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| Author(s) | Hiramatsu, Akio; Huynh, Van-Nam; Nakamori, Yoshiteru |
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# Decision Making Models Using Weather Forecast Information

**Akio Hiramatsu†** **Van-Nam Huynh†** **Yoshiteru Nakamori†**

†School of Knowledge Science
Japan Advanced Institute of Science and Technology, JAPAN
{akio-h, huynh, nakamori}@jaist.ac.jp

**Abstract**

The quality of weather forecast has gradually improved, but weather information such as precipitation forecast is still uncertainty. Meteorologists have studied the use and economic value of weather information, and users have to translate weather information into their most desirable action. To maximize the economic value of users, the decision maker should select the optimum course of action for his company or project, based on an appropriate decision strategy under uncertain situations. In this paper, we will discuss several decision-making models in situations at what weather information is involved in decision problem under consideration. Firstly, the cost-loss model, which has been widely used in meteorological literature, will be briefly reviewed. Secondly, we will introduce the expected utility measures followed by a discussion on the fuzzy target based model. Finally, the relationship between the expected utility model and the fuzzy target based model will be discussed by means of a sample example taken from the literature.

**Keywords:** Weather Forecast, Economic Value, Decision Making, Expected Utility, Fuzzy Target

## 1 Introduction

The value of weather forecasts is a topic of considerable importance, and applied meteorologists, economists and others have attempted to assess the value of such forecasts in a variety of contexts (e.g.,[1][2]). To demonstrate the principles of decision making under uncertainty, textbooks sometimes rely on the so-called umbrella problem. This term refers to the situation in which an individual must decide whether to take an umbrella in the face of uncertainty concerning whether it will rain today [3].

The quality of weather forecasts has gradually improved through time as fundamental knowledge and operational experience has accumulated, but weather forecast is still uncertainty. The meteorologist analyzes and evaluates the present and past weather, and estimates the future state of the weather; the entrepreneur or other user of the meteorological service must be able to evaluate these predictions and analyses and translate them into the most favorable or most desirable course of action [4]. Meteorologists have devoted considerable attention to studies of the use and value of weather information in the context of a simple, static decision-making problem commonly referred to as the “cost-loss ratio situation” [5][6]. The so-called “cost-loss ratio situation” is a decision-making situation frequently encountered in the meteorological literature. This situation involves a decision maker who must decide whether or not to take protective action in the face of uncertainty as to whether or not adverse weather will occur [1].

In formulating these decision making situation, meteorologists have discussed the value of probability forecasts within the conceptual framework of the decision maker’s utilities (i.e., decision maker’s preferences of the consequences) [4]. Several investigations have demonstrated that the expected-utility measures associated with cost-loss decision-making models (e.g. [5][7][8][9][10]). Recently, it has studied a fuzzy target based decision model for decision-making under uncertainty in which it can establish a direct link between the decision maker’s different attitudes about target and different risk attitudes in terms of utility functions [11][12].

This paper discusses about decision-making models using weather forecasts, cost-loss ratio situation model, expected utility measures and the fuzzy target based decision model. First, in section 2, we will review about weather forecasting services and the process diagram of decision making using weather information. Next, in section 3, we describe about the cost-loss ratio decision situation including the concept of utility, and also we introduce the fuzzy target based decision model briefly. In section 4, we try to discuss these decision-making models by an example of simple gain and loss matrix.

## 2 Weather Forecasting Services

In Japan, Japan Meteorological Agency (JMA) provides various types of weather forecasting services, such as very short-range forecasting of precipitation, daily forecasts, one-week forecast and long-range forecast. Daily forecasts in plain text form for today, tomorrow and the day after tomorrow are issued three times a day at 0500, 1100, and 1700 Japan Standard Time (JST). These daily forecasts contain information about weather, winds, coastal ocean waves, maximum/minimum temperatures and probabilities of precipitation. One-week forecast covers a seven-day period starting from the following day of the issue of the forecast. It is issued daily to provide day-to-day forecasts of weather, precipitation probability and maximum/minimum temperatures [13]. In recent years, these weather forecast services are provided visually understandable graphical charts, diagrams and figures, but in the case of decision-making situation, probability forecast is useful to evaluate these predictions and course of action because they are provided by numerical figures. For example, probability of precipitation (PoP) forecast represents the probability that measurable precipitation (i.e., >1mm) will occur during a specific period (generally 6 or 12 hour) at a particular point in the area of concern [14]. In the United States, PoP forecasts have been formulated on an operational basis by National Weather Service (NWS) since 1965. In Japan, JMA started PoP forecast in 1980 [15].

JMA's weather forecast, we can see on television or radio broadcasting, is the highest common factor of national needs. Private weather forecast companies provide original forecast, fitting each user's needs and specification. Figure 1 shows the diagram of process which brings out economic value from weather forecasting and its roles of JMA and private weather companies. It is needed private weather companies in collaboration with weather forecast users to analyze cost/loss mechanism. Only these procedures can provide maximum economic value with weather prediction [15].

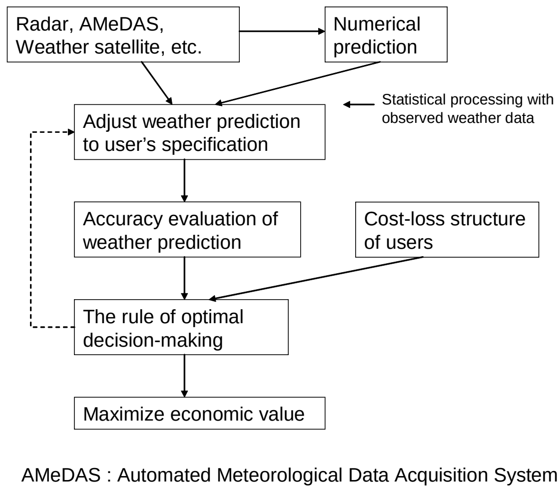


Figure 1. The process which brings out economic value from weather information [15]

## 3 The Decision Making Problems

### 3.1 The cost-loss model

The original model of the cost-loss ratio situation was formulated by Thompson [16][17]. While this model is a very simple normative model, it appears to provide a realistic description of situations faced by many forecast-sensitive decision makers and, as a result, the model has been used extensively by meteorologists and others in both real and hypothetical decision-making situations [10].

The cost-loss situation involves a decision maker who must decide whether or not to take protective action, with respect to some activity or operation, in the face of uncertainty as to whether or not weather adverse to the activity will occur [10]. Specifically, the decision maker has two possible actions, "protect" and "do not protect", and two weather events can occur, "adverse weather" and "no adverse weather" [1]. The so-called umbrella problem refers to the situation in which the protective action is to "take an umbrella" and the adverse weather is "rain" [3].

Table 1 shows the decision matrix, it contains the actions by $a_1$ (protect) and $a_2$ (do not protect) and the events or states by $s_1$ (adverse weather) and $s_2$ (no adverse weather) in probability $p$ for weather forecast. Each action-state pair leads to a different outcome or consequence [10].

Table 1. Cost-loss ratio decision matrix

| | | | States | | |
|---|---|---|---|---|---|
| | | | $s_1$ Adverse weather | $s_2$ No adverse weather | Expected expense ($E$) |
| Actions | $a_1$ | (Protect) | $C$ | $C$ | $E_1=p_1C+p_2C$ |
| | $a_2$ | (Do not protect) | $L$ | $0$ | $E_2=p_1L$ |
| | | Probability Forecast | $p_1$ | $p_2$ | $p_1+p_2=1$ |

The payoffs associated with the consequences in the cost-loss ratio situation are generally expressed in terms of the monetary expenses of the decision maker. In the original model of this situation, the cost of protection is indicated by $C$ and it is assumed that, when protective action is taken, the activity is completely protected against the effects of adverse weather. Further, when protective action is not taken and adverse weather occurs, the loss is indicated by $L$. When protective action is taken but adverse weather does not occur, the cost of protection is only indicated by $C$. Finally, when protective action is not taken and adverse weather does not occur, the monetary expense is zero.

In this model, the decision maker wants to select the action which minimizes their expected expense $E$, then $E_1=p_1C+p_2C=C$ and $E_2=p_1L$. Thus, the decision maker should select action $a_1$ or $a_2$, when the probability of adverse weather $p_1$ is greater than or less than the cost-loss ratio $C/L$ respectively, as shown in Table 2.

Table 2. Decision rule of cost-loss matrix

| | | |
|---|---|---|
| $a_1$ (Protect) | if | $p_1>C/L$ |
| $a_1$ or $a_2$ (Protect or Do Not Protect) | if | $p_1=C/L$ |
| $a_2$ (Do Not Protect) | if | $p_1<C/L$ |

This "standard" two-action and two-event cost-loss ratio situation is simple and useful, but in a practical, the decision maker is concerned with more than two actions and more than two events [6]. In the following subsection, we will discuss about more generalized decision making situation.

### 3.2 Generalized Decision Making and Expected Utility measures

The problem of decision making in the face of uncertainty is generally described using the decision matrix shown in Table 3. In this matrix, $A_i(i=1,\dots,n)$ represent the actions available to a decision maker, one of which must be selected. The elements $W_j(j=1,\dots,m)$ correspond to the possible values associated with the state of weather $W$. Each element $c_{ij}$ of the matrix is the payoff the decision maker receives if action $A_i$ is selected and weather $W_j$ occurs. The uncertainty associated with this problem is that the value of $W$ is unknown before the decision maker must choose an action $A_i$. The decision problem in table 3, we assume a probability distribution $P_W$ over $\boldsymbol{W}=\{W_1,\dots,W_m\}$. And, we restrict the payoff variable to a bounded domain that $D=[c^{min}, c^{max}]$.

Table 3. Decision matrix

| Actions | States of Weather | | | |
|---|---|---|---|---|
| | $W_1$ | $W_2$ | $\cdots$ | $W_m$ |
| $A_1$ | $c_{11}$ | $c_{12}$ | $\cdots$ | $c_{1m}$ |
| $A_2$ | $c_{21}$ | $c_{22}$ | $\cdots$ | $c_{2m}$ |
| $\vdots$ | $\vdots$ | $\vdots$ | $\ddots$ | $\vdots$ |
| $A_n$ | $c_{n1}$ | $c_{n2}$ | $\cdots$ | $c_{nm}$ |

To solve the decision making under uncertainty problem described by Table 3, the most commonly used method for evaluate action $A_i$ is the expected utility measures,

$$EU_i = \sum_{j=1}^{m} P_W(W_j)U(c_{ij}) \quad (1)$$

where $EU_i$ is the expected utility, and $U$ is a utility function defined over $D$ .

Expected-utility measures in the cost-loss ratio decision situation are measures of the "utility" of probabilistic predictions in situations in which the decision maker's knowledge of the cost-loss ratio is expressed in probabilistic terms, i.e., in which the cost-loss ratio is random variable with a probability distribution [8]. The strategy of decision making is to maximize the expected utility, or equivalently minimize the expected expense in the case of the cost-loss ratio model. Utility is the expression of a decision maker's preferences; it is affected by the decision maker's attitude or behavior. It is clear that different attitudes may lead to different results.

### 3.3 The Fuzzy Target Based Model

In section 2, we mentioned the procedure of maximize the economic value. But, in practice, it is difficult to determine the probabilistic relationship between weather event and cost-loss structure of users. Instead, decision maker may be able to assess a fuzzy target based on his experience/feelings. To define fuzzy targets is much easier and intuitively natural than directly defining random targets, especially in decision situations where the decision may be strongly influenced by the personal behavior of decision maker.

Under such observation, a fuzzy target-based decision model has been proposed and studied [11]. In the fuzzy target-based decision model, we assume that the decision maker is able to establish a fuzzy target $T$ which reflects his attitude. Then, after assessing the target he would select the course of action which maximizes the expected probability of meeting the target defined by

$$v(A_i) = \sum_{j=1}^{m} P_W(W_j)\mathbf{P}(c_{ij} \geq T) \tag{2}$$

where $\mathbf{P}(c_{ij} \geq T)$ is a formal notation indicating the probability of meeting the target of value $c_{ij}$. In [18], the authors have provided two methods for determining $\mathbf{P}(c_{ij} \geq T)$, the first method is based $\alpha$-cut representation of fuzzy sets and the second one is making use of simple normalization [19]. In this paper, we follow the second method for defining $\mathbf{P}(c_{ij} \geq T)$. Then, we have:

$$v(A_i) = \sum_{j=1}^{m} P_W(W_j)\int_{c^{\min}}^{c_{ij}} P_T(t)dt \tag{3}$$

where $P_T$ is an associated probability distribution, into which converted a possibility distribution $\mu_T$ of the target $T$ via the simple normalization, as follows:

$$P_T(t) = \frac{\mu_T(t)}{\int_{c^{\min}}^{c^{\max}} \mu_T(t)dt} \tag{4}$$

In the next section, we will consider the cases of the decision maker's attitude.

## 4. An Example of Decision Making Analysis Using Weather Forecast

The problem of selecting an appropriate decision strategy in the face of uncertainty in weather information has been of concern to meteorologists for many years [20]. In a previous study of this problem, there are some examples of decision making strategy to maximize their economic consequences [20][21]. In this section, we discuss the various uses of decision making strategies via a simple example of profits and losses for various weather events which provided by Thompson [20] as shown in Table 4.

### 4.1 Three Decision Models of Economic Expectation

Table 4. Gain and Loss Matrix with Various Weather Events [20]

| | | Weather Events | | | |
|---|---|---|---|---|---|
| | | $W_1$ | $W_2$ | $W_3$ | $W_4$ |
| Decisions | $D_1$ | 1 | 4 | 1 | 0 |
| | $D_2$ | -1 | 0 | 4 | 1 |
| | $D_3$ | -3 | 0 | 2 | 7 |
| Probability Information | $p_j$ | 0.10 | 0.25 | 0.50 | 0.15 |
| | $p_j^{up}$ | 0.30 | 0.40 | 0.60 | 0.30 |
| | $p_j^{low}$ | 0.05 | 0.20 | 0.20 | 0 |

In Table 4, the column headings ($W_j$) represent a series of weather events as, for instance, classes of rainfall. The rows ($D_i$) are the operational decisions which are related to the occurrence of these weather events, for instance, the selection of transporting route for cargo delivery. Elements ($a_{ij}$) are gains and losses associated with each $W_j$ and $D_i$. The lower portion of the table shows relative frequencies ($p_j$) of the occurrence of $W_j$, and the upper ($p_j^{up}$) and lower ($p_j^{low}$) confidence limits for these frequencies.

The decision problem is to select the proper decision $D_i$. For this purpose, several decision strategies were considered [20]:

a) If the operator wishes to conduct his operation so as to minimize large losses, he may select the course of action $D_*^{(\min)}$, which will produce the maximum benefit from the minimum economic expectation model (i.e. mini-max principle) defined as:

$$D_*^{(\min)} = \arg\max_{D_i} \sum_{j=1}^{m} a_{ij} p_{ij}^{(\min)} \tag{5}$$

where $p_{ij}^{(\min)}$ is a fictitious relative frequency of event $W_j$, which is a maximum or minimum when $a_{ij}$ is a minimum or maximum, respectively, subject to the restriction that

$$p_j^{low} \le p_{ij}^{(\min)} \le p_j^{up}$$

b) If the operator takes an average risk, the maximum benefit resulting from the "mean" economic expectation (i.e. expected value model) may be selected as the course of action $D_*^{(\mathrm{mean})}$. This model is defined as:

$$D_*^{(\mathrm{mean})} = \arg\max_{D_i} \sum_{j=1}^{m} a_{ij} p_{ij} \tag{6}$$

c) If the operator is willing to risk possible large losses, he may decide on a course of action $D_*^{(\max)}$ which will produce the maximum benefit from the maximum economic expectation model defined as:

$$D_*^{(\max)} = \arg\max_{D_i} \sum_{j=1}^{m} a_{ij} p_{ij}^{(\max)} \tag{7}$$

where $p_{ij}^{(\max)}$ a fictitious relative frequency of event $W_j$, which is a maximum or minimum when $a_{ij}$ is a minimum or maximum, respectively, subject to the same restriction as $p_{ij}^{(\min)}$.

The results of applying these three models to the gain and loss matrix in Table 4 are shown in Table 5. For the detail of computations involved in this example is referred to Gleeson [21].

Table 5. Economic Expectation with Various Decision Models [20]

| | | Economic Expectation | | |
|---|---|---|---|---|
| | | Minimum | Mean | Maximum |
| Decisions | $D_1$ | *1.30* | 1.60 | 2.20 |
| | $D_2$ | 0.60 | *2.05* | 2.50 |
| | $D_3$ | -0.30 | 1.75 | *2.85* |

It is clear that, depending upon the economic expectation model used, different decisions will produce different maximum gains. But, it is not clear which model should be used for making the decision. So, no single course of action is appropriate in all cases [20]. For decision making using weather forecast, the meteorologist must consider the characteristics of the atmosphere, and the decision maker assess the particular nature of the operation in determining the appropriate strategy.

### 4.2 Fuzzy Target Based Model

Let us consider to apply the fuzzy target based decision model to the problem of decision making using weather information as we discussed in section 4.1. Here we assume to have the relative frequencies ($p_j$) of the occurrence of weather event $W_j$ only. Furthermore, we also suppose that depending upon the ability/behavior of the decision maker, he may assess a fuzzy target $T$ as his aspiration of profit, which can be defined as membership function $\mu_T$ : $[a^{\min}, a^{\max}]$ to [0,1], where $a^{\min}=\min\{a_{ij}\}$ and $a^{\max}=\max\{a_{ij}\}$. Then he may select the course of action which maximizes the probability of meeting his target as follows:

$$D_*^{T} = \arg\max_{D_i} \sum_{j=1}^{m} p_j \mathbf{P}(a_{ij} \ge T) \tag{8}$$

In this model, depending upon the ability/behavior of the decision maker he may assess his own fuzzy target, and prototypical targets may be described as follows [11][22].

1. The first target is called the pessimistic target, which may correspond to the operator who wishes to avoid a serious loss and believes bad things may happen. Therefore he may have a conservative assessment of the target, which corresponds to ascribing high possibility to the uncertain target being a low gain or large loss. For simplicity, the membership function of this target is defined by

$$T_{pess}(x) = \begin{cases} \dfrac{a^{\max} - x}{a^{\max} - a^{\min}} & , \text{ if } a^{\min} \le x \le a^{\max} \\ 0 & , \text{ otherwise} \end{cases} \quad (9)$$

Then we have the decision model corresponding to this target as:

$$D_*^{pess} = \arg\max_{D_i} \sum_{j=1}^{m} p_j \left( 1 - \frac{(a^{\max} - x)^2}{(a^{\max} - a^{\min})^2} \right) \quad (10)$$

2. The second target expresses a neutral behavior on target of the decision maker and is represented by the possibility distribution $T_{neutral}(x)=1$ for $a^{\min} \le x \le a^{\max}$ , and $T_{neutral}(x)=0$ otherwise. In this case, it is easily to see that the model becomes:

$$D_*^{neutral} = \arg\max_{D_i} \sum_{j=1}^{m} p_j \frac{a_{ij} - a^{\min}}{a^{\max} - a^{\min}} \quad (11)$$

This is equivalent to the mean economic expectation model.

3. The third one is called the optimistic target. This target would be set by the decision maker who is able to accept a risk of getting large losses, and has an aspiration towards the maximal payoff. The optimistic fuzzy target, denote by $T_{opt}$, can defined as follows:

$$T_{opt}(x) = \begin{cases} \dfrac{x - a^{\min}}{a^{\max} - a^{\min}} & , \text{ if } a^{\min} \le x \le a^{\max} \\ 0 & , \text{ otherwise} \end{cases} \quad (12)$$

Then we have the decision model corresponding to this target as:

$$D_*^{opt} = \arg\max_{D_i} \sum_{j=1}^{m} p_j \frac{(x - a^{\min})^2}{(a^{\max} - a^{\min})^2} \quad (13)$$

Appling the fuzzy target based decision model with different targets discussed above to the decision problem as described by Table 4, the results are as shown in Table 6.

Table 6. Expectation of Meeting the Target with Different Targets

| | | Expectation of Meeting the Target | | |
|---|---|---|---|---|
| | | Pessimistic | Neutral | Optimistic |
| Decisions | $D_1$ | 0.6880 | 0.4600 | 0.2320 |
| | $D_2$ | *0.7145* | *0.5050* | 0.2955 |
| | $D_3$ | 0.6525 | 0.4750 | *0.2975* |

In Table 6, the result reflects a course of action selected is influenced by the ability of the operator. That is, if the decision maker assessed a neutral target, the decision $D_2$ is selected as in the expected value model. If the decision maker wants to get profit and accept a risk, then he probably assesses an optimistic target which corresponds to $D_3$ being selected. In the case of the decision maker who assesses a pessimistic target, though $D_2$ is still selected, $D_1$ becomes more preferred over $D_3$. In [22], authors discussed about the difference of the results between the expected utility model and the fuzzy target based model. They considered that a linear membership function for $T_{pess}$ is not enough pessimistic, so they assume very-pessimistic target and assessed it. The result was $D_1$ should be selected for avoiding a loss. This means the nature of the target assessment may be influenced by the personal philosophy of the decision maker.

As described above, using fuzzy targets would be easier than expected utility measures, while having a direct link to the traditional notion of utility functions.

## 5 Conclusion

This paper describes about decision making using weather forecast on cost-loss ratio situation model, expected utility measures and the fuzzy target based decision model. To increase the economic value of weather information, the decision maker should select appropriate course of action or strategy. Decision making under uncertainty, the concept of utility is applied. In that case, it is needed to assess the decision maker's attitude or behavior. The fuzzy target based decision model is easier to assess the decision maker's attitude or behavior than expected utility measures.

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