improved forecasting capability. The costs associated with false alarms and missed storms are discussed in the following paragraphs.

Data presented in Reference 9 indicates that there were a total of approximately 1.6 million flights per day (in 1968) of the U. S. trunk and local service airlines (based on revenue miles). It further states that about 0.65 percent of all flights incur weather delays at an average of 55 minutes per incident. Assuming that these figures will hold in 1974 and through the 1980's, the total number of incidents per year is 11,400. Assuming six months per year as the thunderstorm season, the number of delay incidents is approximately 5,700 per year which corresponds to 313,500 minutes. Since this delay is directly proportional to the percentage of miss, it follows from Table 3.15, that the corresponding delay with the Level 1 forecast capability should be 156,750 minutes and for the Level 2 forecast capability should be 78,375 minutes.

Several different airlines have been contacted to determine the dollar loss per minute of delay. As expected, this loss depends on the type of aircraft. However, it has been estimated that approximately $30 per minute of delay is a reasonable average figure after the recent boost in petroleum prices. Thus, not taking into account the inconveniences caused by the delay, the direct cost alone becomes 9.4 million dollars with a conventional forecast capability, 4.7 million dollars with the Level 1 forecast capability, and 2.35 million dollars with the Level 2 forecast capability. These are listed in Table 3.16.

The number of 4,400 flights per day corresponds to the 1.6 million flights per year. Assuming that an average flight has the duration of an hour, and that flying cost is $30 per minute, the total flight expenses become approximately 7.9 million dollars per day. Assuming a uniform distribution of flights throughout the United States, Table 3.15 can be used to find the cost associated with flights that encounter false alarm areas. A false alarm creates expenditures due to the fact that flights have to deviate from the optimal route. Reference 15 indicates that, on the average, a deviation from the optimal increases the cost by 15%. Thus, the false alarm cost which can be avoided by maintaining the optimal route is 15% of the cost of the flights that encounter false alarm areas. These values, given various levels of forecast capability, are listed in Table 3.16.

Military Aviation

It has been difficult to obtain specific data regarding the volume of military transportation and the various costs associated with false alarm and miss. Reference 9 indicates that the expenses of military transportation are on the order of 10% of the expenses associated with commercial transportation. Accordingly, it directly follows from Table 3.16 that the annual cost resulting from false alarms and misses in military transportation is 2.17 million with a Conventional forecast capability, 1.40 million with a Level 1 forecast capability, and 0.75 with a Level 2 forecast capability. This is listed in Table 3.17 which presents the total expense picture of the air transportation industry under the various assumed levels of forecast capability.

Table 3.17 Comparison of the Expenses and Annual Savings of the Air Transportation Industry with Different Forecast Capabilities (in Million$)

Sector	Expenses			Annual Savings	
	Conv.	Level 1	Level 2	Level 1 Rel. to Conv.	Level 2 Rel. to Conv.
General	40.66	29.56	16.10	11.1	24.56
Commercial	21.75	14.04	7.47	7.7	14.28
Military	2.17	1.40	0.75	.8	1.42
Total	64.58	45.00	24.32	19.6	40.26

The present worth of the benefit stream that might accrue as a result of the air transportation industry savings illustrated in Table 3.17 can be determined in a manner similar to that of the construction industry. As discussed previously the present worth of the benefits depends upon the following factors.

1. Magnitude of potential cost savings,
2. The fraction of the potential cost saving which may be realized in practice through user implementation,
3. The date when the implementation program begins,
4. The shape of the implementation curve during the transitional period, and
5. The factor by which the future benefits are to be discounted to calculate the present worth.

With respect to these factors, the magnitude of the cost savings is as indicated in Table 3.17. Since the air transportation industry currently uses weather forecast data on a routine basis it is assumed that this practice will continue. Therefore, it is anticipated that 100% (i.e., referring to Equation 3.5, $\delta=1.0$) of the potential cost savings will be realized in practice through user implementation (i.e., 100% of the users will make use of the improved forecast data).

The date when the implementation program begins depends, as discussed in Section 3.2.1, upon the launch date of an experimental satellite to prove feasibility and the length of time between experimental satellite launching and operational satellite launching. From the point of view of the present worth computation, this time frame is treated in a parametric fashion but with the same basic assumptions as in Section 3.2.1.

For the construction industry an S-shaped implementation curve was assumed to hold during the transitional period. The reason for the S-shaped build-up of benefits was based upon the fact that many companies within that industry would have to change their operations and procedures in order to efficiently utilize the thunderstorm forecast capabilities postulated. This is not the case, however, with the air transportation industry which currently utilizes thunderstorm forecast data on a routine basis. It is assumed that as new and improved forecast data becomes available it will automatically be incorporated and used by the air transportation industry. It is therefore assumed, referring to Equation 3.5, that both m and σ approach zero.

With the above assumptions, the present worth of the benefits calculated for 1974 can thence be obtained using Equation 3.7 where $B_i = o$ prior to the establishment of an operational capability and B_i = savings as indicated in Table 3.17 after the establishment of an operational capability. The present worth of the benefits associated with the air transportation industry are summarized in Figure 3.8 in terms of level of forecast capability and experimental satellite launch date.

3.2.3 Agriculture

The effect of improved information, using satellite remote sensing technology, in the area of agriculture is far reaching and has many aspects to it. Not only may it be possible to improve agricultural production by using more accurate weather forecasts, but it may be possible to achieve better on-line photographic information regarding the status of the agricultural produce, which, in turn, will have an

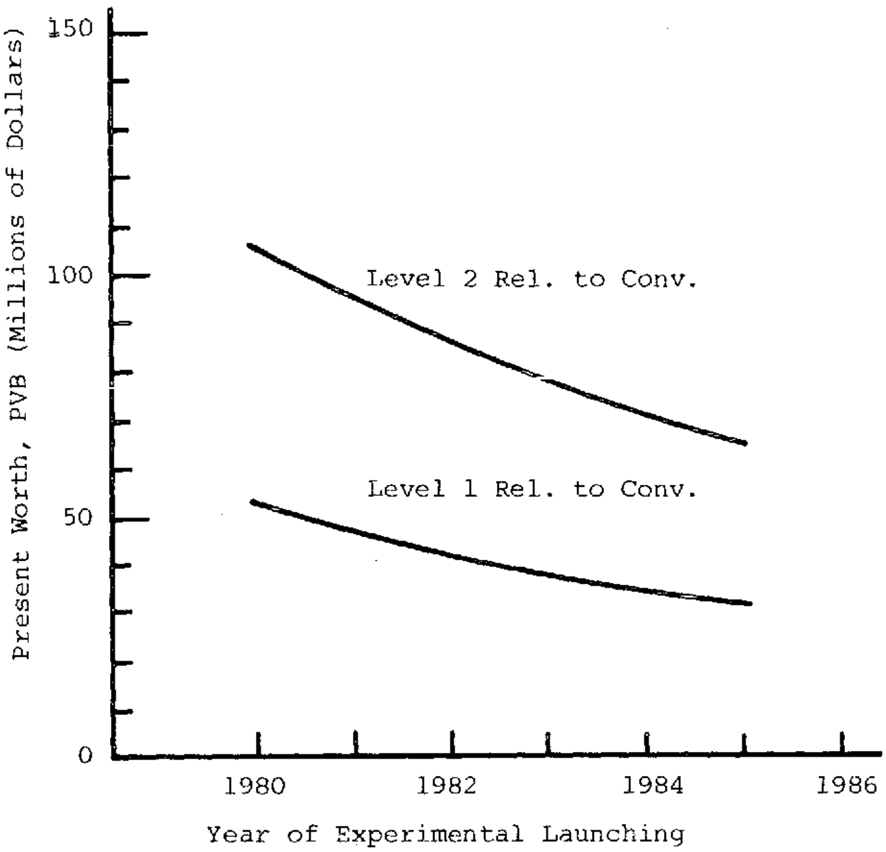


Figure 3.8 Present Worth of Air Transportation Industry and Societal Benefits

effect on the price and the trade of agricultural products. In this section, however, only the effects of improved thunderstorm forecasts are studied in as far as preventive actions can be taken to minimize losses due to such storms. These preventive actions essentially consist of circumventing the effects of storms by rescheduling the following operations:

1. Planting,
2. Spraying,
3. Irrigation policies, and
4. Harvesting.

Planting or harvesting during a storm or immediately prior to it causes the obvious damage. Spraying insecticides just before a storm results in a wastage. Irrigation policies can be modified before a storm so as to minimize the amount of standing water on fields and thus avoid damage to the crops. The underlying assumption, however, is that there is enough lead time associated with a forecast to enable the farmer to reschedule such operations. Since most operations involve a significant labor content and since labor contracts for operations are usually made well in advance, it is assumed that improved thunderstorm forecasts that yield less than twenty-four hours of lead time have little significance. The analysis which follows is based upon the accuracy of the twenty-four hour (lead time) thunderstorm forecasts. It should be noted, and will be discussed later, that certain operations, such as harvesting, may not be alterable within the context of more accurate twenty-four hour forecasts.

A thunderstorm can be the cause of the following situations, each inducing a loss:

a. storm occurrence at the harvesting time,

b. standing water on the surface of the field, and

c. wastage of insecticide and fungicide sprays washed away by the rain water associated with thunderstorms.

If a storm occurs during the harvesting time, the grower has two alternatives. He can either go ahead with the schedule ignoring the storm and, thereby, deteriorating the quality and the price of the harvested crop, or he can postpone harvesting, in which case he cannot meet the demand on time. An order (i.e., demand) which cannot be filled at a specified time but which remains as an open order usually induces a loss, because if the market price increases the grower cannot take advantage of the higher price, and if the market price drops the grower has to supply the product at the lower price.

Standing water on a field surface can produce losses in various ways. If standing water occurs during the sowing time, germination is hampered and new plants are washed out. If it occurs during the harvesting time, the operation of harvesting itself is difficult to carry out, and if carried out creates deterioration in the quality and the yield. If excess standing water occurs during the growing season, the crop will not have the proper nourishment and will tend to rot.

If a thunderstorn occurs just after spraying insecticides and fungicides, the grower loses not only the market value of the chemicals, but the entire cost of the spraying operation.

Reference 17 discusses these loss factors with respect to the production of lettuce in Wisconsin. These results, summarized in Table 3.18 (for 1970), though specific in nature (i.e., pertaining only to lettuce in Wisconsin), may be extendable to all crops of the United States if proper precaution is taken to normalize the results as discussed below.

Prior to considering specific losses it is necessary to consider the general false alarm and miss situations. A false alarm, i.e., a storm warning with no storm occurring, has the effect (if the forecast is utilized) of delaying or postponing operations. It is assumed that this delay or postponement will not result in additional costs to the grower. On the other hand a miss, i.e., a storm occurring when the forecast was for no storm, results in losses as indicated in Table 3.18. Based upon these assumptions only the losses associated with misses have been considered. It should be noted that the optimum course of action is to postpone operations given a storm forecast and to pursue planned operations given a no storm forecast.

With the above in mind the specific loss situations can now be discussed. First, the loss due to spraying operations is considered to be a function of the acreage sprayed and the number of storms missed in the forecast. Hence, this loss can be extrapolated to other crops of other regions as long as it is properly weighted with the corresponding acreage and the percentage of miss (i.e., storm occurring unexpectedly when the forecast is for clear weather) of the geographical area concerned. It is assumed that the cost and frequency of spraying is independent of crop type and region. Secondly, the loss due to crop damage is a function of the farm value of the crop and the number of storms missed. Hence, these losses can also be extended to other crops as long as the proper percentage of loss with respect to the farm value of the crop is maintained and can be extrapolated to other geographical locations if weighted with the corresponding miss figure. These cost factors are shown in Table 3.19, and are arrived at as follows.

Table 3.18 Weather Events and Associated Losses - Lettuce Crop in Wisconsin (From Reference 17)

Event	Operation Affected	Average Loss Per Event	Savings Which Can Be Realized With Accurate Forecasts	Frequency of Event Causing Loss	Annual Per Acre Savings With Accurate Forecast
High temperature at harvest	Sales and shipping	8% of total acreage at \$1.00 per case; 550 cases per acre	100% of loss could be saved	Occurs $1\frac{1}{2}$ times each season	\$66.00 per acre
Rain stopping	Dirty lettuce, loss of goodwill	2% of total acreage at \$.50 per case; 550 cases per acre	100% of loss could be saved	Occurs $3\frac{1}{2}$ times each season	\$19.25 per acre
Standing water on fields caused by heavy rains	1) lost plantings 2) lost harvests	1) 6.6% of total acreage at \$25 per acre 2) 3.3% of total acreage at \$1.00 per case; 550 cases per acre	35% of loss could be saved	Occurs once in two seasons	\$12.75 per acre
	3) reduced quality and yield	3) 25% of total acreage; quality at \$.25 per case and 450 cases per acre; yield: at \$1.00 per case and 100 cases per acre			
Rain influencing spray schedule	Insect and fungicide spray	40% of total acreage at \$2.50	100% savings	Occurs 3 times each season	\$ 3.00 per acre

Table 3.19 Agricultural Loss Due to Thunderstorm When Forecast Is for Clear Weather	
Event	Loss Per Miss Minus Loss if Storm Is Correctly Forecast
Storm Stopping Harvest	0.424% of Farm Value
Standing Water	0.13% of Farm Value
Storm Washing Spray	$0.36 Per Acre

1. Loss due to standing water: The farm value of the vegetable yield per acre in 1970 was $544.87. The standing water on soil is due to heavy rain which, it is assumed, results from thunderstorms (note that this assumption tends to place an upper bound on the estimation of benefits). From Table 3.18, the loss per acre per season is $12.75. From Figure 3.2, Wisconsin has approximately 30 thunderstorm days per season. Therefore, with a conventional forecast capability (π'_{12}=10% from Figure 3.3) it is expected that Wisconsin will experience 3 misses per season. Extrapolating to a "one-miss" area the loss per acre per season is $12.75/3 or $4.25 and can be expressed as 0.78% of crop value per acre. Note that this is only a loss if an action is possible, i.e., farm land has irrigation facilities which may be used to reduce the level of standing water. 16.5% of the harvested farm land of the U.S. is irrigated. Therefore, the average loss due to standing water is equal to 0.78% x .165 or approximately 0.13% of crop value per acre.

2. Loss due to storm stopping harvest: There are an average of 83 days per year of rain in any location in Wisconsin of which 30 days have thunderstorms. From Table 3.18, the cost of rain stopping harvesting is \$19.25 per acre. Therefore, the loss per season due to thunderstorms is \$6.96 (it should be noted that no account has been taken of the fact that both rain and thunderstorms may occur on the same day. Therefore, the assumption of 30 days of thunderstorms implying no other rainstorms on these days leads to an upper bound of the benefits.). Extrapolating this loss to a one miss area yields a loss per acre per miss of \$2.32 which is equivalent to 0.424% of crop value per acre.

3. Loss due to storm washing spray: The annual loss of \$3.00 per acre can be extrapolated to the loss for thunderstorms by considering the ratio of thunderstorm days to rain days (30/83). This results in an average cost of \$1.08 per acre per season. Since, on the average, there are 3 misses per season, the loss per miss is \$0.36 per acre.

In order to apply these cost figures to the agriculture of the United States, it is necessary to obtain a picture of the distribution of crops over different equi-thunderstorm zones. The overall crop production of the United States [16] for the year 1972 and the market value of this production are illustrated in Table 3.20. Reference 16 provides a geographical distribution of some of the main crops; i.e., corn, wheat, irish potato, cotton and tobacco. These distributions, when regrouped according to the equi-thunderstorm zones indicated in Figure 3.2, yield the results indicated in Table 3.21.

Table 3.20 U.S. Agriculture (1972) Crops				
	Field Crop	Vegetable (including melons)	Fruits & Nuts	Horticulture
Harvested Land (thousand acre)	283,902	3,335	4,412	275
Farm Value (Million $)	24,233	2,156	2,267	957
$ Per Acre	85.36	646.48	513.83	3,480

Applying the loss factors per miss as illustrated in Table 3.19 to the geographical distribution of the main crop production as listed in Table 3.21, the geographical distribution of loss per miss of thunderstorm forecast is obtained as illustrated in Table 3.22. The geographical distribution of agriculatural loss due to the miss phenomenon resulting from the various levels of forecast capability is illustrated in Table 3.23 and the annual losses and potential savings resulting from the different levels of forecast capability are illustrated in Table 3.24.

Table 3.24 includes the losses and potential savings associated with field crops, vegetables, fruits and nuts, and horticulture. Unfortunately, detailed data on the geographical distribution of other (than main crops) agricultural products are not easy to find. To obtain a rough idea of the potential savings for the total volume of agricultural products, the results presented in Table 3.24 are

Table 3.21 Acreage & Farm Value of Main Field Crops Distributed over Equi-Thunderstorm Zones										
# of Days of Thunderstorm Occurence	Corn		Wheat		Irish Potato		Cotton		Tobacco	
	Thousand Acres	Million $	Thousand Acres	Million $	Thousand Acres	Million $	Thousand Acres	Million $	Thousand Acres	Million $
10	215	38	487	40.2	67	67	860	248	-	-
20	-	-	3,481	332	242	175	-	-	5	22
30	10,556	1,150	14,891	777.6	680	357	311	96	42	29
40	37,575	4,879	8,563	485.6	237	136	195	19	438	721
50	6,033	719	17,283	844.3	-	-	8,489	900	287	545
60	2,603	212	2,554	94.5	-	-	2,632	391	58	100
70	-	-	-	-	-	-	670	89	-	-
80	307	19	42	1.0	33	16	-	-	13	26
Total	57,289	7,017	47,301	2,575	1,259	751	13,157	1,743	843	1,443

Table 3.22 Loss In Main Crop Production Per Miss in Forecasting Thunderstorm

# Of Days Of Storm Occurrence	Aggregate of Main Crops		Loss Per Miss			
	Thousand Acres	Farm Value (Million $)	Stopping Harvest (Million $)	Standing Water (Million $)	Loss of Spray (Million $)	Total
10	1,629	393	1.67	.51	.59	2.77
20	3,728	529	2.24	.69	1.34	4.27
30	26,480	2,409	10.22	3.13	9.53	22.88
40	47,008	6,240	26.46	8.11	16.92	51.49
50	32,092	3,008	12.76	3.91	11.55	28.22
60	7,847	797	3.38	1.04	2.82	7.24
70	670	89	0.38	.12	.24	.74
80	395	62	0.26	.08	.14	.48
Total	119,849	13,529				

# of Days of Storm Occurrence	# of Miss Days			Loss in Million $								
				Stopping Harvest			Standing Water			Loss of Spray		
	Conv.	Level 1	Level 2	Conv.	Level 1	Level 2	Conv.	Level 1	Level 2	Conv.	Level 1	Level 2
10	1	0.6	0.4	1.67	1.00	6.7	.51	.31	.21	.59	.35	.24
20	2	1.2	0.8	4.48	2.69	1.79	1.38	.83	.55	2.68	1.61	1.07
30	3	1.8	1.2	30.66	18.40	12.26	9.40	5.64	3.76	28.59	17.15	11.44
40	4	2.4	1.6	105.84	63.50	42.34	32.45	19.47	12.98	67.38	40.61	27.07
50	5	3.0	2.0	63.80	38.28	25.52	19.55	11.73	7.82	57.75	34.65	23.10
60	6	3.6	2.4	20.28	12.17	8.11	6.22	3.73	2.49	16.92	10.15	6.77
70	7	4.2	2.8	2.66	1.60	1.06	.81	.48	.32	1.68	1.01	.67
80	8	4.8	3.2	2.08	1.25	.83	.64	.38	.26	1.12	.67	.45
TOTAL				231.47	138.89	92.58	70.95	42.57	28.38	176.71	106.2	70.81

Table 3.23 Geographical Distribution of Loss in Main Coop Production

Table 3.24 Agriculture Losses and Potential Savings in Terms of Thunderstorm Forecast Capability (Million $)

Event	Annual Loss			Potential Annual Savings	
	Conv.	Level 1	Level 2	Level 1 Rel. to Conv.	Level 2 Rel. to Conv.
Stopping Harvest	506.5	304.0	202.6	202.5	303.9
Standing Water	155.3	93.2	62.1	62.1	93.2
Loss of Spray	386.8	232.5	155.0	154.3	231.8

based upon a linear extropolation of the main crop results over the entire range of products as given in Table 3.20. It must be emphasized that the likelihood of achieving the potential benefits differs significantly for each of the three areas listed in Table 3.24. This will be discussed in the following paragraphs.

The present worth or value of the benefit stream that might accrue as a result of the agriculture industry savings illustrated in Table 3.24 can be determined in a manner similar to that of the construction industry. As discussed previously, the present worth of the benefits depends upon the following factors:

1. Magnitude of potential cost savings,
2. The fraction of the potential cost savings which may be realized in practice through user implementation,
3. The date when the implementation program begins,
4. The shape of the implementation curve during the transitional period, and
5. The factor by which the future benefits are to be discounted to calculate the present worth.

With respect to these factors, the magnitudes of the cost savings are indicated in Table 3.24. It must be emphasized that the benefits from improved forecast capabilities are based only upon cost savings. Because of the limited scope of this effort, it should also be noted that price-demand-quantity relationships have not been taken into account.

The potential annual savings associated with thunderstorms stopping harvesting, causing standing water, and washing spray have been considered separately. The reason for this separation is that the implementability and hence, the achievability of these benefits differ significantly. Rescheduling of harvesting operations with twenty-four hours notice is not normally possible. Therefore, the fraction, δ, of these benefits which may be achieved through proper user implementation has been taken as zero. The effects of standing water on fields due to thunderstorms can be reduced with improved forecast data. Not all potential users will use or rely on forecast data nor, if they do use forecast data, will they necessarily have the freedom or capability of modifying the level of standing water so as to achieve the potential benefits. It is assumed that the fraction, δ, of these benefits which may be achieved is equal to 0.20. Note that the capability to take action has already been considered in the determination of the average standing water loss (as a percent of farm value) as given in Table 3.19. Reference 17 indicates that usually the insecticide and the fungicide spraying operations can be rescheduled on short notice. Labor contracts may diminish the magnitude of these benefits. Therefore, it is assumed that the fraction, δ, of these benefits which may be achieved is equal to 0.50.

The date when the implementation program begins depends, as discussed in Section 3.2.1, upon the launch date of an experimental satellite to prove feasibility and the length of time between experimental satellite launching and operational satellite launching. From the point of view of the present worth computation, this time frame is treated in a parametric fashion but with the same basic assumptions as in Section 3.2.1.

It is assumed that an S-shaped build-up of benefits will be achieved as discussed in Section 3.2.1.

With the above assumptions, the present worth of the benefits calculated for 1974 can thence be obtained using Equation 3.7 where B_i=O prior to the establishment of an operational capability. After the establishment of an operational capability

$$\delta B_i = (\delta B)_{\text{stopping harvest}} + (\delta B)_{\text{standing water}} + (\delta B)_{\text{Loss of Spray}} \qquad (3.9)$$

and the values of B are obtained from Table 3.24. The present worth of the benefits associated with the agricultural industry resulting from enhanced thunderstorm forecasting capability is illustrated in Figure 3.9. Two sets of curves are presented, namely with and without the benefits associated with standing water management. It is felt that these curves place upper and lower bounds on the present worth of benefits.

The benefits shown are both the industry and societal benefits since it is assumed that in a competitive market prices will ultimately be adjusted to reflect industry savings.

3.3 Summary

The improvements in the thunderstorm forecasts associated with the Level 1 and Level 2 forecasting capabilities are apt to produce varying degrees of potential benefits in different types of industries. These potential benefits, though not always completely realizable, will produce various

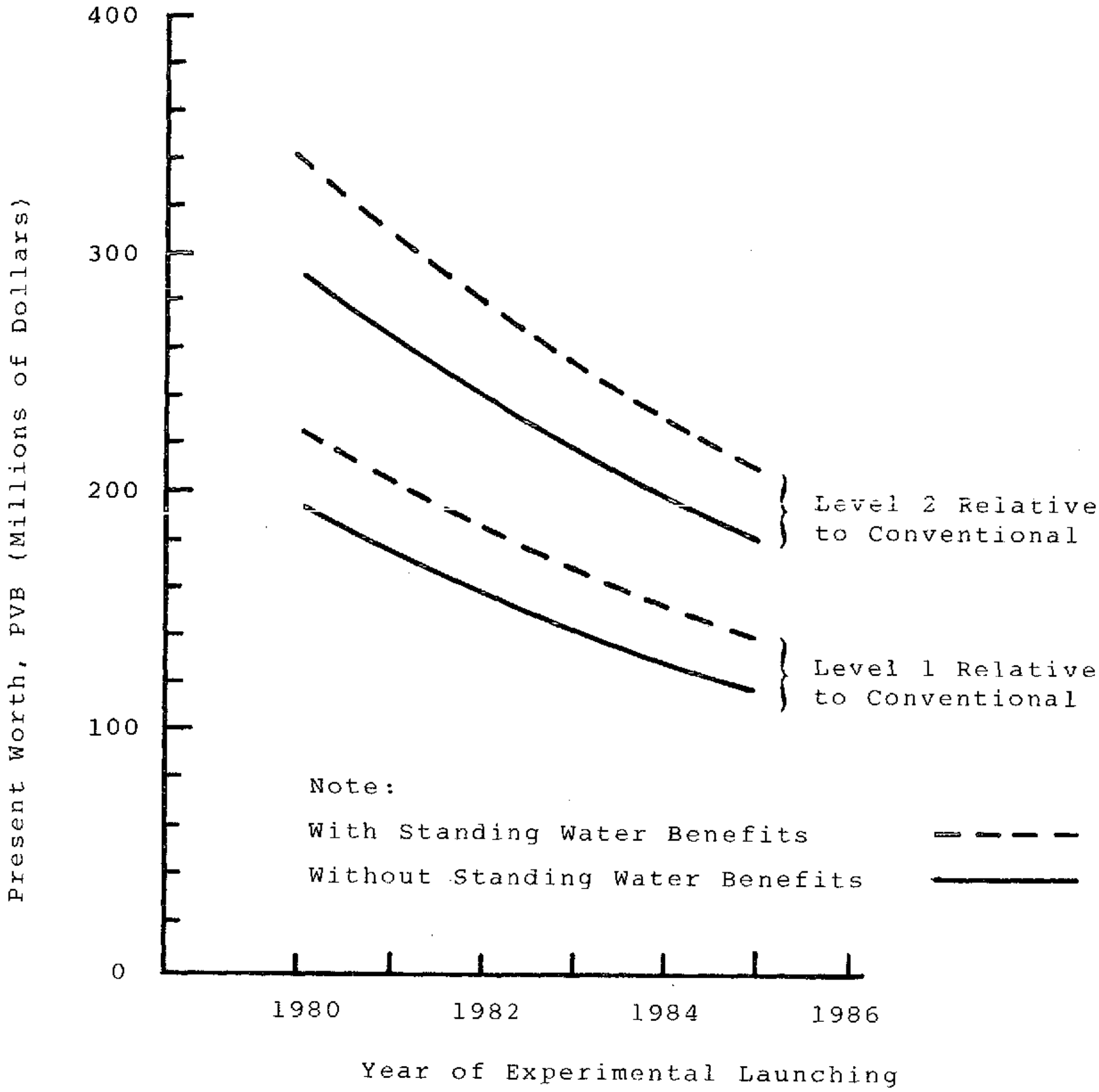


Figure 3.9 Present Worth of Agriculture Industry and Societal Benefits

amounts of realizable benefits, depending on the industry. The benefit areas, considered in some detail in this Section, are the construction industry, air transportation industry and agriculture industry. The potential benefits in these areas, and the estimated present worth of the realizable benefits (assuming the existence of a fully operational system by the year 1990) are illustrated in Tables 3.25 and 3.26, respectively.

Table 3.25 Comparison of Potential Societal Annual Savings (Millions $)

Industry	Level 1 Relative to Conventional	Level 2 Relative to Conventional	Level 2 Relative to Level 1
Construction	767	1366	599
Air Transport.	20	40	20
Agriculture	419	629	210

Note: These savings may not be fully realized in practice. See text! The adjustment for realization is taken into account in the present worth computation.

Table 3.26 Comparison of Estimated Present Worth of Societal Realizable Benefits* (Millions $)

Industry	Level 1 Relative to Conventional	Level 2 Relative to Conventional	Level 2 Relative to Level 1
Construction	447	782	335
Air Transport.	38	75	37
Agriculture**	140-170	220-250	80

* A fully operational system assumed prior to 1990.

** The upper and lower bounds correspond to the inclusion and omission of standing water benefits, respectively.

4.0 FROST WARNING

This Section deals with the evaluation of some of the potential economic benefits that might be derived from such improvements in the forecasting of frost occurrences as might be realized by a satellite system collecting meteorological data on a continuous basis and providing this information as required by users. For comparison purposes, three different levels of forecast capabilities are considered. These have been described previously in Section 3 and have been referred to as the Conventional, Level 1 and Level 2, forecast capabilities. Levels 1 and 2 imply continuous and on demand capability. The accuracy of the forecasts differ. The Level 1 forecast is based upon the anticipated (by NASA) accuracy of a system based upon SMS technology and the Level 2 forecast is based upon the projected capability of a SEOS-type system. As in Section 3, the accuracy of each forecast can be expressed in terms of "False Alarm" and "Miss" days. A false alarm day signifies a forecast for a frost occurrence which does not, in reality, materialize. A miss day signifies a forecast for no frost conditions when, in reality, frost conditions do materialize.

As will be discussed in the following paragraphs, under certain conditions, actions can be taken by agricultural product producers to minimize the effects of frost and the ensuing damage to their crops. This is the classic action-no-action (i.e., protect or do not protect) situation described at length in Sections 2 and 3. The methodology described in

Section 2, and applied to the thunderstorm forecasting situation in Section 3, is applied in this Section to the evaluation of benefits which might be achieved through an enhanced frost warning capability and its effect on the citrus crop [18].

Only a single benefit area has been considered, namely, the reduction of losses associated with crop damage due to frost conditions. Potential annual benefits are considered to be the net savings (i.e., losses foregone) which might result from improved frost warning capabilities. As discussed previously, the net savings take into account both the costs of taking actions and the losses that result if actions are not taken. Crop losses are considered at market value. Because of the limited scope of this analysis, price-demand-quantity interrelationships have not been taken into account.

4.1 Citrus Crop

Table 3.20 illustrates the United States acreage and yield for four principal crop areas for the year 1972. Though the farm value of the total field crop is higher than that of the other areas, it offers little possibility that saving could be realized as a result of improved frost warning capability because (a) the dollar yield per acre of field crop is relatively low thus calling for comparatively large areas to be heated if frost effects are to be reduced, and (b) heater protection is relatively ineffective in the open fields on which field crops are grown since these fields offer but little resistance to the cold air flow. By contrast, the air within groves of fruit trees is easier to heat and hence frost prevention becomes more effective. This, together with the fact that the farm value of the total fruit crop is higher than that of vegetable or horticulture makes the fruit industry a viable candidate for active frost protection measures with the possibility of additional benefits from enhanced frost warning capabilities.

Table 4.1 illustrates the production and the farm value of the leading fruit crops of the United States for the year 1972 [16]. It appears that the orange, tangerine, and grapefruit crops can be aggregated into one group termed the citrus crop. It should be noted that they are grown predominantly in Florida and hence are subject to the same climatic conditions. The farm value of the citrus crop amounts to the largest item in Table 4.1 and constitutes approximately 50% of the total fruit production. Hence, the benefit due to improved frost warning will be more pronounced for the citrus crop than for any other fruit.

Florida harvests 750,000 acres of citrus crop which is 70% of the total citrus acreage in the United States [19]. Also, the production of citrus crops in Florida was approximately 70% of the total U.S. production, that is, 180,000,000 boxes in 1972 with a market value of $526,000,000. The magnitude of damage to the citrus crop from cold weather is indicated by the fact that during the period 1967 through 1971, nearly 5.5 million dollars was paid as an average annual indemnity to 96,000 acres that were insured [20]. These indemnities cover only the production cost of the crop. The market value of the crop lost would be much higher. The Federal Crop Insurance Corporation alone paid a total of $12,000,000 to citrus growers in Florida between 1952 and 1968, and 91.8% of this total indemnity was specified as "frost, freeze, cold, and winterkill". This is only a fraction of the total cold weather loss of the citrus crop in Florida because, in a sample of five counties, it was estimated that only 14% of the growers used this insurance.

The frost and freeze conditions responsible for crop damage can be classified as advective, radiation, or a combination of the two. The advective freeze results from the transport of colder air into an area by wind for periods of up to

Table 4.1 Fruit Production and Value (1972)			
Crop	Production	Farm Value (million$)	Leading States
Oranges and Tangerines	195,370 thou. boxes	569	Florida California
Grapes	2,567 thou. tons	369	California
Apples	5,828 mil. pounds	334	Washington New York
Grapefruit	63,840 thou. boxes	182	Florida
Peaches	2,443 mil. pounds	162	California South Carolina
Note: Other fruits are negligible.			

several days. Because of the wind and the lack of a temperature inversion pattern, protection against this type of freeze by grove heating or wind machines is not likely to be effective. The radiation frost or freeze results from cooling of the earth's surface and vegetation because of heat loss by radiation. Radiation frost or freeze is more frequent, but less damaging, than advective freeze. Radiation cooling occurs under conditions of clear skies, light winds, and low water vapor content in the atmosphere. Because of these conditions, protective measures are likely to be more effective than for advective freeze. Finally, a combination of advective and radiation freeze may occur on many nights with effects intermediate between the two pure types of freezing conditions. The frequency with which an orange crop succumbs to damage depends on the relation of its harvest season to the onset of cold weather in its specific geographical location. The freeze period typically ranges from mid-November to mid-March. Various types of oranges are harvested at different times ranging from mid-October to early June. Hamlin and Parson Brown oranges, for example, are harvested between October and January. Valencia oranges, the most popular type, are a late crop picked between March and July and thus highly vulnerable to winter freeze. Frost occurrences during the early part of the season thus effect the maximum amount of crop. The magnitude and the duration of freezing temperatures increase as mid-winter approaches, but harvesting of early and mid-season varieties of oranges gradually reduces the fraction of the crop subject to damage. Although this reduction in damage potential is gradual, it is convenient to represent the total potential damage by assuming an arbitrary date for the end of the danger period. This would be approximately in mid-January, about halfway through the period of cold weather. Vulnerability to damage is also a function of the location of the orange groves, but the danger to the crops at the higher latitudes is compensated by the growing of early and mid-season varieties and by using heaters, wind machines, or spraying as methods of frost protection.

4.2 Protective Measures

Various types of measures may be taken to protect the citrus crop from damage [21]. In Florida, grove heaters are most frequently used for this purpose. Heaters are of two types, those that burn as open flames, and those that heat metal objects such as a stack that radiates heat. Heating is more effective on calm nights with strong temperature inversions than on windy nights.

Wind machines offer advantages in cold protection because they minimize labor requirements, require less refueling and less fuel storage than heaters, are permanently located in the grove, have a low operational cost per acre, and do not produce smoke and air pollution. These advantages must be weighed against the disadvantages of rather high capital costs and the failure of the wind machine to provide adequate cold protection under all conditions. Wind machines mix warmer air above the trees with the colder air among the trees, taking advantage of the presence of warmer air aloft resulting from a temperature inversion. Under cold windy conditions, the wind machine does not provide adequate protection.

Overhead irrigation is used to perform the function of cold protection. Water is sprayed on the plants and provides a heating action through the heat released when the water changes from liquid to ice. The heat liberated as the water freezes maintains the temperature near 32° Fahrenheit, even though the surroundings may be colder. Permanent overhead irrigation has several attractive features as a cold protection system. The sprinkler system can be started and stopped easily. This labor-saving feature is of particular advantage on cold nights when it is difficult to obtain labor on short notice. Another attractive feature is the possible use of the system for regular irrigation. Sprinkling differs from other cold protection systems in that improper use can result in more damage than if the trees are left unprotected.

Possible benefits from the use of improved weather predictions are most likely to occur in the use of heating equipment because it is the most frequently used protection method and its use requires substantial advance notice and its cost of operation is high. Frost and freeze damages sustained by the orange crop and by orange trees are assumed in this discussion to occur for the following conditions. Damage will be sustained by the orange crop if air temperature of 26° Fahrenheit or lower should continue for a period of four hours or more. Damage to trees themselves will occur if air temperatures of 20° Fahrenheit or lower continue for a period of four hours or more. Thus, critical decisions must be made by the orange grower when temperatures threaten to reach either of these two levels. Temperatures as low as 20° Fahrenheit are relatively rare in Florida. Hence, the following discussion is limited to the protection of fruit.

4.3 Benefit Areas

As discussed previously, the potential benefits associated with enhanced frost warning capability are the result of pursuing an optimal action-no-action policy in the face of false frost warnings (false alarms) and missed frost warnings (misses). The optimal policy is that which minimizes expenses. The benefits are the potential savings and the associated present value of savings which results from the enhanced frost warning capabilities denoted as Level 1 and Level 2 capabilities. For the ranges of false alarm and miss rates considered, the optimum course of action is to protect when given a frost warning and to do nothing when not given a frost warning. The costs, savings, and benefits discussed in the following pages pertain only to these optimum actions.

Figure 4.1 indicates the geographic distribution of the mean annual frequency of the occurrence of freezing temperatures. Figure 4.2 illustrates those geographic areas where extensive frost protection programs are carried out on citrus crops. The two major areas of frost protection are in Florida and California. Frost (in the sense that crop damage occurs) is defined as the phenomenon of temperature reaching 26°F or below. Data derived from Reference 24 indicates that, in a typical cross section of counties in Florida, temperatures reach 26°F (i.e., frost level) with a

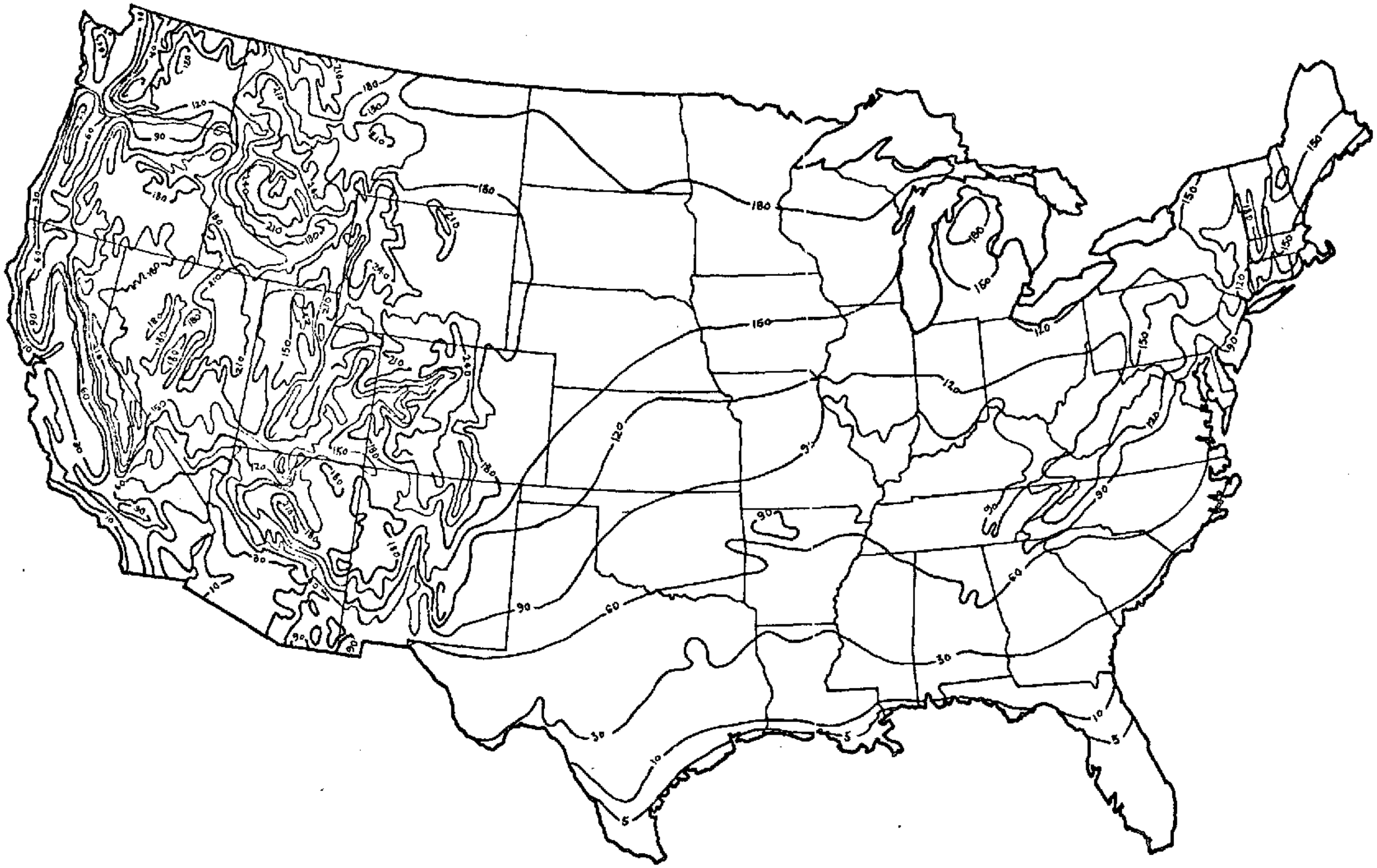


Figure 4.1 Mean Annual Freeze Temperature Frequency (from Ref. 10)

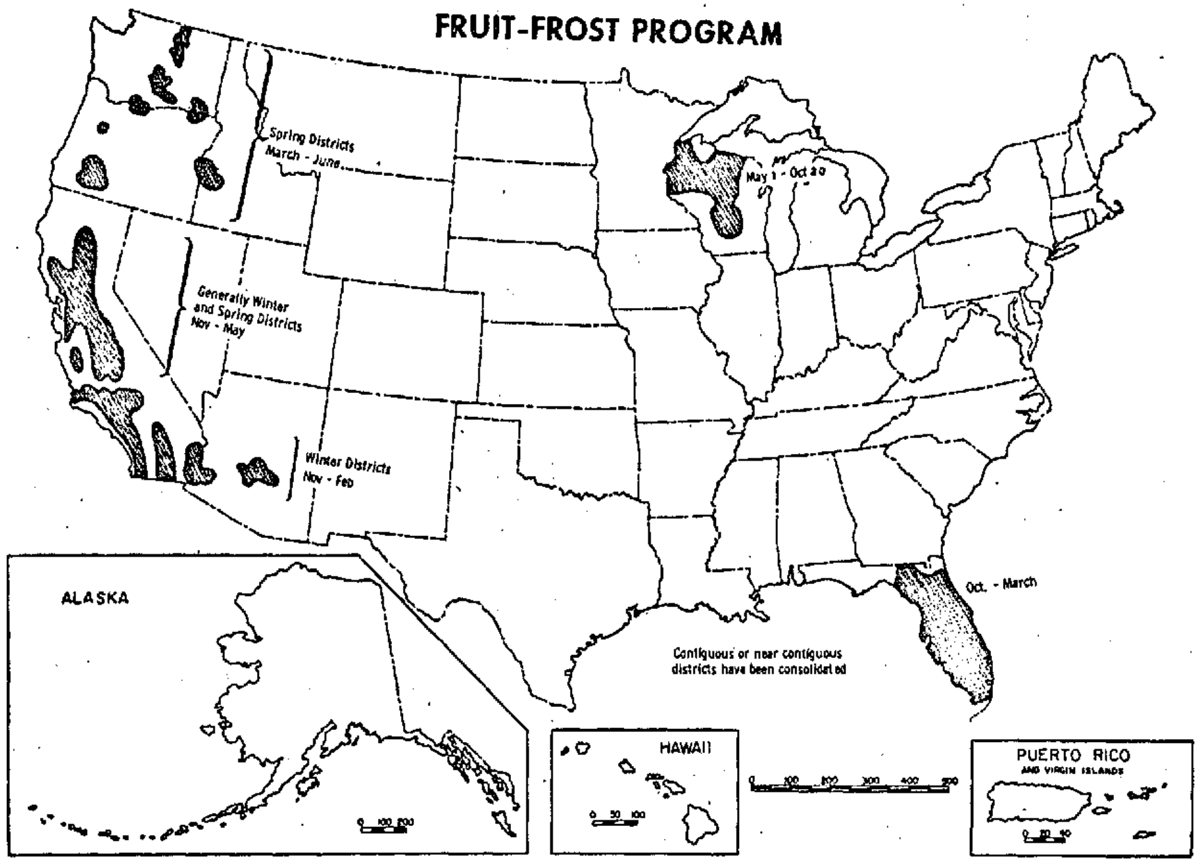


Figure 4.2 Fruit-Frost Program (from Ref. 22)

frequency of about 0.9 day per year, half of them before mid-January. The basic frost statistics used in this analysis are summarized in Table 4.2 in terms of the number of frost occurrences per growing season and the number of false alarm and miss occurrences for different forecasting capabilities. The absolute number of false alarm occurrences is not known with sufficient accuracy. Therefore, relative estimates have been made [18] of the number of false alarm occurrences that would occur with Level 1 and Level 2 forecast capabilities. These results have been extrapolated to California using the data pertaining to freeze frequency indicated in Figure 4.1 and References 23 and 24. It should be noted that the absolute value of number of false alarm occurrences effects the cost associated with false alarms; it does not effect the savings which result from a reduction in the number of false alarms since savings are a relative measure and the quantities N_1 and N_2 (in Table 4.2) cancel.

Table 4.2 Frost* Statistics

State	No. Frost Occurrences Per Growing Season	No. False Alarm Occurrences			Miss (% of Crop Growing Area)		
		Conv	Lev 1	Lev 2	Conv	Lev 1	Lev 2
Fla. [15]	0.9	N_1	N_1-1	N_1-2	10%	7%	5%
Calif. [20]	5.4	N_2	N_2-6	N_2-12	10%	7%	5%

*Frost (in the sense that crop damage occurs) is defined as the phenomenon of temperature reaching 26°F or below.

In the following analysis, only the citrus crops (oranges, tangerines, and grapefruits) in Florida and California are considered. Basic data has been obtained, as discussed, for Florida and extrapolated to California. Florida's citrus crop production is 70% of the U.S. total and California's is 23% of the U.S. total. It is assumed that these percentages and absolute amounts will hold through the time period of concern. It should be noted (Table 4.1) that the citrus crop is the primary fruit crop followed by the grape crop. Sufficient data was not available at the time of this writing to evaluate the benefits which might arise from improved frost warning capability on the grape crop.

The savings resulting from an enhanced frost warning capability can be expressed as

$$\begin{aligned}\text{Savings} = {} & [\text{false alarm expenses + miss expenses} - \text{cost of prevention on improved forecast days}]_A \\ & - [\text{false alarm expenses + miss expenses} - \text{cost of prevention on improved forecast days}]_B\end{aligned} \tag{4.1}$$

where A and B represent two different levels of forecast capabilities. The contra cost of prevention on improved forecast days is actually a savings which results from the reduction of the size of the area of a frost warning. Equation 4.1 can be rewritten as

$$\text{Savings} = \text{false alarm savings + miss savings savings + savings associated with with improved forecast days} \tag{4.2}$$

The evaluations of the expenses and savings associated with Equations 4.1 and 4.2 are discussed in the following paragraphs.

Consider first the false alarm expenses and savings. The annual false alarm expense and potential savings are given by

$$\text{Annual false alarm expense} = \text{(crop growing area)} \times \text{(fraction of growing area effected by heaters)} \times \text{(cost of protection)} \times \text{(average yield adjustment factor)} \times \text{(number of false alarms)} \quad (4.3)$$

$$\text{Annual false alarm savings} = [\text{annual false alarm expense}]_A - [\text{annual false alarm expense}]_B \quad (4.4)$$

where

Fraction of growing area protected by heaters = 0.24
(an additional 20% of area is protected by irrigation systems whose cost is assumed negligible in the false alarm situation)

Cost of protection = $13/acre [18]

Average yield adjustment factor = 0.5
(this accounts for the fact that the output per day is not constant throughout the overlapped growing and frost seasons)

The additional data required to evaluate the annual false alarm expense and savings in terms of forecast capability and geographic area are listed in Table 4.3 and the annual expenses and savings are given in Tables 4.3 and 4.4, respectively.

Consider next the miss expense and savings. The annual miss expense and potential savings are given by

$$\text{Annual miss expense} = \text{(farm value of crop)} \times \text{(fraction of crop having heating facilities)} \times \text{(fraction of crop which receives frost damage)} \times \text{(average yield adjustment factor)} \times \text{(average no. of frost occurrences)} \times \text{(average fraction of area of frost which is missed)} \quad (4.5)$$

Table 4.3 Citrus Crop Annual False Alarm Expenses						
Forecast Capability	Florida			California		
	Acreage	False Alarm Occurrences	Expense Thou. $	Acreage	False Alarm Occurrences	Expense Thou. $
Conventional	750,000	N_1	1170 N_1	246,000	N_2	384 N_2
Level 1	750,000	N_1-1	$1170(N_1-1)$	246,000	N_2-6	$384(N_2-6)$
Level 2	750,000	N_1-2	$1170(N_1-2)$	246,000	N_2-12	$384(N_2-12)$

Table 4.4 Citrus Crop Annual False Alarm Savings (Thousand $)			
Forecast Capability	Florida	California	Total
Level 1 Rel. to Conv.	1170	2304	3474
Level 2 Rel. to Conv.	2340	4608	6948
Level 2 Rel. to Level 1	1170	2304	3474

$$\text{Annual miss savings} = [\text{annual miss expense}]_A - [\text{annual miss expense}]_B \qquad (4.6)$$

where

Fraction of crop having protection facilities ≃ 0.44 (assuming 0.24 with heaters and 0.20 with irrigation systems)

Fraction of crop which receives frost damage = 0.06 [18]

Average yield adjustment factor = 0.5

Average no. of frost occurrences per year =
0.9 for Florida
5.4 for California

The additional data required to evaluate the annual miss expense and savings in terms of forecast capability and geographic area are listed in Table 4.5 and the annual expenses and savings are given in Tables 4.5 and 4.6, respectively.

The final expense area results from the cost of heating on the increased number of frost days which are forecast correctly as a result of the enhanced forecasting capability. This is referred to as the cost of prevention on improved forecast days. The savings which results is given by

Annual savings on frost days correctly forecast = (crop acreage) × (no. of frost occurrences) × (fraction of crop growing area where frost is detected due to improved forecast) × (average yield adjustment factor) × (cost of protection) × (fraction of growing area effected by heaters) (4.7)

where

Fraction of crop growing area where frost is detected due to improved forecast = [average fraction of area of frost which is missed]$_A$ - [average fraction of area of frost which is missed]$_B$ (4.8)

Table 4.5 Citrus Crop Annual Miss Expenses						
Forecast Capability	Florida			California		
	Farm Value Mil.$	Fraction of Area Missed	Expense Thou. $	Farm Value Mil.$	Fraction of Area Missed	Expense Thou. $
Conventional	580	.10	689	190	.10	1,354
Level 1	580	.07	482	190	.07	948
Level 2	580	.05	345	190	.05	677

Table 4.6 Citrus Crop Annual Miss Savings (Thousand $)			
Forecast Capability	Florida	California	Total
Level 1 Rel. to Conv.	207	406	613
Level 2 Rel. to Conv.	344	677	1,021
Level 2 Rel. to Level 1	137	271	408

and values of other terms are as given previously. The annual savings is summarized in Table 4.7.

Total citrus crop annual savings are summarized in Table 4.8.

The present worth or value of the benefit stream that might accrue as a result of the agricultural industry citrus crop saving, illustrated in Table 4.8, can be determined in a manner similar to that of the construction of air transportation and agricultural industries (see Sections 3.2.1, 3.2.2, and 3.2.3). As discussed previously, the present worth of the benefits depends upon the following factors:

1. Magnitude of potential cost savings,
2. The fraction of the potential cost savings which may be realized in practice through user implementation,
3. The date when the implementation program begins,
4. The shape of the implementation curve during the transitional period, and
5. The factor by which the future benefits are to be discounted to calculate the present worth.

With respect to these factors, the magnitude of the cost savings is indicated in Table 4.8. It must be emphasized that the benefits from improved forecast capabilities are based only upon cost savings. Because of the limited scope of this effort, it should also be noted that price-demand-quantity relationships have not been taken into account.

Since the agricultural industry (citrus crops) currently uses weather forecast data on a routine basis, it is assumed that this practice will continue. Therefore, it is anticipated that 100% (i.e., referring to Equation 3.5, δ=1.0) of the potential cost savings will be realized in practice through user implementation (i.e., 100% of the users, those equipped with

Table 4.7 Citrus Crop Annual Savings Due to Increased Number of Days of Correct Forecast (Thousand $)

Forecast Capability	Florida	California	Total
Level 1 Rel. to Conv.	-32	-10	-42
Level 2 Rel. to Conv.	-53	-17	-70
Level 2 Rel. to Level 1	-21	- 7	-28

Table 4.8 Citrus Crop Total Annual Potential Savings (Thousand $)

Forecast Capability	Florida	California	Total
Level 1 Rel. to Conv.	1,345	2,700	4,045
Level 2 Rel. to Conv.	2,631	5,268	7,899
Level 2 Rel. to Level 1	1,286	2,568	3,854

heating devices, will make use of the improved forecast data). Note that it has been assumed that the improved forecast capabilities will not be sufficient to make it worthwhile for additional growers to implement heating systems. This leads to conservative results. Note also that only a limited, though major, part of the citrus crop has been considered.

The date when the implementation program begins depends, as discussed in Section 3.2.1, upon the launch date of an experimental satellite to prove feasibility and the length of time between experimental satellite launching and operational satellite launching. From the point of view of the present worth computation, this time frame is treated in a parametric fashion, but with the same basic assumptions as in Section 3.2.1.

For the construction industry, an S-shaped implementation curve was assumed to hold during the transitional period. The reason for the S-shaped buildup of benefits was based upon the fact that many companies within that industry would have to change their operations and procedures in order to efficiently utilize the thunderstorm forecast capabilities postulated. This is not the case, however, with the citrus crop growers, who currently utilize frost warning forecast data on a routine basis. It is assumed that as new and improved forecast data becomes available, it will automatically be incorporated and used by the citrus crop growers. It is, therefore, assumed, referring to Equation 3.5, that both m and σ approach zero.

With the above assumptions, the present worth of the benefits calculated for 1974 can thence be obtained using Equation 3.7 where $B_i=0$ prior to the establishment of an operational capability and B_i=savings as indicated in Table 4.8 after the establishment of an operational capability. The present worth of the benefits associated with the agricultural (citrus crop) industry are summarized in Figure 4.3 in terms of level of forecast capability and experimental satellite launch date. The benefits shown are both the industry and societal benefits since it is assumed that, in a competitive market, prices will ultimately be adjusted to reflect industry savings.

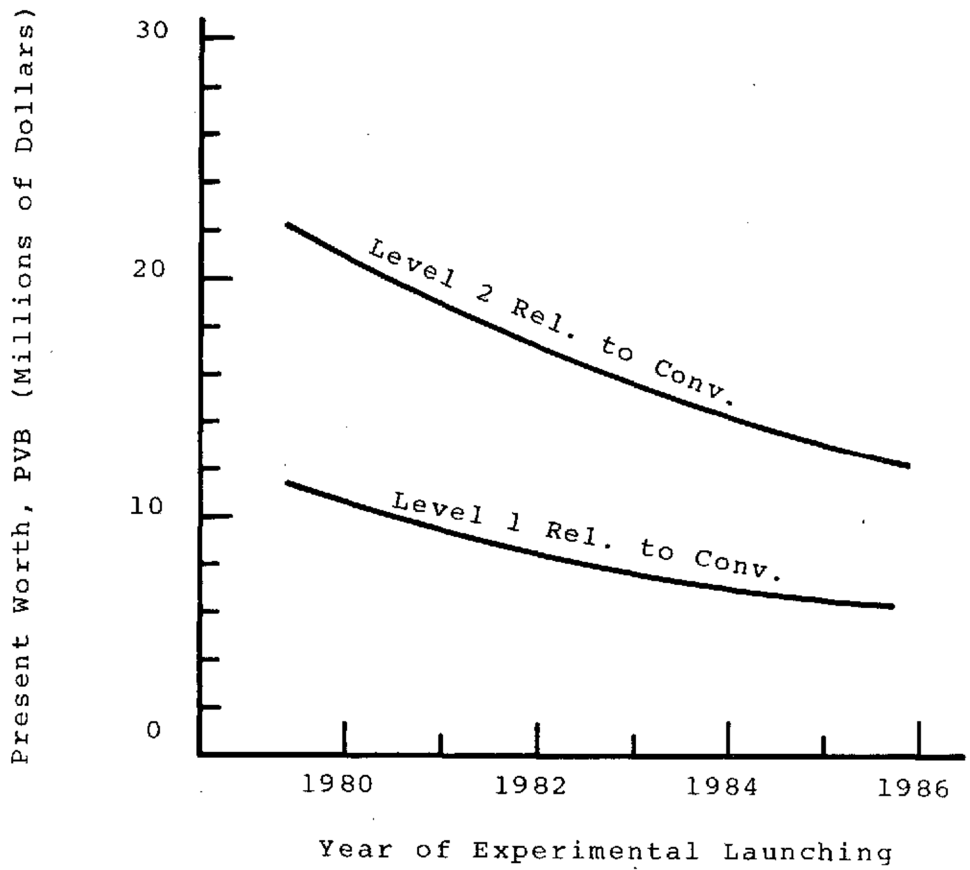


Figure 4.3 Present Worth of Agriculture Industry (citrus crop) and Societal Benefits

5.0 GRAIN DISTRIBUTION

Grain distribution efficiency depends, among other factors, on the accuracy of crop forecasts. The greater the forecast accuracy, the smoother and hence more efficient the distribution. This is due to the fact that erroneous information causes producers to make erroneous decisions on inventory carry-over from one period to another causing price fluctuations that could be avoided with improved forecasts. Hence, improvement in forecast accuracy reduces the social cost of misinformation, which in turn can be considered as an increase in net social benefit.

Appendix A discusses the use of space imagery for crop forecasting. The forecasting accuracy is a function of two factors: acreage estimation, and the estimation of yield per acre. Figure 5.1 illustrates the average crop forecasting error in the United States as a function of the lead time associated with the forecast, as experienced with the current or conventional forecasting capability. It should, however, be kept in mind that the conventional methods of estimation used in the United States are rather sophisticated as compared to the methods followed in many other parts of the world (see Figure 5.2).

A major advantage of a continuous observation system, which can provide continuous and on demand data, is the ability to obtain multiple "looks" at an area. Thus, the total number of samples of observation may increase significantly, which, in turn, reduces the sampling error. Assuming that 50% of the estimation error at any given time is due to inadequate sampling [25] a system which is capable of gathering continuous data may improve the forecast accuracy by a factor of two, in the limit. Further, continuous data available on demand may significantly advance (in time) the information regarding events such as crop infestation. Thus, on the whole, it is assumed in this analysis

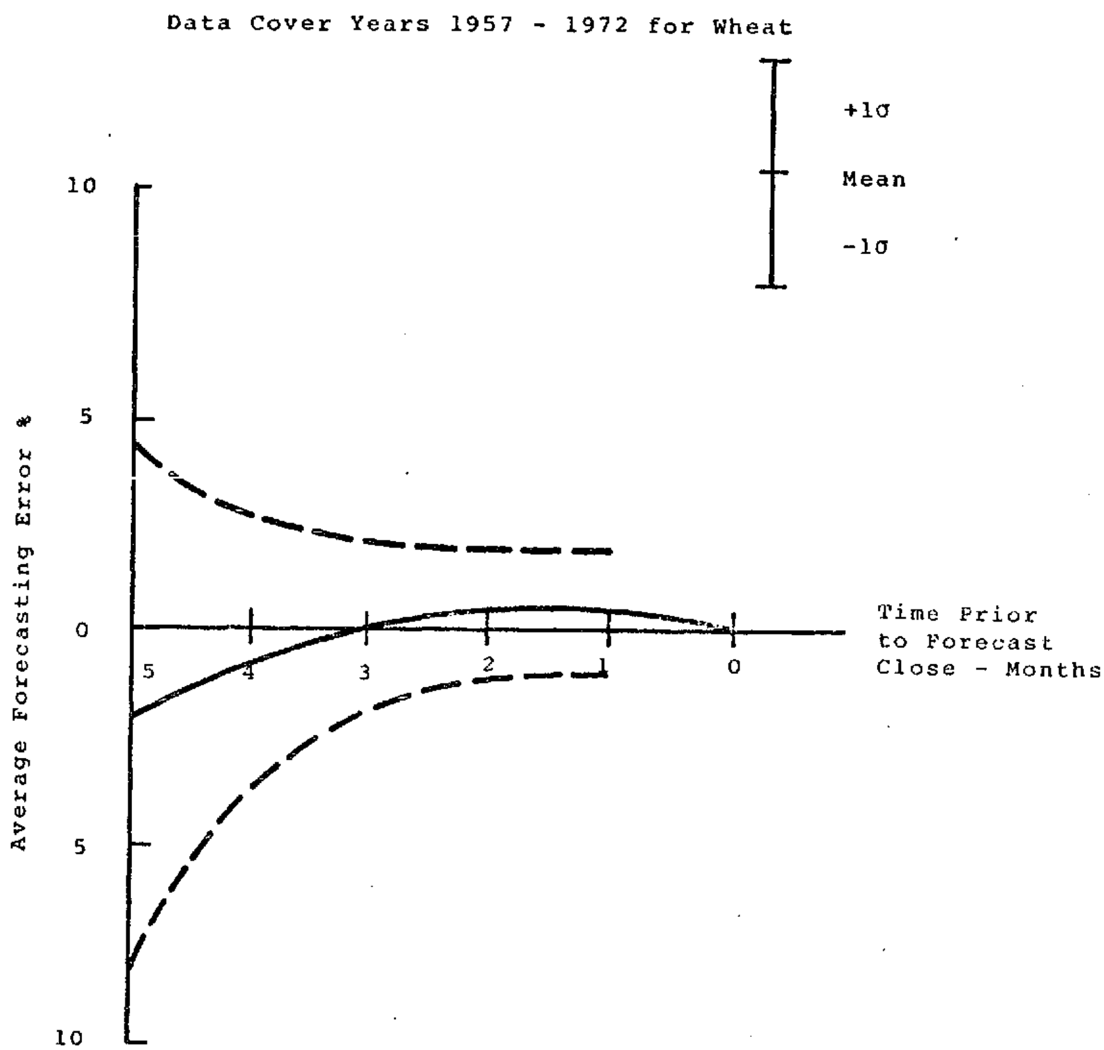


Figure 5.1. Average Crop Forecasting Error Versus Time
(From Reference 29)

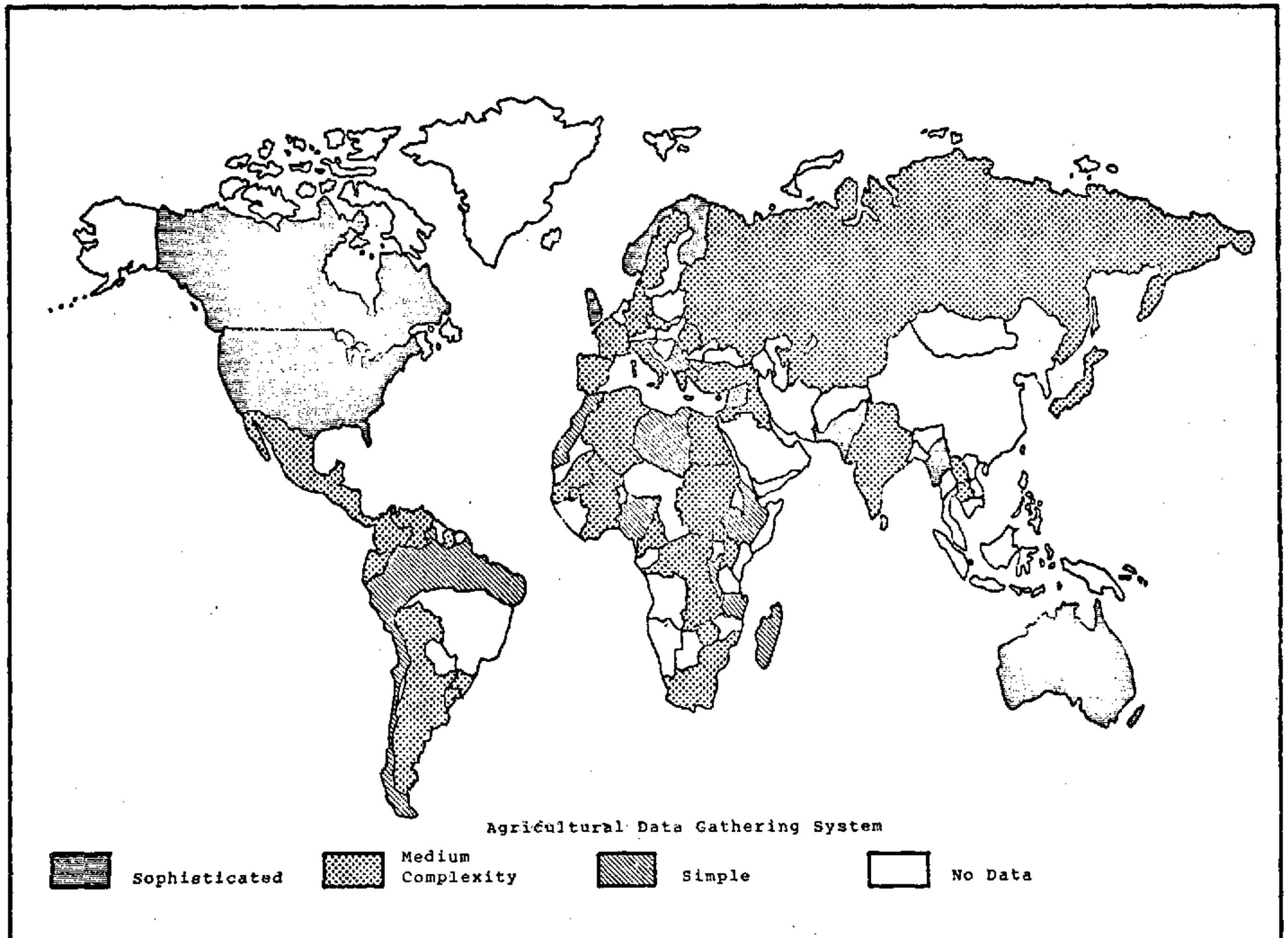


Figure 5.2. Distribution of Crop Forecasting Activities (from Reference 30)

that, with the availability of a continuous data sampling facility, the error in crop forecast, at any particular time during the growing season, improves over that of the conventional system by a factor of two. It should, however, be noted that this improvement in forecast is assumed to be realized only over the United States, since the continuous data gathering facility is assumed to be associated with a synchronous satellite fixed over the United States. The rest of the world is assumed to carry on with the conventional forecasting schemes as are at present followed in different parts of the globe.

The grain distribution benefit, which is the result of improved U.S. crop forecasting can be realized under two distinct situations: (1) assuming the U.S. to be a water-tight region with no interaction with the outside world, a better crop forecast results in a smoother control of the domestic inventory, which, in turn, results in benefit, and (2) the flow of crop between the United States and the rest of the world introduces a variance on the U.S. exports which is a function of both the forecast of U.S. domestic production as well as of the forecast of the production of the rest of the world. This, in turn, creates a perturbation on the U.S. domestic consumption and inventory which can be partly smoothed out with the improvement in the U.S. forecast. It is true that a still further smoothing of U.S. domestic consumption and inventory is possible with an improvement in worldwide crop forecasting. However, that is beyond the scope of this study, since the better forecast facility is assumed to be made available to the U.S. alone.

The precise method of combining these two benefits into a cumulative benefit is complicated, and calls for a detailed study. However, it is felt that, in an approximate sense, the minimum benefit is the maximum of the two and the maximum benefit is the sum of the two benefits. These benefits will be treated separately as follows. However, the entire range of agricultural products of the United States and of the rest of the world is a very wide spectrum. The discussion in this section pertains to wheat only. The rationale behind selecting wheat from among all the crops is that among all the staple crop productions of the world, the production of wheat is the largest as shown in Figure 5.3.

5.1 Benefit in the Domestic Market, Neglecting Foreign Flow

A detailed analysis of the benefits in the domestic market has been conducted and is described in detail in Reference 4. As explained in connection with Equation 2.23, the value of W^t depends on the policies of the inventory holders who are interested in maximizing their profits in the face of a string of crop forecasts. This profit maximizing policy can be derived by using a Dynamic Programming algorithm. It is intuitively clear that such a policy is sensitive to two factors: (1) the nature of the forecast error, and (2) the time it takes for the assessment of a crop situation to be made available to the inventory holder. This time, under a conventional forecast system, has been assumed to be one month, which may be significantly shortened with an earth observation system which has the capability of providing continuous and on demand data.

This analysis has been done both for a conventional forecast capability as well as for a continuous forecast capability under the assumption that the continuous capability reduces the forecast error to half the value associated with the conventional capability. The result shows an annual benefit of 36 million dollars associated with the assumed improved forecast of wheat. However, this seems to be a lower bound, because in this analysis the benefit due to the reduction of the time between assessment and availability has not been considered. The present worth of this benefit stream is illustrated in Figure 5.4 in terms of

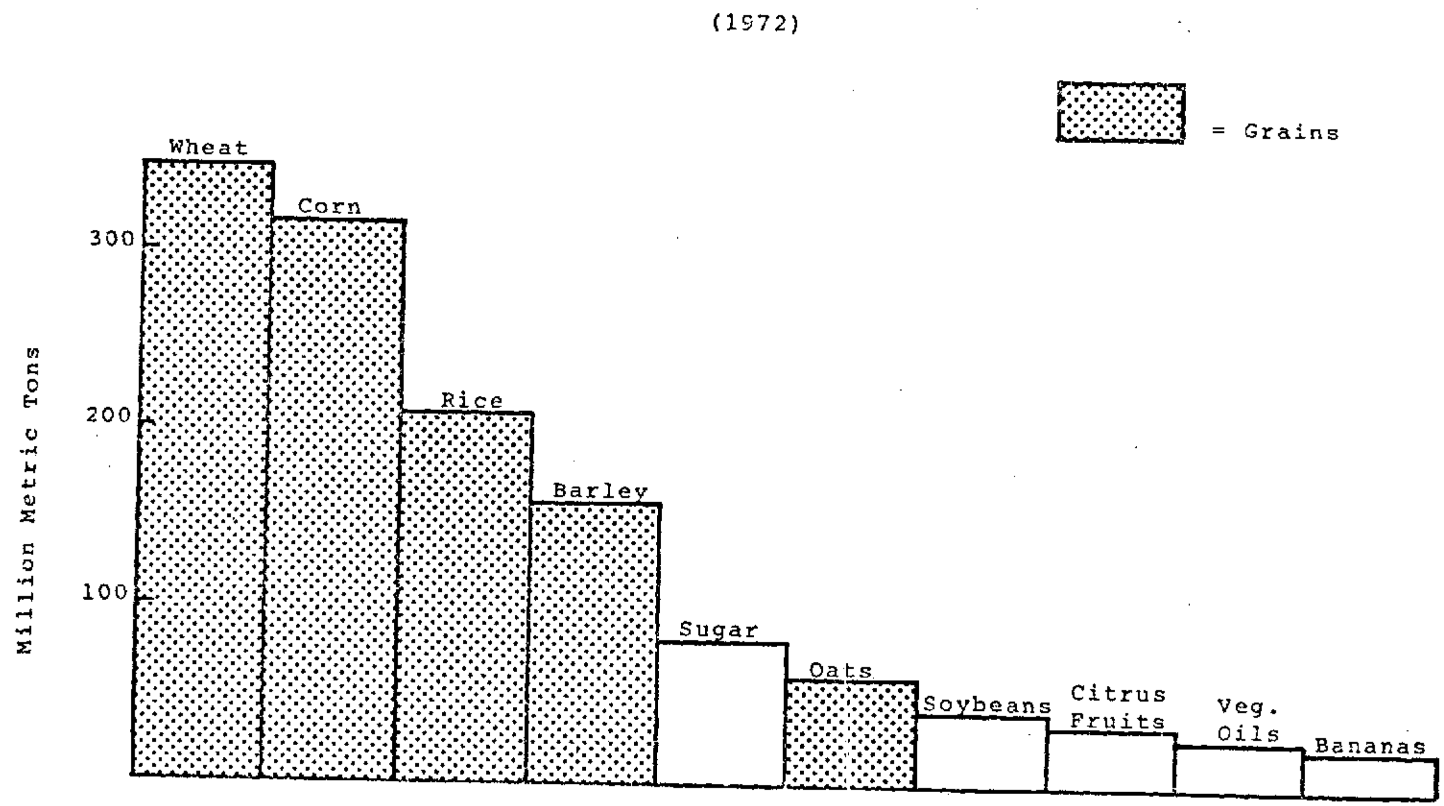


Figure 5.3. World Staple Crop Production (from Refernce 30)

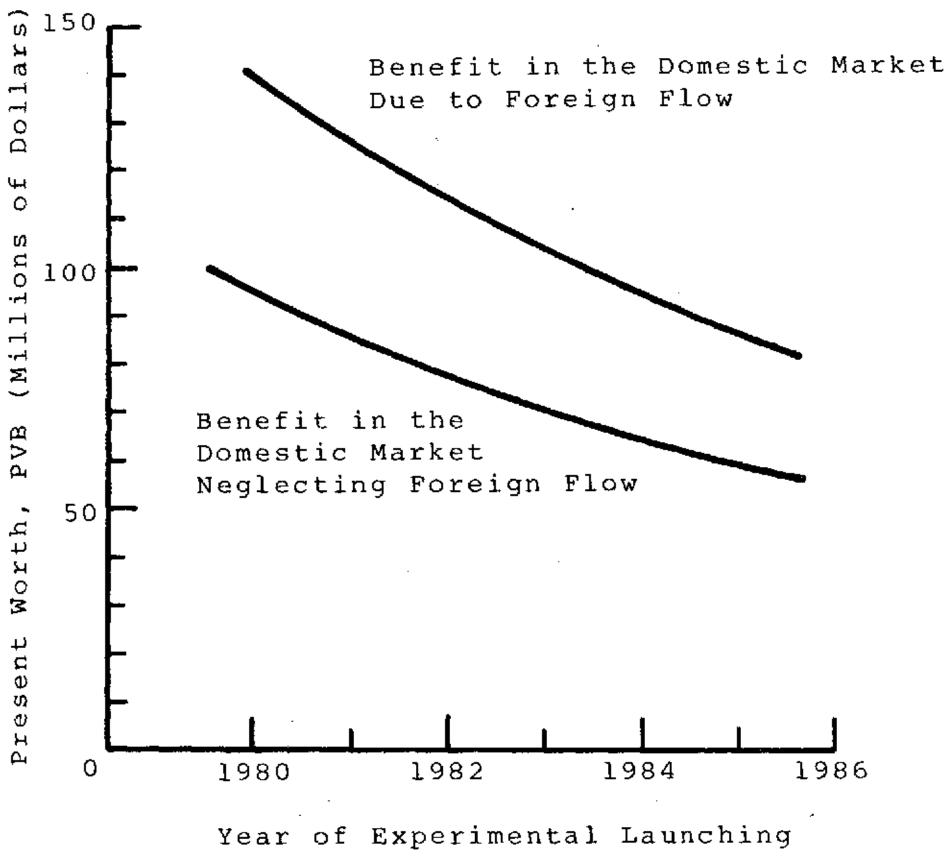


Figure 5.4 Present Worth of Wheat Crop Forecasting Benefits

experimental satellite launch date when it is assumed that there will be complete implementation (i.e., use) of the improved forecast capability when the system is operational. Note that the benefits computed are only for the wheat crop!

5.2 Benefit in the Domestic Market Due to Foreign Flow

Historical data pertaining to wheat flow during the last ten years show that the main producers of wheat are the United States, Canada, Argentina and Australia. This is based on the fact that hardly ever do these countries import wheat. Thus, as explained in Section 2.2, the countries of the world are divided into the following classes:

Class 1: U.S.A.

Class 2: Canada, Argentina and Australia

Class 3: The rest of the world

As expressed in Equation 2.12, the quantities of flow Q_i (for i = 1 to 7) are expressed as:

$$Q_i = K_i + \sum_{j=1}^{5} A_{ij} P_j \tag{5.1}$$

where the P_j's are the various prices, and K_i and A_{ij} are parameters estimated from historical values of Q_i and P_j. Tables 5.1 and 5.2 illustrate the historical data relating to Q_i and P_j, respectively [26-29]. Equations 2.17 and 2.18 are used to estimate the coefficients of K_i and A_{ij}.

As explained in Equations 2.13 and 2.14, the exogenous variables for the year 1973 are as illustrated in Table 5.3. These exogenous variables are used in the analysis, since these constitute the most recent data available.

Forecast errors are imposed on T_1, T_2 and T_3 and the corresponding values of Q_1 are computed using Equations 2.16 and 2.12. The magnitudes of these imposed errors are determined from Figure 5.1. It is observed that the forecast error for the United States with the conventional forecasting capability is typically $\pm$ 5% at the beginning of the growing season and $\pm$ 2.5% towards the end of the season. Figure 5.2 indicates that the forecast errors for Canada and Australia are comparable

Table 5.1 Historical Data on Wheat Flow (Million Metric Tons)									
Quantity	1965	1966	1967	1968	1969	1970	1971	1972	1973
Q_1	17.62	17.62	18.33	19.67	21.03	20.09	23.30	22.50	20.90
Q_2	17.70	22.48	17.47	16.12	12.09	20.10	17.20	31.30	26.00
Q_3	18.02	13.62	16.25	20.36	24.00	19.77	23.27	11.47	12.57
Q_4	11.47	10.68	11.30	11.11	11.12	11.24	12.13	11.75	10.40
Q_5	20.31	21.96	23.30	17.51	18.01	21.69	23.06	24.82	24.80
Q_6	19.20	25.18	21.59	28.40	35.46	24.39	17.98	10.63	11.38
Q_7	200.73	235.83	229.94	257.11	242.61	257.78	281.11	276.52	276.05

Table 5.2 Price History of Wheat (Dollars/Metric Tons)									
Price	1965	1966	1967	1968	1969	1970	1971	1972	1973
P_1	49.60	59.68	51.06	45.56	45.92	48.86	49.23	64.66	146.96
P_2	60.09	62.10	64.10	61.59	60.06	58.02	58.46	76.78	174.50
P_3	51.27	60.78	51.94	46.76	47.27	47.72	50.00	66.82	150.50
P_4	62.11	63.03	65.20	63.21	61.82	56.67	59.38	79.36	178.15
P_5	61.44	62.72	64.65	62.67	61.24	57.12	58.92	78.07	176.32

to that of the United States. Since they constitute the major bulk of production of the Class 2 countries, it is assumed that the forecast error for Class 2 countries is the same as for the United States. Previous ECON studies have indicated that the forecast error for Class 3 countries is significantly higher, to the extent that it can reach as high as $\pm$ 25%. However, this high percentage does not apply to some of the countries of Western Europe as indicated in Figure 5.2. Further, though the error of one country can go as high as 25%, the probability

Table 5.3 Exogenous Variables for 1973 (Million Metric tons)

T1	T2	T3	T4	T5
59.47	46.58	276.05	10.40	326.85

that the cumulative error of all the countries in Class 3 will reach this high value is somewhat less because of the averaging of positive errors against negative errors in different countries. Considering all these factors, it is assumed that for the Class 3 countries, the forecast error is typically 12% at the beginning of the growing season, and 6% at the end of the season. Table 5.4 illustrates the high/low forecasts for T_1, T_2 and T_3 with the conventional forecasting capability at the beginning as well as at the end of the growing season.

The numerical values of the bounds illustrated in Table 5.4 follow directly from Table 5.1. To clarify this, consider the upper and the lower bounds of T_1 at the beginning of the season. Since $T_1 = Q_1 + Q_2 + Q_3$, the true value of T_1 (from Table 5.1) is 59.47 as shown in Table 5.3. However, the inventory carried over from the previous year, as illustrated in Table 5.1, is 11.47. Hence the true production of the U.S. in 1973 is 48. With a 5% forecast error, the upper and lower bounds on this production figure become 50.4 and 45.6 respectively. This added to the previous year's carry over inventory of 11.47 yields the upper and the lower bounds of T_1. The rest of the numbers of Table 5.4 are calculated in the same fashion. However, under the continuous data gathering system, the upper and the lower bounds of T_1 at the beginning of the growing season become 60.66 and 58.26, respectively while the end of

Table 5.4 Upper and lower bounds on exogenous variable with the conventional forecasting capability (million metric tons)

Variable	Upper Bound at the beginning of season	Lower Bound at the beginning of season	Upper Bound at the end of season	Lower Bound at the end of season
T_1	61.87	57.07	60.66	58.26
T_2	48.38	44.78	47.48	45.68
T_3	309.18	242.92	292.61	259.48

the season, the bounds become 60.07 and 58.87, respectively. The bounds on T_2 and T_3, with the improved forcast capability remain the same for reasons discussed earlier.

The benefit associated with the improvement in forecast capability is computed both for the beginning of the season, as well as for the end of the season. To clarify this, consider, first, the conventional forecast at the end of the season. It is clear that eight possible combinations of T_1, T_2 and T_3 are possible using their upper and lower bounds. In each of these cases, Equation 2.16 is used to calculate $\bar{P}$ which is inserted in Equation 2.12 to find the value of Q_1. Thus there are eight possible values of Q_1 computed for the eight combinations of T_1, T_2 and T_3. The upper and the lower bounds of these computed values of Q_1 are found to be 24.17 and 17.63 respectively. Note that they are equidistant from the true value of Q_1 which is 20.90. The disbenefit associated with the error in Q_1 is calculated by drawing the shaded rectangle shown in Figure 2-10. For a constant elasticity of demand equal to -0.1, the demand curve becomes:

$$Q_1 = 34.422 \times 10^6 P^{-0.1} \qquad (5.2)$$

The constant in Equation 5.2 is obtained by considering the fact that the values of Q_1 and P_1 for the year 1973 (as shown in Tables 5.1 and 5.2) ahould lie on the demand curve. The area of the shaded rectangle under the demand curve of Equation 5.2 between the bounds 24.17 and 17.63 becomes 365.68 million dollars.

With an improved U.S. forecast capability the upper and the lower bounds on the computed value of Q_1 become 23.94 and 17.86 respectively. The area of the corresponding rectangle becomes 329.51 million dollars. Thus the benefit due to the improved forecast is 365.68 - 329.51 or 36.17 million dollars. This benefit is associated with the improvement in the U.S. crop forecast from $\pm$ 2.5% error level to $\pm$ 1.25 % error level, as realized at the end of the growing season. However, at the beginning of the growing season, this improvement is more pronounced, because it reduces the error from $\pm$ 5% to $\pm$ 2.5%, which corresponds to an error difference of $\pm$ 2.5% as against an error difference of $\pm$ 1.25% at the end of the season. The annual U.S. benefit associated with the forecast improvement realized at the beginning of the growing season is calculated following the same analysis, and is found to be 70.16 million dollars. The two benefit figures - one for the beginning of the season, and one for the end of the season show that the benefit under one forecast capability with respect to another, at a certain level of approximation, is a linear function of the difference in the forecast errors under the two forecast capabilities. Assuming that the mean forecast error over a growing season is approximately equal to the average of the forecast errors at the beginning and at the end of the season, the average annual benefit with the improvement of wheat forecast over the United States becomes the average of 36.17 and 70.16, i.e., 53.16 million dollars.

The annual benefit attributable to the domestic market due to better regulation of the foreign flow of wheat is on the order of 53 million dollars. The present worth of this benefit stream is illustrated in Figure 5.4 in terms of experimental satellite launch data, where it is assumed that there will be complete implementation (i.e. use) of the improved forecast capability when the system is operational. Note that the benefits computed are only for the wheat crop!

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Appendix A

USE OF SPACE IMAGERY FOR CROP FORECASTING

A.1 INTRODUCTION

Improved crop forecasting holds out the possibility of substantial economic benefit. The prospects for improved forecasting by means of space-acquired data depend on the accuracy and reliability of these methods compared to present methods. These present methods vary widely from country to country. In more developed countries, like the United States, major effort is devoted to providing results frequently within 1 or 2 percent for major crops. On the other hand, in developing countries, less comprehensive methods are used and there is substantial opportunity for improvement.

Although a number of experiments have been conducted or are presently in progress to obtain quantitative data on relationships of spectral signature to physical or biological condition, adequate data do not yet exist for estimating reliability or accuracy of advanced crop prediction techniques. This appendix uses such data as are presently available to indicate how a continuous satellite might improve existing levels of forecasting performance. In Section A.4, a rough evaluation is made of possible improvement of wheat crop forecasting performance.

A.2 THE ROLE OF A CONTINUOUS SATELLITE

The ability of a system combining information from SEOS and from other sources to improve grain crop forecasting can be studied with respect to the forecasting of (1) acreage and (2) yield per acre. The use of remote sensing methods to improve acreage forecasts will combine procedures for crop identification, needed to designate fields growing the crop, with procedures for measuring their area.

Examination of wheat forecasting errors of present methods for all U.S. wheat over the ten-year period, 1964-73, indicates that the error in area measurement remains relatively constant throughout the forecasting period both in sign and magnitude. Percent error in yield prediction is larger than percent error in area estimation during the early months of the forecasting cycle but falls below it as harvest time approaches. See Figure A-1.

For errors in both quantities, we must expect that appreciable improvement in U.S. crop forecasting will require that errors be kept within 1 or 2 percent in order to result in appreciable improvement of existing methods. At the present state of the art, both area measurement and crop identification with accuracies approaching 99 percent are admittedly difficult to achieve by remote sensing. Improving on existing ground-based methods will therefore require the full use of special techniques for remote sensing from space. For this reason, an operational system is assumed to combine SEOS data with that from other satellites.

The major advantage of SEOS which makes it uniquely valuable for crop forecasting is its ability to obtain multiple critically-timed looks at a given area. Each look may provide information on area measurement, crop identification, or yield prediction at the optimum time for each function, and the continuity of observation improves the forecast by increasing the probability of observation, by observing the crop at critical points in its development, or by advancing the time at which information becomes available. The quick-look capability of SEOS is particularly valuable for observing discrete events, such as storm damage or harvesting.

A substantial part of the forecasting error during the early part of the growing season results from the inability to foresee future weather or plant disease conditions which will reduce total yield. Space imagery cannot reduce errors in forecasting which result from these effects. It may, however, reduce those errors caused by conditions which are observable in the space imagery.

The techniques discussed in the following sections are intended to result in improved crop forecasting through the following mechanisms employed singly or in combination:

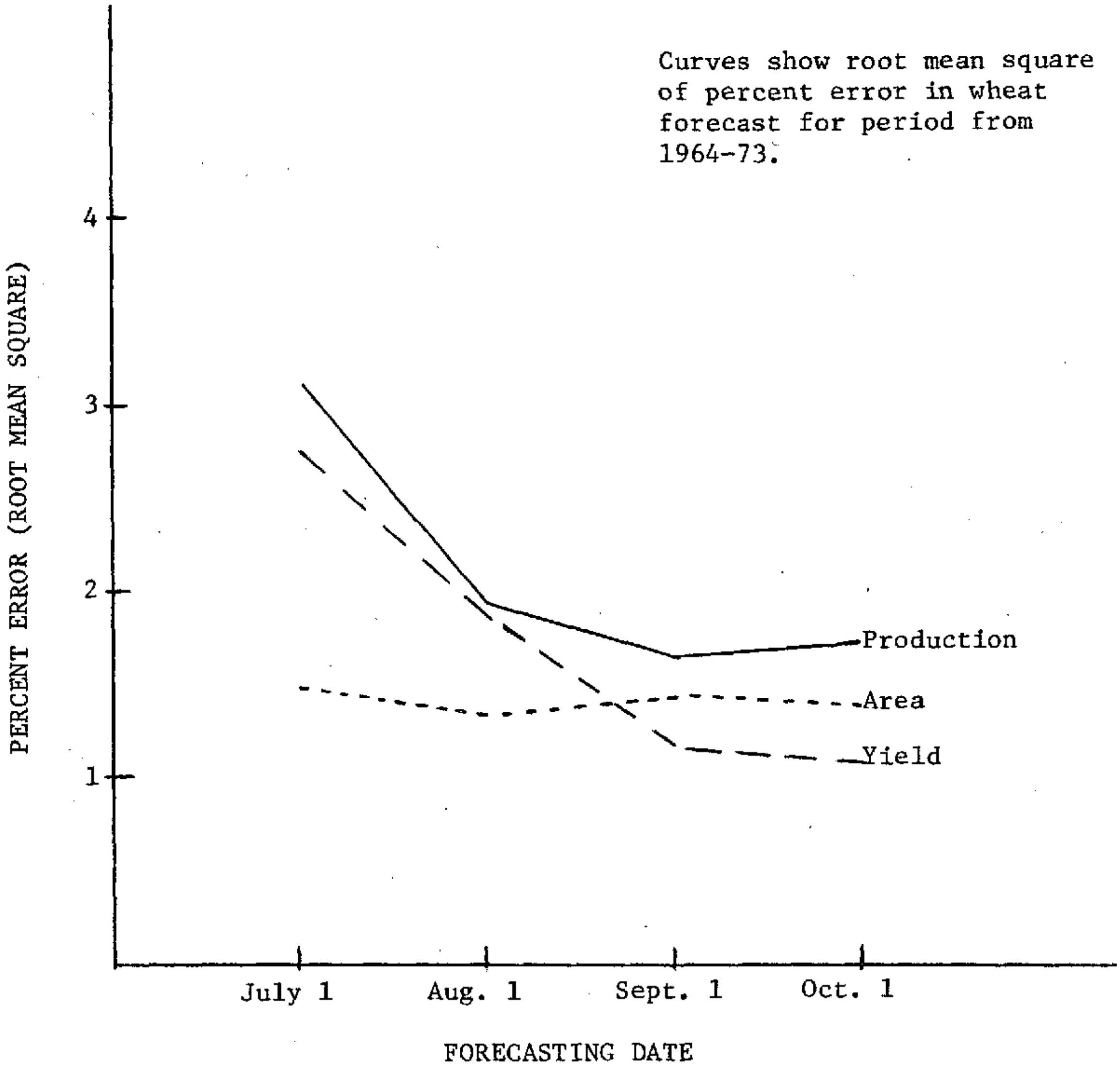

Figure A-1 ERRORS IN WHEAT FORECASTING

1. New types of data which are entirely independent sources of information for estimation and forecasting.
2. Increased accuracy in measurement of crop acreage or prediction of yield through the survey of larger sampling areas.
3. Earlier information on changes in crop acreage or yield than would be available from conventional ground-based methods.
4. Accurate determination of incremental changes in crop acreage or yield.
5. Indications of possible discrepancies in ground survey data to be resolved by further ground checks.

A.3 OPERATIONAL METHODS

This section summarizes the anticipated modes of operational use of SEOS and other space acquired data for crop forecasting and suggests realistic objectives for improvement of forecasting performance. Since information presently available does not permit us to precisely estimate the improvement of crop forecasting, we present performance targets which we feel can realistically be achieved with adequate research and development effort. These performance objectives should be recognized as being the result of subjective judgment applied to the experimental information discussed in this report rather than the result of rigorous analysis of forecasting procedures.

A.3.1 CROP IDENTIFICATION PROCEDURES

As indicated previously, the crop identification function is a prerequisite to procedures for estimating both area and yield.

Two measures of crop identification performance are of concern in this discussion. Classification accuracy refers to the fraction of the total area or total number of fields which are correctly classified. In contrast with this, estimation accuracy is the accuracy with which the total number of fields or total crop area is estimated. The estimation accuracy will usually be higher than the classification accuracy, since omission and commission errors will tend to cancel each other.

A.3.1.1 ERTS Experience

Several ERTS studies concerned with identification of important crops have showed results in classification accuracy falling in the range from about 50 percent to 90 percent, depending on the specific growing conditions, time of observation, and the special techniques employed to maximize accuracy.[1,2,3] The various studies show that improved crop identification performance was achieved by such measures as use of a priori information on percentage of farm area devoted to a given crop and repeated looks at the crop during the growing season. Although the classification obtained by either photointerpretation or automatic processing in most studies did not reach accuracies needed to accomplish absolute estimation of crop areas, the estimation accuracies in some cases reached acceptable limits. For example, in estimating winter wheat area in Kansas reported in Reference 2, estimation accuracies approaching 100 percent were obtained by special methods of subregion stratification, correlation with soil and landform maps, photo density estimation, and field-by-field identification.

In practice, the crop identification function will be applied to the recognition of complete fields rather than individual pixels. Field recognition should improve crop identification performance since it should result in reliable recognition of those fields where pixel recognition is reasonably good, even though pixel recognition does not approach 100 percent. Some early results with field recognition using both aircraft and ERTS data indicate that some difficulties will be experienced under certain conditions.[1,4,5] Field recognition may suffer for fields that are small compared to the sensor resolution (e.g., 20 acre fields in an ERTS image). In addition, the failure of field classification accuracy to surpass pixel classification accuracy in these early results is due to the ability of the processing system to distinguish variations in spectral character of individual fields that are associated with real differences in crop maturity or vigor. Properly interpreted, this signature variation can increase the overall forecasting capability. Indeed, it is a prime source of information which can be used to predict yield, as discussed in Section A.3.3.

A.3.1.2 Application of SEOS

SEOS could contribute to the crop forecasting task by improving the accuracy and timing of crop identification. It could do this by several methods:

1. Multiple viewing can increase the reliability of crop identification. Multi-aspect viewing could be accomplished by combining the vertical view obtained by ERTS with the oblique view obtained by SEOS. For multi-angle illumination, SEOS could be scheduled to look at a given area at various times of day.
2. In the early stages of plant growth, the oblique view provided by SEOS would increase the percentage of projected area covered by vegetation observed by the sensor over that seen in a vertical view, and thus advance the time at which the crop can be identified.
3. The ability of SEOS to observe a given area on demand further advances the time at which positive crop identification can be achieved. By comparison, Figure A-2 shows the limitation of ERTS coverage.

An effective method of increasing crop recognition performance is to view the terrain more than one time, under a variety of conditions of view angle, illumination angle, or season. Repeated viewing of crops at various dates has been tested under various ERTS studies and in investigations of airborne scanners, and has been found to be an effective method of improving classification accuracy.

Improvements in crop identification have also been achieved by the use of multi-aspect viewing (i.e., utilization of crop signatures obtained by viewing the crop from two or more view angles).[6] Multi-aspect viewing could be achieved by a SEOS satellite operating in an inclined orbit, since such a satellite would view individual fields at various angles at different times of day. However, the present study is restricted to consideration of a SEOS operating in an equatorial orbit. Under these conditions, multi-aspect viewing would have to be performed by the combination of ERTS data with SEOS data obtained nearly simultaneously. This would pose a considerable operational problem.

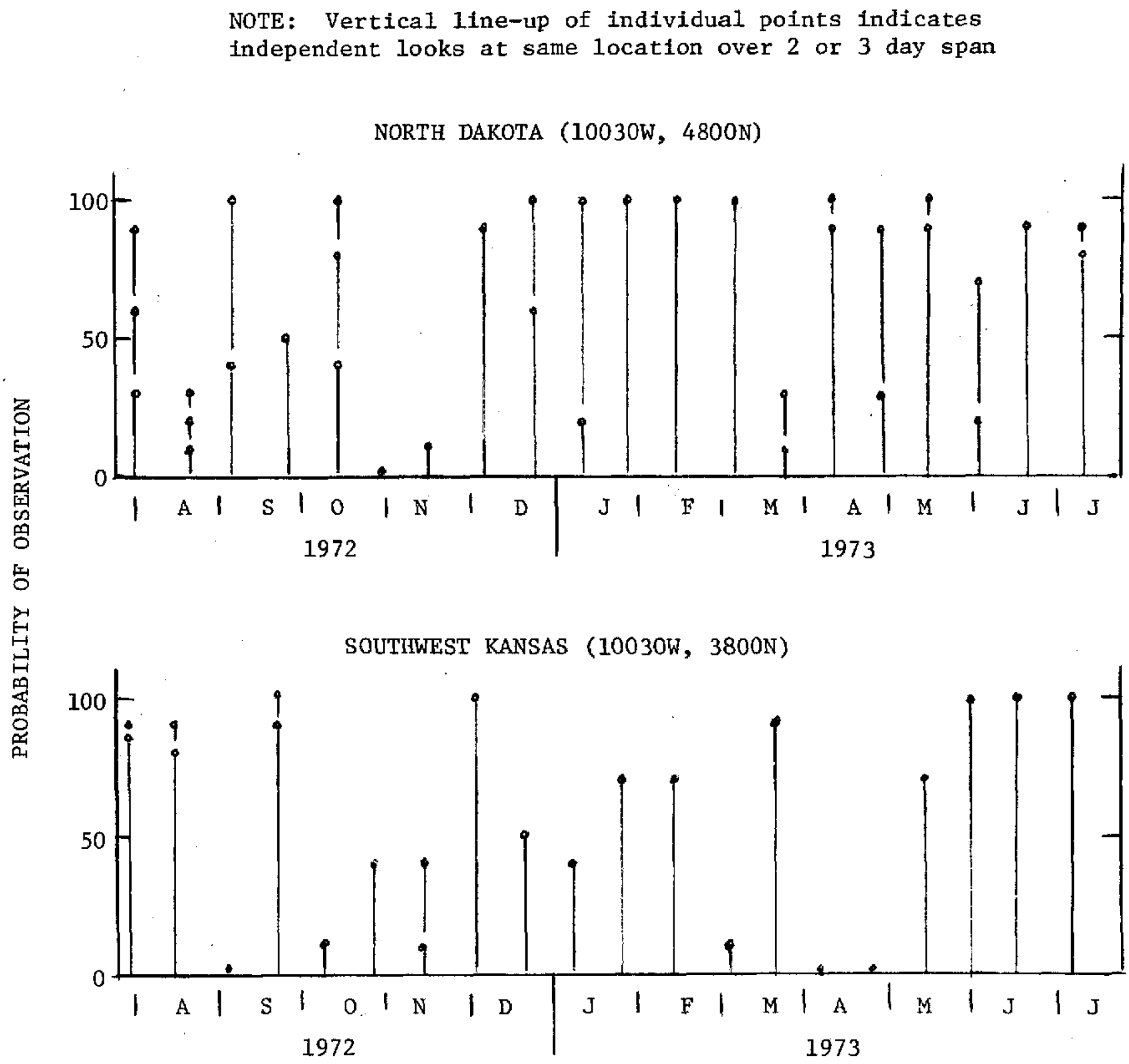

Figure A-2 REPETITIVE OBSERVATION BY ERTS

A related method would be to use SEOS data obtained for a given sample area at various times of day. This opens up the possibility of crop identification or yield estimation through analysis of signature variations associated with variations of illumination angle. Information is not available on potential improvements in performance from this technique, but it seems likely that crops having different dimensions and structure could be successfully differentiated in this manner.

Oblique viewing is capable of increasing the rate at which vegetation cover in a field becomes apparent to the sensor. Spectral measurements of the field can thereby provide an earlier and more reliable indication of crop type or condition. Data derived from Reference 8 for the geometric and spectral characteristics of oats indicates that the percentage vegetation cover for oblique viewing of oats 9 cm high is as great as the cover for vertical viewing of oats 14 cm high. As compared with vertical viewing, oblique viewing should advance the date at which crop recognition can be achieved, and provide an earlier and more reliable measure of biomass growth or other factors related to yield.

The improvement in observation timing which can be achieved by SEOS as compared with ERTS could avoid the substantial delays which are inherent in the use of ERTS data. The use of this quick-look capability implies the design of data processing and dissemination system with short turn-around times. With this capability, it would be possible to observe crops at critical points in their seasonal growth when crop identification can be most effectively performed.

A.3.2 AREA ESTIMATION PROCEDURES

As discussed in Section A.3.1, SEOS can contribute to the crop identification function, which is fundamental to any accurate space method of area measurement. However, SEOS would be less accurate than ground-based surveys or low-altitude satellites in field area measurement, and should not therefore be considered for this function.

A.3.2.1 Estimation Techniques

The problem of estimation of field areas from ERTS imagery has been considered by several investigators. The primary problem in accurate measurement of area is that posed by the limited resolution of space imagery. If the area of a single field is being measured, errors will occur in assigning correct crop areas for those pixels which fall on field boundaries. For a relatively small or narrow field these errors may be a substantial fraction of the total area of the field.

Such errors cannot be completely eliminated, but can be minimized by at least two approaches. One approach is the technique of proportion estimation, in which the spectral characteristics of the border pixels are analyzed to estimate the percentage of the area covered by the known surface types.[9] The other approach takes advantage of the reduction in percent error with increased sample size. Thus, if the sample area is increased by a certain factor, the percent error in crop acreage estimation will be reduced by the square root of that factor.

Measurement errors will be reduced as the average field size increases. A sampling of four states (Kansas, Idaho, Missouri, and South Dakota) indicates that the fraction of fields that are less than 20 acres varies from 20 percent in Kansas to 74 percent in Idaho, and that the total area of fields less than 20 acres ranges from 1.5 percent in Kansas to 32 percent in Missouri.[2] Thus, the bulk of total acreage for many major crops in the midwest and west is located in fields of 20 acres or larger.

We would expect area measurement of individual fields even as large as 20 acres to be relatively poor, since most pixels in the image of that field would be border pixels. It would seem that the best operational method of using space imagery would be to apply it to fields of 40 acres and larger in a stratified sampling system based on field size. The imagery could also be used indirectly to check for the occurrence of year-to-year changes in size of smaller fields.

Reference 10 cites an early attempt to measure the area of 1,221 acres of rice fields in California. In this case, the area estimate was initially low by about 16 percent, but the use of proportion estimation procedures brought the measured area within 0.25 percent of the true value. Excessive reliance should not be placed on the favorable results obtained in this special case, because the fields were of large size, averaging 175 acres, and because the tests were not performed under operational conditions. However, the results do indicate that accurate absolute measurement of area is within the realm of feasibility given enough research and development effort. Some additional approaches to improving area measurement performance are discussed next.

One way of improving area measurement performance from space is by the use of regression analysis. Variations of this method are already in extensive use for crop forecasting.[11] With space data, area measurements obtained from the current year would be compared with similar measurements made during previous years. The area measurements for the current year would then be adjusted by the amount of the discrepancy between measured and true areas in previous years. This technique tends to cancel our systematic biases which may be present in the space data or measurement procedures.

Still another technique for reducing area estimation errors is to use space data to detect incremental changes in area that occur during the growing season. These changes normally constitute a small percentage of the total area under cultivation, so that even moderate accuracies in estimating area changes can significantly improve estimation accuracies. Such changes would be detected by comparison of imagery from two dates to note significant deviations of field signatures from those expected in accordance with the normal crop calendar. Since this is basically a crop identification function, SEOS could be used for this purpose.

Instead of using space data to make an independent estimate of crop areas, the data could be used as an independent check against the ground sampling data to indicate the possibility of errors in that data. Apparent differences in crop type or field size would indicate the need for additional ground checking and could point to specific locations where changing crop conditions may be causing the discrepancies. The space data need not be used to measure field area, but could be limited to confirming that fields are of standard size (e.g., 40 or 80 acres) or that they have not changed from previous recorded area. By looking at the space imagery for large sampling areas or by following the changing spectral characteristics of individual fields, the local crop reporting service would have additional information to improve its forecasting performance. In the following analysis of overall improvement in crop area estimation, no allowance is made for such methods of improving the existing procedures for area estimation.

A.3.2.2 Performance Assessment

The implication of the above discussion is that by intensive use of special techniques, estimation accuracies approaching those used in existing ground-based surveys could be achieved. In attempting to predict attainable performance of space systems of crop forecasting, we will assume that the contribution of the space system consists of providing an independent estimate of crop acreage which can be combined with that from existing crop surveys.

As indicated in Section A.3.1.1, the methods already used by ERTS investigators have been shown to be capable of keeping estimation errors within 1 or 2 percent under certain favorable and carefully controlled conditions. The additional features of the SEOS system or of special processing techniques just discussed should make it possible to increase the effectiveness of the crop identification function beyond that obtainable from ERTS. With these additional capabilities available from space systems, it is not unrealistic to estimate that root mean square errors falling within 3 percent could be achieved under operational conditions. We would then be able to produce an estimate of crop area, essentially independent of the ground-based estimate.

In order to evaluate the potential improvement in the overall area estimate, we may assume a procedure in which the two independent estimates are combined to produce a single estimate with lower error than either one. The acreage estimate based on space data with a 3 percent error could be combined with the present estimate, having an rms error of about 1.4 percent.

To obtain the minimum error of the combination, a greater weight should be assigned to the better estimate as compared to the poor estimate, the weight being inversely proportional to the square of the standard deviation. The resulting standard deviation of the new estimate will be equal to

$$\sigma_t = \frac{1}{\sqrt{\frac{1}{\sigma_1{}^2} + \frac{1}{\sigma_2{}^2}}}$$

The resulting combined error would be about 12 percent less than the present method. Obviously, for less accurate forecasting methods currently employed by many other countries, the potential percentage improvement would be much greater.

The acreage measurement function depends on accurate crop identification, which improves as the season progresses because of increased visibility of the crop. Consequently, we would expect that the improvement of acreage estimation just mentioned would apply to most crops only during the last half of the season and at harvest time.

A.3.3 YIELD ESTIMATION PROCEDURES

Improvement in yield prediction by the use of SEOS or other space data can be accomplished by observing 3 basic types of spectral change: (1) change related to biomass productivity (such as leaf area index), (2) change resulting from normal or abnormal cultivation and growth patterns of the crop, and (3) change associated with yield reducing factors.

A.3.3.1 Measures of Productivity

Early in the growing season, the best single indicator of crop condition and potential yield appears to be current leaf area index, L.A.I. L.A.I. of a wheat crop peaks fairly early in the growing season, so the information inherent in this parameter will be available early.

A number of experimenters have found high correlations between ERTS spectral data and leaf area index and other significant plant parameters. This high correlation indicates that with consistent and frequent viewing conditions, these characteristics of plant development and yield could be reliably monitored.

A.3.3.2 Phenological Change

During the later stages of the growing season, as L.A.I. reaches its maximum, spectral changes associated with cultivation or phenological changes of the developing crop may become the best indicators of potential yield. These spectral changes result from such events as plowing, irrigation, increase in ground cover, flowering, senescence and harvesting. Variations from normal schedules may indicate abnormal conditions which will affect yield. Late planting or harvesting, or variations in timing of maturation are examples of conditions which might have a bearing on yield. The capability of SEOS for critical timing of observations is a distinct advantage for observing and assessing such phenological change.

A.3.3.3 Plant Condition

A variety of factors may affect the yield available from a particular crop. These include plant disease, insect infestation, nutrient deficiencies, irrigation, flooding, drought, and storm or frost damage. If the physical extent of these effects is great enough, they can be detected from space. The oblique view of the fields, emphasizing vegetation as compared to soil, would increase the ability of SEOS to detect these changes early in the growing season. In addition, significant events could be observed within a few days at most, whereas the delays characteristic of an intermittent satellite system would be great enough in some cases to render the observation ineffective.

Some evidence exists that plant disease can be detected from space if the diseased areas are large enough in size. In one study it was found that areas of chlorotic sorghum of 1.1 hectares or larger could be detected.[12] The application of this ability to detect plant disease seems feasible for moderate disease levels, but only for widespread disease conditions.

Drought is one of the most important factors which can reduce yield. Detection of the effects of drought on crops may be difficult to detect directly unless the drought is prolonged. As a surrogate for moisture stress in crops, the condition of pasture may be observed instead, since pasture condition exhibits more variation with moisture availability than does crop condition.[11]

A.3.3.4 Operational System Features

The procedure for accomplishing yield prediction would begin by identifying crop type, field by field. The pixels identified as covering a given crop can then be analyzed with respect to those spectral characteristics that are related to yield. For this purpose, boundary pixels would have to be eliminated, even though this would degrade the quantitative analysis of yield.

The quantitative estimate of yield reduction will consist of associating a fractional yield reduction with certain spectral characteristics. Ground truth data collected at or near the same time as the space observation will be of major help in identifying yield-reducing conditions which can be used for analyzing the space data. Observations should be made of the fields currently used in the Crop Reporting Service sampling as well as selected fields where abnormal conditions are known to exist, such as disease infestation or hail damage.

Multi-temporal, multi-illumination, or oblique viewing, and critical timing of observations are the SEOS characteristics which could improve the accomplishment of the aforementioned functions. Even partial improvement of yield estimation data and added information of a qualitative nature should improve crop prediction accuracy. Regression analysis and change detection methods described for area estimation could also be used in yield forecasting.

A.3.3.5 Performance Assessment

As distinguished from the area estimation procedures, in which we anticipate that an independent estimate of a crop area would be made and combined with the ground-based estimate, it seems likely that yield prediction would be performed by directly using the additional information from space data to improve the ground survey prediction of crop yield.

Improvement in yield forecasting is expected to come about partly through earlier detection of changes. Observation from SEOS can be made for large areas within a few days, one way or the other, of a desired date. A single ERTS satellite might be subject to delays sufficient to eliminate the value of the resulting information. Compared with ground-based surveys, we may also expect the synoptic view of SEOS to improve the timeliness of available information on changing conditions over large areas. We will therefore assume that estimates of reductions in yield resulting from damaging agents under present forecasting schedules could be advanced by a matter of two weeks if critically timed observations from space are performed. Referring to Figure A-1 this may be accounted for by shifting the curve of decreasing yield forecasting error to the left by two weeks. This may then be interpreted as equivalent to a reduction in forecasting error. This time advantage might be even greater during the early part of the season if further research can establish reliable relationships between remote sensing observations on spectral characteristics of vegetation and values of yield per acre as discussed in Section A.3.3.1.

Improvement in yield forecasting would also come about through several additional means. Space data provides certain new types of objective information which are not presently used in ground-based surveys (i.e., spectral data related to vegetation density and plant stress), and therefore increases the total amount of information from which yield can be forecast. Through its synoptic view, it enables crop reporting personnel to detect the extent and severity of abnormal conditions, from which they can improve their sampling efficiency and subjective judgment in evaluating these conditions. It also provides a means of extrapolating ground-based survey data to larger areas, in effect increasing sample size. Finally, the same data will be useful for detecting and measuring incremental changes. Since these changes produce a relatively small percentage variation of total yield, even moderate success in detecting change will translate into fairly accurate evaluation of the changes in total yield.

In order to evaluate the value of space data, the advantages cited above must be expressed in terms of anticipated yield forecasting improvement. The ability to forecast yield cannot realistically take account of future events. Consequently, a reasonable expectation for yield forecasting improvement would be to reduce the yield forecasting error throughout the season by 25 percent of the error which occurs in the latest estimate prior to harvesting. In the case of U.S. wheat, where the October 1 yield forecast is in error by 1.07 percent, as shown in Figure A-1, this would amount to a reduction of 0.27 percent throughout the forecasting months. As distinguished from improvements in area estimation performance, the improvement of yield forecasts would cover the entire growing season.

A.4 IMPROVEMENT OF FORECASTING PERFORMANCE

Using the estimates of forecasting performance improvement mentioned in previous sections A.3.2.2 and A.3.3.5 as a basis for calculation, the potential improvement of U.S. wheat forecasting is shown in Figure A-3. To provide error data which could be directly compared, theoretical current and improved production error curves were computed from yield and area curves for each date plotted by determining the square root of the sum of the squares of the area percent error and the yield percent error. The theoretical current curve for production error of Figure A-3 therefore does not match that of Figure A-1 which was based on actual observations. The production errors of Figure A-3 are also recorded in Table A-1. The reduction for each date is approximately 20 percent.

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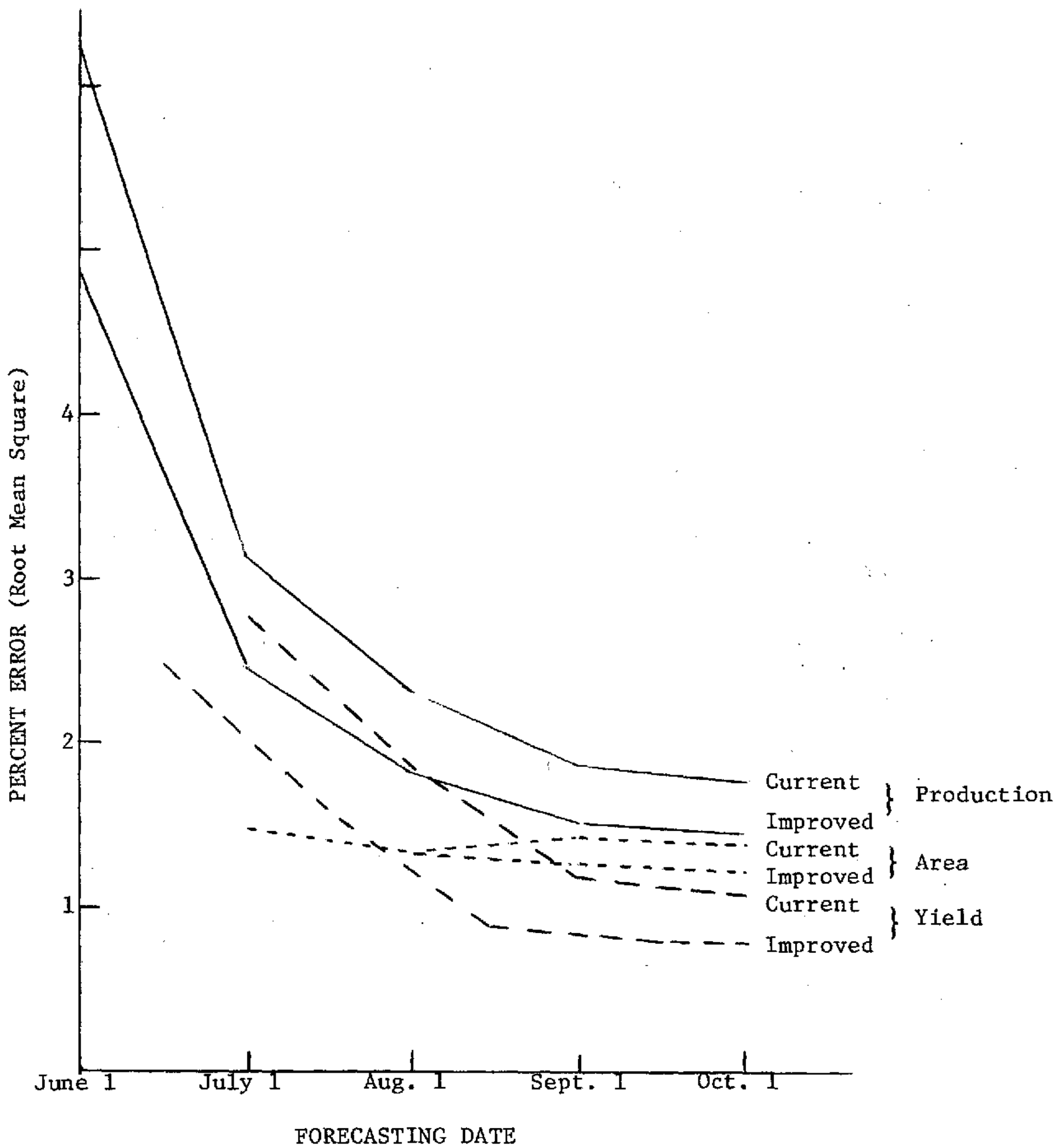

Figure A-3. PROJECTED IMPROVEMENT IN WHEAT FORECASTING

TABLE A-1. ASSUMED ERRORS IN PRODUCTION FORECASTS OF U.S. WHEAT

DATE	CURRENT FORECASTING (percent error)	IMPROVED FORECASTING (percent error)
June 1	6.25	4.86
July 1	3.19	2.46
August 1	2.28	1.80
September 1	1.85	1.50
October 1	1.75	1.44

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