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or probabilities. In actuality, most, if not all, inputs used in arriving at a decision are uncertain. If range meteorologists are forced to give "yes" or "no" meteorological inputs, then they are denied the option of expressing the degree of uncertainty. A single probability number may contain all the operator needs to know about the weather, its effects on a particular aspect of the mission objective, and the confidence of the meteorologist's in his forecast given a particular situation (Lyon and Leblanc, 1976). If the probability forecast is used as an input into an operational decision model, the usefulness should be even more impressive.

Since 1970, more and more defense agencies have learned to depend on operational decision models for assistance in making day-to-day decisions. Yet range meteorologists have been successful, perhaps reluctant, to make weather probabilities a part of the decisionmaking process. This document presents a methodology that will permit more complete and effective use of probabilistic planning and operational weather forecasts at the ranges. If implemented, this support information will provide considerable cost savings and increased scheduling efficiency to both users and range operators.

This document provides range meteorologists with an introduction to the basic concepts and operations of decisionmaking. It is not expected to make the reader an expert. Instead, the material will provide an awareness of the capabilities of operational decision models and typical situations where they should be used, and demonstrate to range customers the value of using meteorological forecasts in decisionmaking.

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PREFACE

Meteorologists have long been aware of the problem of providing meteorological information in a meaningful form for use by decisionmakers. Some decisionmakers will accept no meteorological advice while others insist on a "yes" or "no" determination regarding any question of the future state of the atmosphere, and a rare few will allow range meteorologists to present their forecasts in terms of probabilities. Obviously there will always be a degree of uncertainty in weather forecasts, therefore, it is imperative that decisionmakers be educated to accept weather forecasts which are provided to assist in the decision process in terms of probabilities. In actuality, most, if not all, inputs used in arriving at a decision are uncertain. If range meteorologists are forced to give "yes" or "no" meteorological inputs, then they are denied the option of expressing the degree of uncertainty. A single probability number may contain all the operator needs to know about the weather, its effects on a particular aspect of the mission objective, and the confidence of the meteorologists in his forecast given a particular situation (Lyon and Leblanc, 1976). If the probability forecast is used as an input into an operational decision model, the usefulness should be even more impressive."

Since 1970, more and more defense agencies have learned to depend on operational decision models for assistance in making day-to-day decisions. Yet range meteorologists have been unsuccessful, perhaps reluctant, to make weather probabilities a part of the decisionmaking process. This document presents a methodology that will permit more complete and effective use of probabilistic planning and operational weather forecasts at the ranges. If implemented, this support information will provide considerable cost savings and increased scheduling efficiency to both users and range operators.

This document provides range meteorologists with an introduction to the basic concepts and operations of decisionmaking. It is not expected to make the reader an expert. Instead, the material will provide an awareness of the capabilities of operational decision models and typical situations where they should be used, and demonstrate to range customers the value of using meteorological forecasts in decisionmaking.

ACKNOWLEDGMENTS

This report contains previously established methods and techniques for applying probabilistic forecasts in decisionmaking. Many of the terms and theories used have been taken from several sources listed in the bibliography. In fact, most of the material in Chapter 2 was adapted from Air Weather Service Pamphlet 105-51.

1.0 INTRODUCTION

1.1 General. The job of every range meteorologist is to provide the best meteorological support possible to customers. This report is an attempt to improve the capabilities of those providing meteorological advice for decision assistance.

a. Chapter 2 provides guidance on how to apply probabilistic weather forecasts in decisionmaking. The basic models are described along with some simple examples to explain the use of such models.

b. The contents of Chapter 3, which is the heart of this report, should grow with time. It contains proven cases of meteorological assistance in decisionmaking. In some of the cases, customers did not accept the advice even though the techniques were proven. In others, the customers gratefully acknowledged the support of their range meteorologists and have documented the cost savings resulting from that support. Chapter 3 will be expanded as more and more use the guidance in Chapter 2 (and other sources) and document their successes.

1.2 Background. It is assumed users of this document have a knowledge of statistics and can prepare probabilistic weather forecasts. The reference material listed in the bibliography will provide a source of reference for those who need further training or retraining. The text book by Panofsky and Brier and Air Weather Service Technical Report (AWSTR) 77-267 are very good sources for basic statistics review. Chapter 6 of Air Weather Service Publication (AWSP) 105-51 contains a helpful review of the forms of probability forecasts, i.e., Weather Impact Indicators (WII), and how WII can be used to predict the success of a particular mission (Mission Success Indicators (MSI)). A more detailed discussion of customer support using MSI is given in the referenced Air Weather Service Research Paper (AWSRP) 105-2.

1.3 Terms/Definitions. Basic terms and definitions are updated in Appendix A. It is recommended that readers review them now and use them as they work with this report. Some terms are included which are not mentioned in this report but used in several of the publications referenced.

2.0 PROBABILITY FORECASTING IN RANGE SUPPORT DECISIONS

2.1 Introduction. The range meteorologist can aid the Range Commander in effecting tremendous savings through the proper use of probabilistic forecasts when making weather-sensitive decisions. Since weather has a bearing on almost every facet of testing those systems designed to operate in the natural environment, the opportunity exists for a wide range of applications of probability forecasts. By the introduction of this kind of forecast and indoctrination of range personnel in its proper use, the range meteorologist can make a substantial contribution to his/her range's cost avoidance program. The national and military weather services are moving toward the increased use of probability forecasts, and all weather services are faced with similar problems of educating the customer. Range meteorologists, in particular, seldom find recipients of this kind of forecast well versed in the use of this information. The meteorologist thus has an inherent responsibility to furnish the guidance needed to use his/her forecasts most effectively (Glahn, 1964; Lyon and Leblanc, 1976). The objective of this guidance should not be to make the customer an expert in decision theory, which is a complete field of study in itself. This chapter provides most of what you need to present some of the simpler techniques which can be applied to weather-related decision problems. Specifically, it describes a general decision matrix, illustrates applications of the simple cost-loss model, defines critical probability, and demonstrates methods for calculating the value of forecast information. Brief examples illustrate the concepts introduced in this chapter.

2.2 General Decision Matrix. Decisionmaking under risk considers that one of two or more future events may occur, each with a specified probability. This can apply to meteorological situations in which the frequencies of the various future weather states are estimated or predicted, i.e., probability forecasts (Epstein, 1962). A matrix is the most convenient method for summarizing all the elements involved in weather decision problems. The generalized form of a decision matrix using expenses as a measure of value is shown in table 2-1. It can be used directly or may serve as the framework for developing specialized models.

Table 2-1. General Expense Matrix
(Murphy, 1976b)

ACTION	STATES OF WEATHER					EXPECTED EXPENSE (E)
	w_1	...	w_n	...	w_N	
a_1	e_{11}	...	e_{1n}	...	e_{1N}	$E_1 = \sum_{n=1}^N p_n e_{1n}$
.	.		.		.	
.	.		.		.	
.	.		.		.	
a_m	e_{m1}	...	e_{mn}	...	e_{mN}	$E_m = \sum_{n=1}^N p_n e_{mn}$
.	.		.		.	
.	.		.		.	
.	.		.		.	
a_M	e_{M1}	...	e_{Mn}	...	e_{MN}	$E_M = \sum_{n=1}^N p_n e_{Mn}$
PROBA- BILITY	p_1		p_n		p_N	

a. Explanation.

(1) In the general matrix, all possible courses of action, strategies, or decision options under consideration are listed in the left column, i.e., $a_1 \dots a_m \dots a_M$ ($m = 1, 2, \dots, M$). Under the states of weather, the notations $w_1 \dots w_n \dots w_N$ ($n = 1, 2, \dots, N$) represent the various weather thresholds which have an effect on one or more of the courses of action. For each action-state pair (a_m, w_n) there is a corresponding consequence or outcome (e_{mn}) which represents the expense that results for action a_m if weather state w_n occurs (Murphy, 1966).

(2) Each weather probability, P_n , represents the probability that the weather state W_n will occur. The sum of all the weather probabilities must equal one ($P_1 + \dots + P_n + \dots + P_n = 1$).

(3) Given the expense associated with each action-state pair and the probabilities of each state of weather, the long-term expected expense (E) can be calculated by using the equations in the right-hand column. For example, the expense E resulting from action a_1 would be computed as follows:

$$E_1 = P_1 e_{11} + \dots + P_n e_{1n} + \dots + P_N e_{1N}. \quad (2.1)$$

Assuming the decisionmaker wants to minimize his losses, the course of action selected is the one which yields the smallest value for E_m (Murphy, 1976b), i.e., the course of action which will cost the decisionmaker the least amount over the long-term, provided the probabilities are reliable.

b. Example. Consider the situation in which a range commander must decide between four forms of protective action for his aircraft when faced with the threat of a hurricane.

(1) Table 2-2 is a matrix showing how this decision problem would be set up. Four wind thresholds are listed under the states of weather. As structured, this type of model might help decide what action should be taken regardless of what is causing the threat of wind damage. Assuming the range commander wants to minimize expected costs, the costs associated with each consequence (e_{mn}) must be obtained and entered in the matrix. There may be many, but for this example we will consider only two types of costs.

Table 2-2. Incomplete Cost Matrix for Protection Against Wind Damage

ACTIONS	STATES OF WEATHER				EXPECTED COSTS (E)
	$W_1 = \text{WIND}$ <30 kts	$W_2 = \text{WIND}$ >30<50 kts	$W_3 = \text{WIND}$ >50<65 kts	$W_4 = \text{WIND}$ >65 kts	
$a_1 = \text{No Protection}$					
$a_2 = \text{Tie Down}$					
$a_3 = \text{Hangar}$					
$a_4 = \text{Evacuate}$					
PROBABILITY	$P_1 =$	$P_2 =$	$P_3 =$	$P_4 =$	

(a) First is the cost of taking each of the actions indicated. Assume that the figures given in table 2-3 reflect the costs obtained from the customer. They would include such factors as manpower required to tie down, hangar and unhangar aircraft; costs for evacuation; the flying costs to and from the refuge base with TDY expenses; and nonroutine costs generated by the action taken.

Table 2-3. Costs of Taking Protection Action
(Thousands of Dollars)

ACTION	W ₁	W ₂	W ₃	W ₄
a ₁	\$ 0	\$ 0	\$ 0	\$ 0
a ₂	1	1	1	1
a ₃	4	4	4	4
a ₄	120	120	120	120

(b) The other costs would be the estimated cost or losses as a result of damage when aircraft are not protected or when protection is inadequate. Table 2-4 will be used to represent these costs.

Table 2-4. Potential Losses Due to Wind Damage
(Thousands of Dollars)

ACTION	W ₁	W ₂	W ₃	W ₄
a ₁	\$0	\$300	\$1,500	\$12,000
a ₂	0	0	600	6,000
a ₃	0	0	0	1,500
a ₄	0	0	0	0

These figures would also be supplied by the customer.* As these values reflect, the potential loss varies with the degree of protective action taken and the severity of wind thresholds.

(c) To obtain the total costs or expenses associated with each consequence (e_{mn}) of the decision matrix, the corresponding values in tables 2-3 and 2-4 would be added. Table 2-5 shows the resultant matrix whose data are now ready to be applied to a decision problem.

Table 2-5. Cost Matrix for Protection Against Wind Damage Prior to Use
(Thousands of Dollars)

ACTION	STATES OF WEATHER				EXPECTED COSTS (E)
	W_1 <30 kts	W_2 >30 & <50 kts	W_3 >50 & <65 kts	W_4 >65 kts	
a_1 = No Protection	\$ 0	\$300	\$1,500	\$12,000	E_1 =
a_2 = Tie Down	1	1	601	6,001	E_2 =
a_3 = Hangar	4	4	4	1,504	E_3 =
a_4 = Evacuate	120	120	120	120	E_4 =
PROBABILITY	P_1 =	P_2 =	P_3 =	P_4 =	

(d) Assume a hurricane is threatening the installation (a possibility at two-thirds of the RCC ranges) and that the forecast probabilities for the different states at time of landfall, 24 hours from now, are as follows: $P(W_1) = 5\%$, $P(W_2) = 80\%$, $P(W_3) = 10\%$, and $P(W_4) = 5\%$.

Expected costs (E_m) would be computed as shown below:

$$E_m = P_1 e_{m1} + P_2 e_{m2} + P_3 e_{m3} + P_4 e_{m4} \quad (2.2)$$

*AWSP 178-2 provides guidance in computing cost figures. Standard cost factors are included in AFR 173-10, Vol I. Similar publications are available from other sources.

$$E_1 = (.05 \times 0.0) + (0.8 \times 300) + (0.1 \times 1,500) + (.05 \times 12,000) = \$990$$

$$E_2 = (.05 \times 1.0) + (0.8 \times 1.0) + (0.1 \times 601) + (.05 \times 6,001) = \$361$$

$$E_3 = (.05 \times 4.0) + (0.8 \times 4.0) + (0.1 \times 4.0) + (.05 \times 1,504) = \$79$$

$$E_4 = (.05 \times 120) + (0.8 \times 120) + (0.1 \times 120) + (.05 \times 120) = \$120$$

By entering the probabilities and expected costs in their appropriate matrix positions, the final decision matrix as illustrated in table 2-6 can be obtained.

Table 2-6. Final Cost Matrix for Protection Against Wind Damage
(Thousands of Dollars)

ACTIONS	STATES OF WEATHER				EXPECTED COSTS (E)
	W_1 <30 kts	W_2 >30 & <50 kts	W_3 >50 & <65 kts	W_4 >65 kts	
a_1 = No Protection	\$ 0	\$300	\$1,500	\$12,000	\$990
a_2 = Tie Down	1	1	601	6,001	361
a_3 = Hangar	4	4	4	1,504	79
a_4 = Evacuate	120	120	120	120	120
PROBABILITY	$P_1 = .05$	$P_2 = .80$	$P_3 = 0.1$	$P_4 = .05$	

(e) The decision rule assumed earlier is that the preferred choice is the course of action which results in the least expected cost. By using this rule, course of action a_3 (hangar the aircraft) is preferred for this set of probabilities. Different combinations of probabilities would yield different values of expected costs and, thus, different decisions. However, when one course of action affords total protection, such as evacuate (a_4), the expected cost (E) of that action will remain unchanged.

(2) Two key assumptions in this decision process are that the probabilities are reliable and the expected costs are long-term averages. The effect of the latter assumption can be illustrated by one of the computations for expected costs. Computation of E_1 shown under equation 2.2 above is repeated for illustration:

$$E_1 = (.05 \times 0.0) + (0.8 \times 300) + (0.1 \times 1,500) + (.05 \times 12,000) = \$990.$$

The first component of E_1 contributes nothing to the expected cost because there was no potential loss; i.e., no damage will occur as long as the winds are less than 30 knots. In the second component, the 0.8 means that 8 times out of 10 (reliable forecasts assumed) the wind will be within that threshold ($30 \text{ kts} < V < \text{kts}$). On each of those eight occasions the damage will amount to \$300K with no damage on the other 2 days (total = \$2400K). The average damage amount is \$2400K divided by 10 occasions or \$240K which is 0.8×300 . Similar reasoning applies to the remaining components. Thus, if the forecasts are totally reliable (bias = 0), average costs will equal the expected costs in the long-term. Otherwise, actual costs will differ in proportion to the net reliability error (bias).

2.3 Utilities. Money (dollar value) is the most common unit of value used to represent consequences of decision actions (e_{mn}). However, it is very difficult to assign a monetary value to many types of consequences such as loss of military readiness, political impact, loss of prestige, loss of human life, and reduced combat effectiveness in a conflict. In order to account for monetary value as well as nonmonetary factors, the term "utility" was coined as the unit of value of consequences when non-monetary factors are involved. Utility is an all encompassing term which reflects a decisionmaker's true value (preference or importance weight) associated with a given consequence or outcome (Murphy, 1976b).

a. Utility Matrices. A utility matrix takes the same form as that of the general expense matrix (table 2-1). The only difference is substitution of utility value (u_{mn}) for expenses (e_{mn}) for each consequence and expected utility (U) for expected expense (E). Utility values can be either positive or negative. The objective is to maximize positive utilities, such as profits or economic gains, and to minimize negative utilities.

b. Transformation of an Expense Matrix into an Equivalent Utility Matrix. In general, if a customer's utilities are linearly related to the respective expenses of the consequences, an expense matrix can be transformed directly into an equivalent utility matrix with an arbitrary scale ranging from 0 to 1. The equation for performing the transformation (Murphy, 1976a) is given by:

$$u_{mn} = (e_{mn} - e_L) / (e_M - e_L) \quad (2.3)$$

where:

u_{mn} = the utility value equivalent to expense e_{mn} (ranges 0 to 1).

e_{mn} = the expense value of the consequence being transformed.

e_L = expense value of the least preferred consequence.

e_M = expense value of the most preferred consequence.

By using this transformation, the most preferred consequence, e_M (the one of least expense) takes on the utility value, $u_{mn} = 1$ (the greatest utility). Likewise, the least preferred consequence, e_L (the largest expense), transforms to the utility value, $u_{mn} = 0$ (the least utility).

(1) Example. Table 2-7a is an abbreviated form of the general expense matrix shown earlier (table 2-1). We will use this table to demonstrate the transformation technique described above.

Table 2-7a. Abbreviated Expense Matrix

$e_{11} = -5.0$	$e_{12} = 70$	$e_{13} = 85$
$e_{21} = 5.0$	$e_{22} = 50$	$e_{23} = 90$
$e_{31} = 15$	$e_{32} = 30$	$e_{33} = 95$

From table 2-7a we find that the most preferred consequence (e_M) is e_1 , and the least desired (e_L) is e_{33} . In this example then, equation 2.3 takes the form:

$$u_{mn} = (e_{mn} - 95)/(-5.0-95) = (e_{mn} - 95)/-100 \quad (2.4)$$

Substituting values for e_{mn} , we obtain the equivalent utility values u_{mn} shown in table 2-7b.

Table 2-7b. Abbreviated Equivalent Utility Matrix

$u_{11} = 1.0$	$u_{12} = .25$	$u_{13} = .10$
$u_{21} = .9$	$u_{22} = .45$	$u_{23} = .05$
$u_{31} = .8$	$u_{32} = .65$	$u_{33} = .00$

(2) Such a transformation is useful for two reasons. First, it assigns the highest utility value (1) to the most preferred consequence and places the decision objective of maximizing utilities in a positive sense. Second, it establishes a standard scale from 0 to 1 to which the customer can better relate by using ratios to confirm whether or not the equivalent utilities do in fact reflect true preferences. If adjustments to the utilities are required, this scale simplifies and expedites the modifications.

2.4 General Cost-Loss Model. The literature on probability forecasting frequently makes reference to the "cost-loss" model. The cost-loss model is a very simple and specialized case of the general decision model given earlier. It provides a realistic description of situations faced by many decisionmakers and has been used extensively by meteorologists and others in the civilian community. This model was originally developed to describe a situation where the decisionmaker must decide whether or not to take protective action with respect to some activity or operation based on an uncertain forecast of adverse weather. However, it also has other applications when only two courses of action are under consideration (protect or not protect, go or no go). The basic cost-loss model assumes that protective action completely eliminates losses due to adverse weather. However, in many situations all resources cannot be protected; in others, the protective actions available to the decisionmaker only reduce the losses. A version of the general cost-loss model which accounts for unprotected losses is shown in table 2-8 (Murphy, 1976a).

Table 2-8. Matrix for the General Cost-Loss Model

ACTION	STATES OF WEATHER		EXPECTED EXPENSES (E)
	ADVERSE	NOT ADVERSE	
$a_1 = \text{Protect}$	$C + L'$	C	$E_1 = C + P_1 L'$
$a_2 = \text{No Protection}$	$L + L'$	0	$E_2 = P_1(L + L')$
PROBABILITY	P_1	P_2	

a. Terms. In this model the cost of protection is denoted by C , losses which are unprotectable by L' , and the protectable losses by L . No loss or cost results when no protection is taken and no adverse weather occurs.

b. Explanation. Expected costs are calculated like the general expense matrix, $P_1 = C + P_1 L'$ and $P_2 = P_1(L + L')$, since $P_1 + P_2 = 1$. Now assume the decisionmakers want to select protection which minimizes expected costs. We equate the two expected costs (L_1 and L_2) and solve for the probability associated with taking action P_1 . Thus, when $P_1 = C/L$ (the cost-loss ratio), the expected costs are equal. By the same

token, if $P_1 > C/L$, the expected cost is least for a_1 (protect). On the other hand, if $P_1 < C/L$, action a_2 (no protection) yields the least expected cost. Note that the unprotectable losses do not enter into the decision logic. For example, if this model was applied to a wind damage decision, such unprotectable items (L') as buildings, towers, fences, power lines, etc., would not be included unless they are afforded protection by the action taken. To make economic sense, the ratio C/L must have a total range between zero and unity. If C/L is greater than unity, the cost of protection would exceed the loss and, therefore, be uneconomical. Similarly, negative values of C/L are also economically meaningless (Thompson and Brier, 1955).

c. Example. Assume the test engineer has some wind sensitive targets set up for an extended period of air-to-ground tests. If winds speeds greater than 25 miles per hour occur, the targets will be destroyed at a cost (loss) of \$5000. However, the targets can be removed and stored in a hangar at a cost of \$500 for labor and materials. The most economical course of action can be determined by computing the cost/loss ratio (C/L) and comparing it to the probability of windspeeds greater than 25 miles per hour. For this situation, $C/L = 500/5000 = 0.1$. Therefore, the targets should be removed if the probability of winds greater than 25 miles per hour is more than 10 percent.

2.5 Critical Probability. In the discussion of cost-loss models, a decision rule was derived by which the cost-loss ratio determined the probability threshold above which protective action should be taken. Critical probability is an extension of the cost-loss ratio concept in that it can be applied to any two-by-two, action-state decision matrix.

a. Derivation. Critical probability (P_c) may be derived by using the procedures of the cost-loss ratio and given the consequences A, B, C, and D (in utility units) from tables 2-9a and 2.9b below, while remembering that $P_1 + P_2 = 1$.

Table 2-9a. Protection Matrix for Definition of Critical Probability

ACTION	STATES OF WEATHER		EXPECTED UTILITIES (U)
	Storm/ Rain	No Storm/ Rain	
a_1 = Protect	A	C	$U_1 = P_1A + P_2C$
a_2 = No Protection	B	D	$U_2 = P_1B + P_2D$
PROBABILITY	P_1	P_2	

Table 2-9b. Launch Matrix for Definition of Critical Probability

ACTION	STATES OF WEATHER		EXPECTED EXPENSES (U)
	Favorable	Unfavorable	
a ₁ = Go	A	C	U ₁ = P ₁ A + P ₂ C
a ₂ = No Go	B	D	U ₂ = P ₁ B + P ₂ D
PROBABILITY	P ₁	P ₂	

$$P_c = \frac{C - D}{B + C - A - D} \quad (2.5)$$

The decision rule for a critical probability is:

Act (a₁) if P₁ > P_c

Indifferent (a₁ or a₂) if P₁ = P_c

No Action (a₂) if P₁ < P_c

(1) Critical probability is the threshold or breakeven probability above which it is cost effective for a decisionmaker to take a specific action, i.e., the long-term positive utility (value, payoff, etc.) maximized and the negative utility (cost, loss, expense, regret, etc.) is minimized. It may be based on monetary value or other measures of utility. Note that the critical probability must be stated in terms of the weather event which causes the action to be taken. This is a subtle but important point and the reason two different examples are given. In the first matrix, action is taken when unfavorable or adverse weather (storm, rain, etc.) threatens. But in the second case, the action is associated with favorable weather.

(2) Equation 2.5 reduced to P_c = C/L for the general cost-loss model.

b. Matrix Example. Consider a test flying operation as depicted in the matrix of table 2-10. This is a range mission in support of a customer who is supplying some TDY test personnel.

Table 2-10. Test Flying Matrix (Dollars)

ACTION	STATES OF WEATHER		EXPECTED EXPENSES (E)
	Favorable	Unfavorable	
$a_1 = \text{Fly}$	$A = + 1000$	$C = -5700$	$E_1 = 1000P_1 - 5700P_2$
$a_2 = \text{Standdown}$	$B = - 1200$	$D = -1200$	$E_2 = 1200P_1 - 1200P_2$
PROBABILITY	P_1	P_2	

(1) Definitions.

A is the benefit realized by the customer when the weather is favorable and the mission goes. In this case, the benefit less operating costs was \$1000.

B is the cost (negative benefit) incurred if the test stands down and the weather is favorable -- a lost opportunity. Assume a missed testing day costs \$1200 in additional TDY funds for the test personnel.

C is the cost or loss if the customer takes action, but because of unfavorable weather cannot accomplish the mission (aborts). Each test mission is a 1.25-hr flight by an F-4. Assuming the mission is aborted because of unfavorable weather over the test site, the costs would be \$4500 (1.25 hrs X 3600/hr) plus \$1200 for another TDY day (total \$5700).

D is a cost or benefit. If there is a cost for mission delay, it is a cost. If a delay has no cost, the abort cost can be saved and D is in effect a cost avoidance benefit (correct standdown). In this example, the customer considers this a delay cost of \$1200.

P_1 is the probability that no weather factors (ceiling, visibility, wind, hazards, etc.) will cause mission cancellation, abort, or failure from launch to recovery. This is called a tailored probability forecast. Recall that $P_1 + P_2 = 1$ and therefore, $P_2 = 1 - P_1$.

(2) Explanation. By using equation 2.5, the critical probability for this example is:

$$P_c = \frac{-5700 + 1200}{1200 - 5700 - 1000 - 1200} = .67$$

Thus, the decision rule for this decision problem is:

Fly if $P_1 > .67$

Indifferent if $P_1 = .67$

Standdown if $P_1 < .67$

Referring to the matrix in table 2-10, the expected expense for each mission will equal \$1200 when the probability of favorable weather is $P_1 \leq .67$, and gets smaller as P_1 increases.

(3) Transformation to utilities. In the example above, the critical probability of 67 percent will result in a significant number of missed opportunities. Suppose the supported agencies complained about the recent number of cancellations due to weather and stated that it is essential for their test project to complete 12 missions during the next 20 days. Faced with this situation, the range meteorologist agrees to help work out a compromise in the critical probability used for making their launch decisions.

(a) Applying the utility transformation equation (2.3) to the expense matrix (table 2-10), the meteorologist prepared an equivalent utility matrix (table 2-11) and showed it to the test agency. Test agency personnel were appalled by the importance weight indicated by the utility value ($B = .67$) for a standdown with favorable weather (missed opportunity). They were satisfied with the most preferred ($A=1$) and least preferred ($C=0$) consequences, but the other two did not reflect their true preferences in the present situation. After discussion between the range meteorologist and personnel from the supported agency and range test operations, consequence B was adjusted to a value of 1.0 because this consequence was now considered nearly as undesirable as the least preferred consequence. This action should significantly reduce the number of missed opportunities and satisfy the supported agency. Consequence D was also adjusted to a lower value (0.6).

Table 2-11. Test Flying Equivalent Utility Matrix

ACTIONS	STATES OF WEATHER		EXPECTED UTILITIES (U)
	Favorable	Unfavorable	
$a_1 = \text{Fly}$	$A = 1.0$	$C = 0.0$	$U_1 = P_1$
$a_2 = \text{Standdown}$	$B = .67$	$D = .67$	$U_2 = .67$
PROBABILITY	P_1	P_2	

(b) With these adjustments in utilities (table 2-12), a modified critical probability was calculated as follows:

$$P_c = \frac{0.0-0.6}{0.1+0.0-1.0-0.6} = 0.4$$

Therefore, the new decision rule becomes:

Fly if $P_1 > 0.4$

Indifferent if $P_1 = 0.4$

Standdown if $P_1 < 0.4$

Range test operations personnel state that they are much more comfortable with this decision rule because it reduces the number of lost opportunities and should help satisfy the needs of the supported agency.

Table 2-12. Modified Test Flying Utility Matrix

ACTIONS	STATES OF WEATHER		EXPECTED UTILITIES (U)
	Favorable	Unfavorable	
$a_1 = \text{Fly}$	$A = 1.0$	$C = 0.0$	$U_1 = P_1$
$a_2 = \text{Standdown}$	$B = 0.1$	$D = 0.6$	$U_2 = 0.1P_1 + 0.6P_2$
PROBABILITY	P_1	P_2	

c. Other factors. Many other factors can be incorporated into the test flying matrix. For example, the customer may not be another DoD agency, but a contractor. In such cases, TDY costs can be stated in terms of relief of the contractor from penalties if the contract is not completed in time due to unfavorable weather. Still another matrix can be devised, one not restricted to flying costs. This might add the expense of operating theodolites and radars, range crews, and data reduction requirements to aircraft costs.

d. Merits of Using Critical Probabilities.

(1) The obvious advantage of using critical probabilities in decisionmaking is that they can be predetermined by the decisionmaker and appropriate action implemented whenever the critical probability threshold is exceeded. Thus, some decisions can be made without direct involvement by the decisionmaker.

(2) The use of monetary value is a good starting point for determining critical probability. When actual values are not available, rough approximations are usually adequate. The accuracy of the critical probability need not be any more than one-half the value of the probability intervals used in making the forecasts. That is, if forecasts are made up 0-19, 20-39, 40-59, 60-79, 80-100, the critical probability needs to be correct to within 10 units of the actual critical probability.

(3) Critical probabilities can be adjusted either objectively or subjectively as priorities and other factors that affect the decision change. For example, a test director may establish a critical probability for use when test missions are on schedule, but if testing falls behind schedule, a lower value (depending upon the number of missions needed and time remaining) can be substituted.

(4) If a customer is opposed to using probability forecasts directly, critical probabilities furnish an alternate, but formal, way of providing tailored categorical forecasts. Rather than using 50 percent as the threshold for deciding whether or not an event will occur, the critical probability may serve as the threshold. In the long run, the resultant decisions will be more cost-effective than conventional categorical forecasts.

e. Problems in Using Critical Probabilities.

(1) A customer's critical probability may be outside the limits within which reliable forecasts can be reasonably assured. In such a case, the customer should be making decisions based on climatology.

(2) Forecasters may let the value of the critical probabilities influence the value of their forecast probabilities. Beware of this fixation because there may be occasions when a customer changes the critical probability without the forecaster's knowledge.

3.0 EXAMPLES

Specific applications of probability forecasting and decision assistance vary from range to range. Examples of either or both should be made available to those at the other ranges so that they may profit by the knowledge and success experienced by each other. While every example may not be directly applicable to your range, it may trigger an idea on how to do the job better. This chapter is expected to grow rapidly with your help.

3.1 ARMAMENT DIVISION (AD)

3.1.1 Situation

a. The AD (formerly the Armament Development and Test Center) has a centralized scheduling Directorate office which coordinates all test and training missions for the Division. This Test Engineering Directorate (TED) does not consider weather forecasts in its original request for missions over the Eglin AFB land and water range complex. The schedule is printed several days prior to the valid period which precludes accurate weather forecasts as input data. At noon on the day prior to tests (rundown), the schedule is finalized. Some flexibility exists at this point which can allow missions to be cancelled or added, or objectives changed.

b. The engineers responsible for tests coordinate at their discretion with the duty forecaster as their respective test period approaches but rarely cancel based on forecasts. As of this writing, the AD charges range users only if they use the range. This encourages engineers to wait until the last minute before cancelling or changing test objectives. Since the range is vast and many resources are committed several hours in advance, most last-minute changes must be minor.

c. The AD meteorologists are convinced that test scheduling and mission success rates can be improved by coordinating weather forecasts along with other parameters in the scheduling process at rundown time. This would allow more flexibility to cancel and add missions or to better coordinate test objective changes. To this end, the meteorologists began in March 1977 to issue planning forecasts (PF's) every morning. Each PF was valid for the following day from 0600 to 0000L. The hard-copy forecasts contained normal forecast parameters in standard coding and additionally provided probabilities of occurrence for ceilings greater than 1,500, 3,000 and 10,000 feet; visibility greater than 1, 3 and 7 statute miles; no rain; no TSTM; no fog; and surface wind less than 25 knots (see figure 3-1-1). These forecasts were sent to TED to assist in the daily test scheduling process.

3.1.2 Results

a. Although the PF was not used in the scheduling process as intended, it became widely accepted. By July 1977 the TED was reproducing 17 copies which were distributed to Test Engineering offices and posted in sections for use by test engineers. These forecasts alerted engineers to weather factors which might affect scheduled tests. Further reproductions of the forecasts were common, although the distribution/reproduction chain was not traced further.

b. An attempt (unsuccessful) was made to prove to the Test Wing that the weather forecasts could save it money. The 4-month period December through March 1978 was chosen for the exercise, and only periods when the weather was observed or forecast to be less than 12,000/6 (12,000-foot ceiling and < 6 miles visibility) were looked at. This narrowed the scope of the analysis to days when the weather could affect test missions.

EGLIN AFB WEATHER Test Planning Forecast for

18 April 1978 Tue

LOCAL TIME	CLOUDS - VISIBILITY - WEATHER - WINDS	PROBABILITIES OF:									
		CEILING (greater than)		VISIBILITY (greater than)			NO RAIN		NO TSTM		SFC WIND 25KTS
		1500	3000	10, 000	1	3	7			NO FOG	
		1500	3000	10, 000	1	3	7			NO FOG	
06 TO 10	6SC 010/030 6CI 250/300 3F 1305	3	2	1	6	4	1	8	9	4	9
10 TO 13	5SC 030/050 6CI 250/300 7 1610	6	5	4	8	7	6	8	9	7	9
13 TO 18	2SC 030/050 2AS 100/120 5CI 250/300 7 1810	8	7	6	8	8	7	7	8	8	9
18 TO 00	5SC 030/050 5SC 100/130 8CI 250/300 7 1805	7	5	3	8	7	6	6	8	7	9
TO											

REMARKS: Early morning fog and stratus. A trough moving into the area will cause increasing cloudiness with a chance of rain.

Figure 3-1-1. Weather Forecasts Schedule

DET TO FORM 0-17
MAR 79

Each test mission scheduled during this period was monitored to determine if the forecast (based on the test engineers' requirements) was either good or bad. Those requirements changed from test to test.

c. Table 3-1-1 summarizes the 248 test missions evaluated.

Table 3-1-1. Test Mission Summary

FORECAST	OBSERVED	
	GOOD	BAD
GOOD	127	48
BAD	16	57

(1) The weather for 127 missions was correctly forecast when the tests were conducted successfully or could have been conducted successfully during days when the weather was forecast or observed to have conditions less than 12,000/6. It is significant to note that this number would be much larger if clear weather days had been included in the analysis. Knowledge of good weather conditions correctly forecast is important, but was excluded to make this analysis tougher on the meteorologist.

(2) The weather for 57 missions was forecast correctly when the missions were not conducted due to adverse weather. All of these missions could have been cancelled at 1200 the day prior to the scheduled test period or preparations begun as a result of changes in mission objectives. This figure is probably low because test engineers used the PF to change some mission objectives and conducted successful missions that would otherwise have been cancelled.

(3) The weather for 48 missions was forecast to be good when in fact it was too poor to conduct the tests. This figure represents aborts for the crews and missed opportunities for the meteorologists to provide accurate forecasts.

(4) The weather for 16 missions was forecast bad and the observed weather was good. If tests had been cancelled because of the PF, these 16 missions would have been lost opportunities. Table 3-1-1 figures look bad for the met team until the costs for these 248 missions, based on the weather forecasts versus the "fly-them-all" attitude that existed before, are considered.

3.1.3 Value analysis

a. Proponents of the "fly-them-all" attitude say: "if you can take off 'go,' try the mission because the forecaster might be wrong and you can get a successful mission." As can be seen from table 3-1-1, that is true for 16 cases but very false for 57 cases.

b. To compare values, the costs for missions, set up, per diem, etc., were needed. These costs were not available since the missions were different and the test times variable. However, the meteorologists and the test engineers came to a temporary agreement on the data in table 3-1-2.

It was assumed that there was no value to a forecast that allowed the mission to proceed, since that was the standard philosophy -- "fly-them-all." There is room for argument about that assumption, although it is of no consequence here. In addition, it was presumed that if the crew flew a mission based on a forecast of good weather and had to abort, at least \$10,000 would be lost. Also, if a forecast of bad weather caused a mission cancellation 24 hours in advance, and the weather was good, at least \$2000 would be required for per diem, rescheduling, etc. Lastly, if the forecast of bad weather caused a mission cancellation, and the weather was indeed bad, \$5,000 could be saved in fuel, repairs, wasted preparations, etc.

Table 3-1-2. Observed States of Weather

ACTION	GOOD	BAD
FLY	0	-\$10,000
STAND DOWN	-\$2,000	\$ 5,000

c. Based on these figures and those in table 3-1-1, the Division incurred no cost (additional) for the 143 (127+16) good weather periods. Conversely, the 105 missions during the bad weather periods (48+57) cost \$10,000 each, with no usable data, for a total cost of \$1,050,000.

d. Using the cost figures and assuming the missions were flown based only on the weather forecasts (table 3-1-1), \$480,000 was expended for 48 missions that had to abort; \$32,000 for 16 lost opportunities; and \$285,000 was saved on 57 missions that were properly cancelled because bad weather was correctly forecasted. This represents a net cost of \$227,000.

e. Although the actual savings that could have resulted are still unknown, a potential savings of \$823,000 (\$1,050,000 minus \$227,000) was enough evidence to convince the test engineers to take a harder look at the PF provided one day in advance of each mission. A year later there are still very few missions cancelled 24 hours in advance, more test objectives are changed (fly the high profile tomorrow because low clouds are forecast, etc.), and many more requests for tailored forecasts are received. AD meteorologists hope to refine the PF and eventually provide tailored forecasts for each test through the use of utility matrices and critical probabilities.

3.2 EASTERN TEST RANGE (ETR)

3.2.1 Introduction

As part of the support provided to the Eastern Test Range, Detachment II (Det II) has been forecasting launch conditions for the Navy's Trident missile development program. The most critical constraint is acoustical propagation, a safety factor based on the damaging overpressures which might occur should a missile explode immediately after liftoff. Temperatures, lapse rates and component winds are the important factors in determining the rate and direction of sound propagation and the likelihood that "blast focusing" could result in damage to nearby civilian property.

When the Trident launches began in January 1977, Det II personnel briefed their customers on the expected conditions and provided a go/no-go forecast. This satisfied Navy personnel because they assumed Det II met people were completely confident of their forecasts, but they were not pleased if any of their forecasts were less than precisely accurate.

To improve service, Det II switched from go/no-go forecasts to a probabilistic format beginning with the Trident launch on 12 April 1978. It quickly developed that the Navy would try to launch if provided go conditions higher than 10 percent. Although Det II made the change to numbers, customers continued to interpret the numbers in a go/no-go fashion. This mode still did not allow the flexibility to communicate; an important benefit of probabilistic forecasting.

With the Trident launch on 11 August 1978, Det II inaugurated a different form of probabilistic forecasting. The percentages the met people used were those that communicated true confidence in their forecasts. For the first four or five briefings Det II personnel had to stop and explain, in very basic language, exactly what the new numbers meant since they were generally much higher than the numbers previously used. A 20 percent chance of go conditions would be described as a go condition during the the launch period on only 1 of 5 days with similar synoptic conditions.

The Navy and ETR decisionmakers reacted well to the new forecast format. After the first few briefings they began to seriously apply the weather inputs Det II provided. On a day with no other demands on Range use, they would elect to attempt to launch on a low probability forecast. While on other days, with the same forecast but when other Range users were available, they would not attempt to launch.

This attempt at probabilistic forecasting was limited because the customer made no inputs - it was purely a forecaster-derived number reflecting his/her confidence in the forecast. What was missing was an input from the customer describing in cost or utility terms the effect of favorable or unfavorable weather on the decision to count or hold. Without customer inputs, no critical probability could be determined above which the Navy would launch or below which the Navy would hold. The percentages Det II met personnel had been providing lacked consistency between forecasters and were still very subjective.

3.2.2 Probability Matrix

Although the land-launched Trident program is now over, a probability matrix could have been used. The analysis follows:

a. Two cost factors were used from the 3 September 1977 value analysis: Cost of a Trident countdown = \$81,000; Overhead cost for keeping the range up but not fully manned for a countdown = \$19,000.

b. The Launch Matrix for Definition of Critical Probability is contained in table 3-2-1.

Table 3-2-1. Launch Matrix for Definition on Critical Probability

ACTIONS	OBSERVED STATES OF WEATHER		EXPECTED EXPENSES (E)
	Favorable	Unfavorable	
Count	A = 81	C = 162	$E_1 = AP_1 + CP_2$
Don't Count	B = 100	D = 100	$E_2 = DP_1 + DP_2$
	P_1	P_2	

A = Cost of counting down a missile and launching it (most desirable occurrence)

B = Overhead cost of having range ready and not counting for 1 day, plus the cost of a full count for launching the next day (represents missed opportunity)

C = Cost of a full count with no launch, plus the cost of a full count for launching the next day (least desirable occurrence)

D = Basically same as B; Overhead, plus cost of count during launch day (represents area of greatest potential savings)

P = Probability a given weather condition will occur

c. The key number needed is the Critical Probability, P_c . This represents the probability threshold at which a count/don't count decision should be made. In this matrix:

$$P_c = \frac{C-D}{B+C-A-D} = \frac{162-100}{100+162-81-100} = \frac{62}{81} = .77$$

This means: Count if $P_C > .77$

Indifferent if $P_C = .77$

Don't Count if $P_C < .77$

d. There are some problems with this key number. Not counting with a value near 0.7 would not be acceptable to the customer because if an opportunity is missed it might be days before another favorable day. To handle this problem, translate the dollar figures into terms of utility. Do this by using the formula:

$$u = \frac{e - e_L}{e_m - e_L}$$

Where: u = utility

e = expense of consequence being transformed.

e_L = expense of least desirable consequence.

e_m = expense of most desirable consequence.

The previous matrix had: $A = 81$ $C = 162$

$B = 100$ $D = 100$

The most expensive consequence, C, becomes e_L and the least expensive consequence, A, becomes e_m . By letting e equal 81, 100, 162, and 100, the new matrix becomes:

$A = 1.0$ $C = 0.0$

$B = .77$ $D = .77$

With this matrix, the most desired consequence has a utility of 1.0 and the least desired consequence, a utility of 0.0. The others lie somewhere in between.

e. If .77 is too high for P_C as far as missed opportunities go, reassign a new utility for B that more closely reflects the customer's thoughts. For Trident, a missed opportunity (B) is only slightly more desirable than counting during unfavorable conditions (C). If, in coordination with the customer, B was lowered from .77 to 0.1, the new critical probability would become:

$$P_C = \frac{C-D}{B+C-A-D} = .46$$

This, as it turned out, was more aligned with Det II customers' desires and comprised a more realistic countdown decision parameter. This form of probability matrix is called a Modified Equivalent Utility Matrix.

f. There are some obvious problems in applying the above analysis directly to countdown decisions. The cost figures would be significantly greater when holding a launch for extended periods, as was frequently the case. However, the principle of the probability matrix remains since the utility terms can be modified to an acceptable compromise value to account for these extended holds.

3.3 WESTERN TEST RANGE (WTR)

3.3.1 Introduction

The Western Space and Missile Center (WSMC) manages the Western Test Range (WTR) which extends from the launch site at Vandenberg AFB, CA, to the Indian Ocean. The weather is extremely important when R&D ballistic missile launches are planned because of uprange, midrange and downrange weather constraints. Activation of all facilities and sensors necessary to support such a complex launch must begin several hours before scheduled launch time. If the operation is scrubbed late in the countdown, thousands of dollars (in some cases hundreds of thousands) in range costs are expended with no payoff. To avoid these costly "weather scrubs," WSMC began using probability forecasts for decisions to activate the range and continue a countdown. A very special mission required met personnel to increase their efforts in this area and the results were outstanding.

3.3.2 Background

The Minuteman Natural Hazards Program involved six launches of specially designed re-entry vehicles from Vandenberg into predetermined and precisely defined weather conditions in the Kwajalein impact area. A prime objective was to evaluate RV performance and to relate that performance to the meteorological conditions encountered by the RV's. The success of each of the six flights was essential for accomplishment of the overall program objective. Since each test could only be conducted during the occurrence of certain weather conditions in the impact area, test planners were faced with the problem of how to determine the best times to schedule range support. To activate the ranges and begin the missile countdown at random times or repeatedly on a day-by-day basis would have resulted in an enormous expense and would have required virtually full-time dedicated support by range resources that were required to support other programs. Weather probability forecasts were therefore relied upon to limit activation of WSMC and other support range resources to those times when there was a reasonable likelihood that the necessary weather conditions would occur.

3.3.3 Weather Severity Index

A weather team composed of a Minuteman Special Projects Office (SPO) representative, the WSMC meteorologist, and other technical consultants prepared probability forecasts and go/no-go recommendations which were briefed to key test personnel at Vandenberg via telephone conference at critical decision points. This usually occurred 12 hours before the scheduled launch time. Based upon the weather team's recommendations, test planners would either activate the resources of all ranges involved in the test and begin the countdown, or reschedule the test and plan to evaluate the situation at the critical decision point for the new launch window. Conventional weather forecasts were of limited value for those tests. A critical parameter upon which decisions were based was a Weather Severity Index (WSI), a complicated function of the liquid water content, ice water content, and ice crystal structure in the re-entry corridor. This number could be directly related to expected re-entry vehicle performance. The WSI was extremely variable spatially and temporally because

of the frequent convective shower activity in the area. Probability forecasts were issued based on the predominant cloud features expected, the amount and duration of expected convective activity, and the forecaster's confidence. Conventional meteorological data, plus data from instrumented aircraft and special radar equipment, were used to verify the forecasts.

3.3.4 Setting Thresholds

It became apparent very early in the test series that the "bad" weather requirements (those calling for large WSI values) would be difficult to satisfy. In order not to miss an opportunity, it became necessary to "threshold" at a very low probability value. For the high WSI launches, go decisions were generally made if the probability of success was greater than about 20 percent. In retrospect, when the tests were successfully concluded, it was determined that the high WSI values occurred only .10 percent of the time, so the 20-percent threshold-value was reasonable. (This is an important concept for those who use probability forecasts to understand. If the climatological expectancy of the desired weather is small and the mission urgency is high, thresholds should be set low so an opportunity will not be missed. If, on the other hand, the weather is easy to obtain and/or the mission urgency is not great, thresholds should be set high so that resources are not wasted. The decisionmaker should set these threshold values in advance, although real-time adjustments will sometimes be necessary.)

3.3.5 Innovations

Two innovative procedures were developed as a result of WSMC's involvement with the Minuteman Natural Hazards Program. Since the high WSI requirements were hard to satisfy and since there was normally a large spatial variation in WSI values, a real-time retargeting capability was developed that allowed targeting of the RV's into any one of three widely separated impact areas as late as 20 minutes before launch. Using the sampling aircraft and radar, the weather team could then make last-minute recommendations as to which target was to be used. The second innovation was implemented to use the range resources more efficiently.

Again, since high WSI values ("bad" weather) were hard to find and low WSI values ("good" weather) were relatively easy to find, WSMC adopted the practice of scheduling high and low WSI missions for the same time and then making a decision based on the probability forecasts made 6 to 12 hours prior to launch as to which mission would be activated. With this procedure, seven "good" weather launches were completed during a period when "bad" weather launches had the highest priority. Thus, WSMC avoided a potentially serious scheduling problem that could have adversely impacted other range users' programs.

3.3.6 Results Achieved

Over a period of 14 months, 6 Minuteman Natural Hazards Program launches were successfully completed with 13 actual countdowns, 7 of which were terminated prior to launch because the weather criteria could not be satisfied. If we assume that without special weather probability forecasts

and reasonably established threshold values, the ranges would have been activated each time a launch was scheduled and scrubbed late in the count if criteria could not be met, 31 attempts would have been required. A documented value analysis has shown that by avoiding 18 unsuccessful countdowns through the use of weather probability forecasts, a net avoidance of \$3,200,000 in range support costs was achieved for this program.

4.0 IMPLEMENTATION AND CAPABILITIES

4.1 Deficiencies and Recommended Improvement Areas

Deficiencies in Probabilistic Meteorological Decision Assistance occur in two primary areas: implementation and capabilities. To be effective, the implementation of probability forecasts must proceed through four phases: development, testing, evaluation, and operational use. These phases take time, direction and funding. The decision to allocate resources to develop probability forecast capabilities must come from levels high enough to fund for these resources. The decisionmakers must believe that the benefits of increased capability are worth the costs of the capability. Long-range accuracies must indeed demonstrate that users can decrease risk of loss. Studies such as those in Chapter 2 of this document serve as a good starting point.

4.2 Meteorological Probabilities

Although meteorological probabilities are used operationally within the National Weather Service, they are not generally employed within the DoD and, in particular at DoD Test and Evaluation Ranges. For them to be employed would require training programs for the meteorological personnel involved. Such programs would consider the weather parameters of interest, a climatology of these parameters, the impact of these parameters on the customer's mission, and the techniques for assessing the probability of occurrence of these parameters. The customer also must be trained to understand the meaning of the event forecast. Most of the current misunderstandings of probability forecasting on the part of the public stems as much from the uncertainty of the meaning of the event (for example, precipitation at a point as opposed to precipitation over an area) as it does from the uncertainty of the meaning of the probability. Furthermore, the customer must understand the impact of various weather elements on the operations in question, and must be able to put dollar values on the impact of these weather occurrences in order to assess actions to be taken when specific probabilities are forecast.

4.3 Centralized Facilities Vs. Field Activities

A decision must be made on whether probability forecasts will be developed from centralized facilities, in the field, or a combination of the two. Conceivably probabilities can be issued for large areas by a centralized facility and modified by field forecasts for local use. A possible innovation would be the incorporation of the Air Weather Service's Output Statistics (MOS) into range probability forecasts. However, MOS and similar data need to be tested and verified for accuracy before routinely accepted and used.

4.4 Climatological Data

Finally, there are deficiencies in climatological data and other baseline information which could be applied to assess the operational effectiveness of new high-technology systems. Such environmental variables as

infrared and microwave transmissions, exceptionally long-range visibility, refractive index, stability index, and optical turbulence fall into this category. Information on these elements is already being sought, but the availability is nearly negligible except in a very few areas convenient to laboratories. An alternative would be to establish correlations among these elements and the standard observables (temperature, humidity, cloud cover, visibility, etc.) for which extensive climatologies are extant. Unfortunately, there is much disagreement on the potential effectiveness of such a program. Again, the decision to establish programs such as these must be deferred to those empowered to allocate funds.

APPENDIX A

TERMS EXPLAINED

1. Probability. The chance that a prescribed event will occur, represented as a number ranging from 0 to 1. The probability of an impossible event is 0.0, that of an inevitable event is 1.0. The percentage equivalent (0 to 100 percent) is frequently substituted when discussing probabilities; however, the decimal equivalent (0 to 1) should be used when performing mathematical computations.
2. Climatological Probability. The probability that an event will occur based on extensive historical observations or experimental data. The simplest form of climatological probability (commonly called climatic frequency) is the number of occurrences of an event divided by the sum of the number of occurrences and nonoccurrences over a given time period. More complex forms of climatological probability frequently use climatic models when historical observations are not available. In these cases, the models are used to obtain estimated climatological probabilities of the desired event.
3. Sample Climatological Probability. The climatological probability based on observations that are made only during a sample period. Examples are climatological probabilities based on one month's data.
4. Objective Probability. The probability that an event will occur based on a fixed set of rules which produce a unique and reproducible outcome. The rules may be derived by empirical or theoretical considerations or a combination of both.
5. Subjective Probability. A personal estimate of the probability that an event will occur. Subjective probability estimates give good results if the individual knows the forecast problem (dynamics of the situation, climatology of the event, etc.) and is aware of basic probability laws and limitations of forecast skill. Subjective probability forecasts may not be reproducible.
6. Event. A specific occurrence that is defined by a weather element(s), time, location, and/or duration; e.g., visibility less than 1 mile in the period 1700-2000Z lasting more than 30 minutes at Scott AFB. Some events do not require all of the above specifications, e.g., rain at Offutt AFB at 0600Z.
7. Probability Forecast. Meteorological advice consisting of two parts--a well defined weather event and the expectation that the event will occur.
8. Post Agreement. A measure of how often an event occurs when it was forecast (forecast hits divided by total forecasts). This is a measure of categorical forecasting reliability.

9. Prefigurance. A measure of how often an event was forecast when it occurred (forecast hits divided by total occurrences). This is a measure of categorical forecasting capability.
10. Correlation. The measure of how well the forecasts agree with the observed weather. Correlation values range from 0 to +1, where -1 is perfect negative correlation, 0 is no correlation, and +1 is perfect positive correlation (Reference AWS TR 75-259).
11. Sharpness. The degree of certainty of a probability forecast. A set of forecasts containing only 0 percent and 100 percent probability values has perfect sharpness. Zero sharpness occurs if all forecasts are for a probability value equal to the sample climatology.
12. Reliability. The degree to which forecast probabilities resemble the observed frequency for each forecast probability value or interval. For example, an event would occur 80 percent of the time for a series of perfectly reliable 80 percent probability forecasts.
13. Decision Theory. A set of rules designed to use probabilities and other information to make an optimal decision: information about the state of nature (a weather forecast), and information (utility, value, expense, regret, etc.) on the outcome (consequence) of the decision. This information is usually given in the form of a utility matrix.
14. Utility. The value a decisionmaker associates with a given outcome with respect to other possible outcomes. It may be based on monetary value alone, or other factors which influence the decisionmaker's order of preference for the outcomes.
15. Utility Matrix. (Also called decision matrix, cost-loss matrix, expense matrix, payoff matrix, value matrix, etc., depending upon the writer and the way outcomes are quantified). A two-dimensional array arranged in rows and columns. Normally, rows represent possible courses of actions (strategies, options, decisions) and columns represent the different states of nature (weather categories or thresholds). Entries at intersections of each row and column represent the outcome (utility, cost, loss, expense, payoff, value, regret, or opportunity) associated with each course of action and state of nature pair.
16. Critical, Threshold, or Breakeven Probability. The probability above which it is cost or mission effective for a decisionmaker to take a specific action, i.e., the long-term positive utility (value, payoff, etc.) is maximized and the negative utility (cost, loss, expense, regret, etc.) is minimized. Critical probability serves as the threshold which, when exceeded, generates a decision to act. It may be based on monetary value or other measures of utility. When weather is the only factor affecting the decision, the critical probability must be stated in terms of the weather event which will cause action to be taken, e.g., hangar aircraft when the probability of hail exceeds a critical probability of 10 percent. When other variable, nonweather mission factors affect the decision, the customer may use a critical probability stated in terms of mission success.

17. Mission Success Indicator (MSI). The probability that a mission will succeed. An MSI is tailored to a specific decision. It includes both weather (probability forecasts) and nonweather elements that are needed to make an optimal decision.

18. Weather Impact Indicator (WII). A WII is the weather input for decision assistance. It is the probability of exceeding a particular threshold of a given weather event or the probability distribution of the weather event. Customers can combine the WII with nonweather parameters to calculate a Mission Success Indicator (MSI) for use in decisionmaking.

19. Climatological Weather Impact Indicator (CWII). A WII based on climatological probabilities rather than forecasts. CWII's are useful for planning military operations, such as scheduling events or selecting areas or routes.

20. Simulated Weather Impact Indicator (SWII). AN SWII is produced by using a model which simulates the variability of observed and forecast weather for specified climatic regimes. SWII's can be used independently (or combined with nonweather factors to produce simulated MSI's) to study the impact of weather and weather forecasts on operations, for training aids and illustrative purposes, or to assist decisionmakers in the optimal use of WII's, such as determining critical probability.

APPENDIX B

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