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Decision Making Using Early Warning Information on Extreme Weather

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***Abstract*—Though probability weather forecasts such as seasonal forecasts offer several benefits over categorical forecasts, they have not been used effectively in practical application. Recently, a new type of probability forecast named early warning information on extreme weather has started service in Japan. It has much more information available than previous seasonal forecasts. This paper describes a way of decision making using early warning information on extreme weather, and considers inventory management at a small shop as an example.**

***Index Terms*—weather forecast, decision making, uncertainty, inventory management**

I. INTRODUCTION

Weather forecasts have improved dramatically over the past few decades and particularly in the last 20 years [1]. Forecasts produced by operational forecasters using the new observational data and results of improved numerical models have become more accurate at practically all time and space scales for all weather elements. These forecasts may provide very useful but often critical information for decision making.

However, there is much more information available than is being provided to users. Present-day forecasts are predominantly "categorical" in that the uncertainty inherent in the forecast is not made explicit. Making this information available would require that the uncertainty be quantified and put into understandable terms. This quantification would almost certainly involve numerical probabilities [2].

There is an extensive literature documenting the potential socioeconomic value of uncertainty information over traditional deterministic forecasts (e.g., Karz and Murphy [3]). Many of these studies consider simplified forecast-related decisions with a certain cost for protection and a specified loss if the event occurs without mitigation [4]. For example, Murphy [5] demonstrated that for such predictions reliable probabilistic forecasts always had a higher economic value than categorical forecasts or those based on climate averages, and that even unreliable uncertainty predictions reduce costs over categorical forecasts for most cost/loss ratios.

Japan Meteorological Agency (JMA) provides long-range forecasts which are the weather outlook up to several months ahead. These outlooks offer a prognosis on temperature, precipitation and sunshine duration for one-month forecasts in the three categories of above normal, near normal and below normal. Ensemble prediction techniques play an increasing role in long-range forecasting, and are used as a unique basis for one-month forecasts. Ensemble prediction techniques are applied for three-month and warm-/cold-season outlooks in combination with statistical techniques [6]. Some trials were made to use probability forecast of long-range weather forecasts for decision making [7] [8], but they were not enough quantitative because of insufficient forecasts information.

Recently, Early Warning Information on Extreme Weather has been started by JMA. This information is issued when a high probability (30% or more) of very high or very low seven-day averaged temperature is predicted in the week starting from five to eight days ahead of the date of announcement. This information provides much more probability forecasts than the previous seasonal forecast; it includes not only categorical probability but also time-sequence diagram of seven-day averaged temperature, cumulative probability distribution and probability density distribution of predicted temperature.

In this paper, we will consider an effective use of these probability weather forecasts to control merchandise inventory of a small shop as an example. This consideration shows quantitative decision making of inventory problem with probability forecasts.

II. EARLY WARNING INFORMATION ON EXTREME WEATHER

JMA has started Early Warning Information on Extreme Weather since March, 2008. It is issued at 14:30 JST (Japan Standard Time) every Tuesday and Friday when a high probability (30% or more) of very high or very low seven-day averaged temperature is predicted in the week starting from five to eight days ahead of the date of announcement. If information was issued on the preceding announcement date, follow-up information is issued on the next date of announcement. The terms very high and very low refer to high or low seven-day averaged temperatures that are in the top 10% of all samples [9] (see Fig. 1). This information is available on JMA webpage.

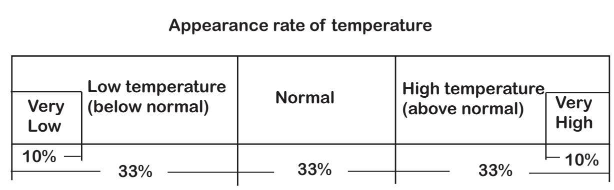

Fig. 1. Appearance rate of temperature (source: JMA)

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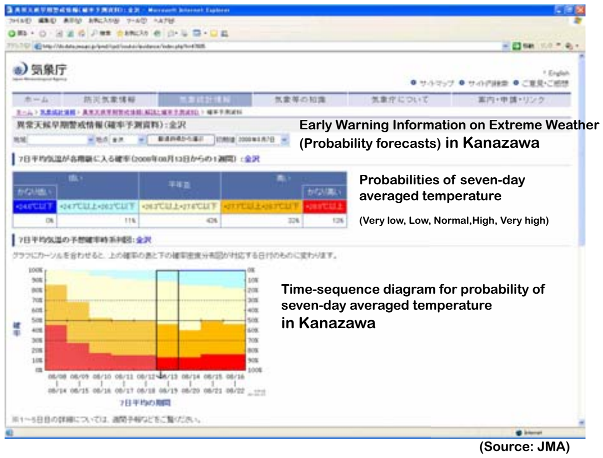

Fig. 2. An example of probability information of Early Warning Information on Extreme Weather (source: JMA)

This information also includes these items at every weather observatories in Japan.

1) Probability of seven-day averaged temperature for each category, which are very high, high, normal, low and very low.
2) Time-sequence diagram for probability of seven-day averaged temperature.
3) Cumulative probability distribution and probability density distribution of predicted temperature for each time-sequence of seven-day averaged temperature.

The previous seasonal forecasts provide only three categories probability, which is high (above normal), normal and low (below normal). Early Warning Information on Extreme Weather adds two more categories, very high and very low. Its time-sequence diagram shows predicted probability of seven-day averaged temperature for each category (Fig. 2). And, cumulative probability distribution and probability density distribution diagram shows probabilistic information of any threshold; we can read most probable temperature from the chart. In the following section, we will show the effective use of this probability weather forecast.

III. Decision Making of Merchandise Inventory Management

A. Theoretical Economic Order Quantity

In this section, we consider theoretical economic order quantity of merchandise with probability density function of predicted temperature. Now, $y(T)$ is the amount of sales which is affected by temperature T, $p(T)$ is probability density function of predicted temperature T supposing that is normal distribution with average μ and standard deviation σ, that is:

$$p(T) = \frac{1}{\sqrt{2\pi}\,\sigma} \exp\left(-\frac{(T-\mu)^2}{2\sigma^2} \right) \tag{1}$$

A theoretical expected value of sales amount $E[y(T)]$, which is the summation of sales amount $y(T)$ multiplied by probability $p(T)$ at each temperature T.

$$E[y(T)] = \int_T y(T)p(T)\,dT \tag{2}$$

On the other hand, economic order quantity (EOQ) of inventory problem q^* is

$$q^* = \sqrt{\frac{2KD}{c}} \tag{3}$$

here, D is the demand during the relevant period, K is the cost of each order, and c is the inventory carrying cost per unit quantity. If D is determined by $E[y(T)]$, the demand $D'(T)$ at a temperature T is

$$D'(T) = kE[y(T)] \tag{4}$$

Here, k is a coefficient except temperature. Therefore, economic order quantity at a temperature T; $q^*(T)$ is

$$q^*(T) = \sqrt{\frac{2KD'(T)}{c}} \tag{5}$$

B. Application Example

In this subsection, we will show some application examples which use probability weather forecasts available on JMA webpage, applying to a small convenience shop located in the suburbs of Kanazawa city, Japan[1] .

1) How many pieces of goods shall we order?: Here, we try to support for determining the order quantity of ice-cream. We suppose that the sales amount of ice-cream depend on daily average temperature only. Based on the statistical data [10] [11] from January 2000 to May 2008, the relationship between daily average temperature per month and purchased amount for ice-cream per month in Kanazawa is shown in Fig. 3. That relation is expressed as

$$y(T) = 2.32T^2 - 33.4T + 542 \tag{6}$$

its determination coefficient is $R^2 = 0.82$.

According to the probability forecasts from August 13 to 19 in Kanazawa, issued on August 7 in 2008 by JMA, the probability density distribution of predicted temperature $p(T)$ is nearly normal distribution as predicted average temperature $\mu = 27.5$ (°C) and standard deviation $\sigma = 1.07$ (°C) (see Fig. 4). Thus, expected value of purchased amount for ice-cream $E[y(T)]$ is

$$E[y(T)] = \int_T y(T)p(T)\,dT \approx \sum_T y(T)p(T)\Delta T \tag{7}$$

The result of calculation $E[y(T)]$ is nearly monthly 1,381 Japanese Yen (JPY) per household. Let's say that households in this market area of this convenience shop are 200 (households)

[1]Japan Advanced Institute of Science and Technology (JAIST) is located in the suburbs of Kanazawa-city, Ishikawa-prefecture, Japan.

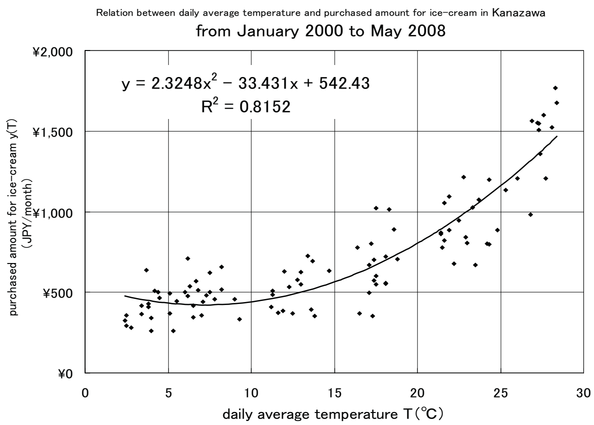

Fig. 3. Relation between daily average temperature and purchased amount for ice-cream in Kanazawa

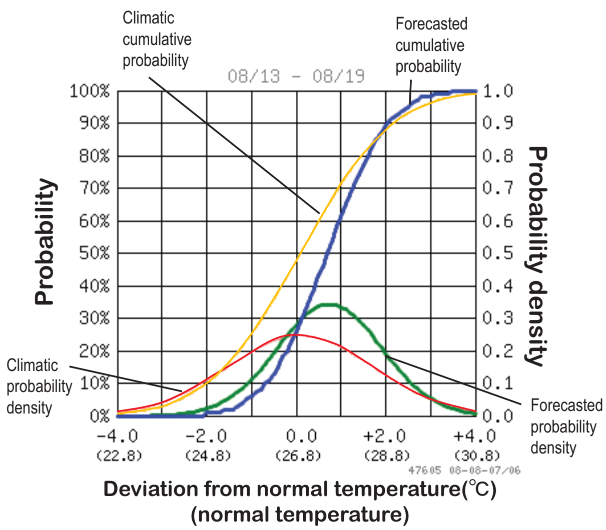

Fig. 4. Probability density distribution of seven-day averaged temperature in Kanazawa

and unit price of ice-cream is 120 (JPY), the demand of this period under predicted temperature would be $D^{'}(T) = 575$ pieces per week. The procurement cost at this shop is $K = 500$ JPY per order, the inventory carrying costs for ice-cream is $c = 10$ JPY per piece, then the weekly economic order quantity (EOQ) would be $q^{*} = 240$ pieces of ice-cream, consequently.

2) Which item of goods shall we put on store shelves?: Here, we try decision making of which item is better to put on store shelves, chocolate or ice-cream, for example. One of the easiest ways is to compare two expected values. We also suppose that the sales amount of chocolate and ice-cream depend on daily average temperature only. Based on the statistical data [10] [11] from January 2000 to December 2008 in Kanazawa, the relationship between daily average temperature per month and purchased amount per month for chocolate and ice-cream are shown in Fig. 5 and Fig. 6, respectively.

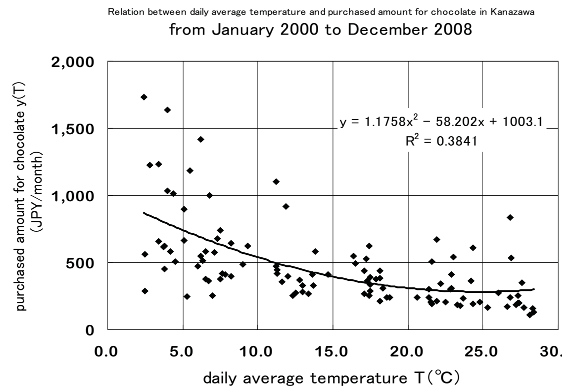

Fig. 5. Relation between daily average temperature and purchased amount for chocolate in Kanazawa

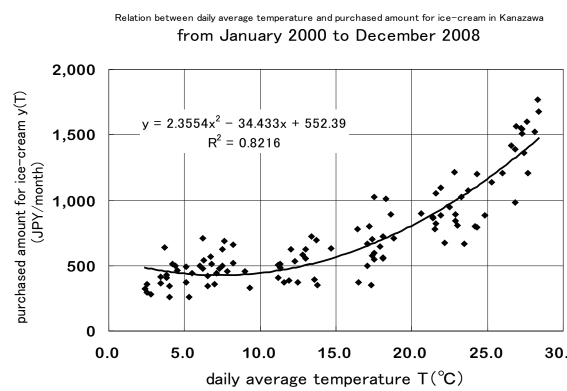

Fig. 6. Relation between daily average temperature and purchased amount for ice-cream in Kanazawa

Those relations between daily average temperature and sales amount of each item respectively are

$$y(T) = 1.18T^2 - 58.2T + 1003 \tag{8}$$

and

$$y(T) = 2.36T^2 - 34.4T + 552 \tag{9}$$

Table I shows the probability forecasts of averaged temperature presented by Early Warning Information on Extreme Weather in Kanazawa from February 16 to 22 (the first half) and February 23 to March 1 (the second half) in 2009.

From these data, the expected values of each item are as follows. The first half: chocolate 879 (JPY), ice-cream 490 (JPY). The second half: chocolate 696 (JPY), ice-cream 434 (JPY). This result tells if forecasted temperature is low like the first half, the sales amount of chocolate will increase. So, if the forecast says it will be cold, the shop owner may order chocolate more than ice-cream.

TABLE I

PROBABILITY FORECASTS OF SEVEN-DAY AVERAGED TEMPERATURE BY EARLY WARNING INFORMATION ON EXTREME WEATHER IN KANAZAWA

[The first half] one week from February 16, 2009

Very low	**Low**	**Normal**	**High**	**Very high**
below +1.1°C	+1.2°C to +2.7°C	+2.8°C to +4.9°C	+5.0°C to +6.5°C	above +6.6°C
22%	46%	31%	1%	0%

[The second half] one week from February 23, 2009

Very low	**Low**	**Normal**	**High**	**Very high**
below +1.8°C	+1.9°C to +3.3°C	+3.4°C to +5.1°C	+5.2°C to +6.9°C	above +7.0°C
0%	2%	21%	46%	31%

TABLE II

EOQ CALCULATED BY THE PROBABILITY OF EARLY WARNING INFORMATION ON EXTREME WEATHER

Early Warning Information on Extreme Weather at Kanazawa **One week from August 13**

	Very low		**Low**		**Normal**		**High**		**Very high**	
Probability	0%		11%		43%		33%		13%	
Lower, Upper (°C)	22.8	24.6	24.7	26.2	26.3	27.6	27.7	28.7	28.8	30.8
$y(T)$ (JPY/month)	987	1,124	1,132	1,259	1,268	1,387	1,397	1,494	1,504	1,714
Purchase amount (JPY)	1,055		1,196		1,328		1,446		1,609	
EOQ q^* (piece/order)	210		223		235		245		258	

Expected value of EOQ: $E[q^*] = 240$ (piece/order),
Standard deviation $\sigma = 9.9$ (piece/order)

Early Warning Information on Extreme Weather at Kanazawa **One week from August 16**

category	**Very low**		**Low**		**Normal**		**High**		**Very high**	
Probability	1%		17%		36%		30%		16%	
Lower, Upper (°C)	22.6	24.3	24.4	26.1	26.2	27.4	27.5	28.6	28.7	30.6
$y(T)$ (JPY/month)	972	1,100	1,108	1,251	1,259	1,369	1,378	1,484	1,494	1,692
Purchase amount (JPY)	1,036		1,179		1,314		1,431		1,593	
EOQ q^* (piece/order)	208		222		234		244		258	

Expected value of EOQ: $E[q^*] = 238$ (piece/order),
Standard deviation $\sigma = 11.7$ (piece/order)

IV. DISCUSSION

A. Spread of EOQ

In the case of III-B1, the economic order quantity (EOQ) q^* was 240 pieces per order. On the other hand, if we put predicted temperature $T = 27.5$ (°C) without thinking about probability density distribution, the result of EOQ $q^{*'}$ is also 240 pieces per order. But, when we use the probability forecasts, even categorical probability of seven-day averaged temperature, we can estimate each category's expected EOQ and standard deviation of EOQ. Table II shows each category's probability forecasts of seven-days average temperature in Kanazawa predicted by Early Warning Information on Extreme Weather issued on August 8 in 2008, with expected sales amount of ice-cream and its EOQ. Based on the one week forecast from August 13 (the upper part of Table II), the standard deviation of expected value of EOQ is $\sigma = 9.9$. The one week forecast from August 16 (the lower part of Table II) tells decreasing the probability of *Normal* and increasing the probability of *Very high* and *Very low* than the forecast of the upper part, therefore the standard deviation of expected value of EOQ is $\sigma = 11.7$. This means that the week from August 16 was predicted it will lower temperature than the week from August 13, EOQ was decreased, too. As the probability distribution of forecast spreads, the spread of EOQ increases with its risk. When we use forecasts of a long ahead, we have to consider its risk.

B. Compare with seasonal forecast

At the same day, seasonal forecast for Hokuriu-area also issued by JMA Niigata observatory. That forecast said in the same period (from August 16 to 22), the probability of predicted temperature was *Low* 30%, *Normal* 30% and *High* 40%. Table III shows the expected amount of sales for ice-cream and EOQ for each category. Based on this forecast information, the expected value of EOQ was $E[q^*] = 234$ pieces of one order, standard deviation of EOQ was $\sigma = 11.1$ (see Table III). Compare it with the above mentioned, EOQ was almost same as the result based on the Early Warning Information on Extreme Weather. But, the decision maker could estimate the risk of low temperature smaller when he uses the probability information of Early Warning Information on Extreme Weather. Against the forecasted probabilities as *Normal* 30% and *Low* 30% at the seasonal forecast, the probabilities were *Normal*=36%, *Low*=17% and *Very low*=1% at Early Warning Information on Extreme Weather.

V. CONCLUSION

Probability weather forecasts offer several benefits over categorical forecasts. They contain more information, because the uncertainty in the forecast is specifically expressed; the user is made aware of that uncertainty and can use that information

TABLE III
SEASONAL FORECAST : ONE-MONTH FOR HOKURIKU AREA

Seasonal forecast (One-month : Hokuriku) converted into Kanazawa announced on August 8, 2008. (for 2nd week) **from August 16 to 22**

	Low		**Normal**		**High**	
Probability	30%		30%		40%	
Lower, Upper (°C)	23.7	26.1	26.2	27.5	27.6	28.9
$y(T)$ (JPY/month)	1,054	1,251	1,259	1,378	1,387	1,514
EOQ q^* (piece/once)	220		234		246	

Expected value of EOQ : $E[q^*] = 234$ (piece/order),
Standard deviation $\sigma = 11.1$ (piece/order)

in decision making. In this paper, we described the decision making of inventory management at a small shop. We supposed the sales amount of items are only affected by temperature at this case. Of course, if we apply this example to real situation, we must consider another factor (e.g., rain or no rain, humidity, shop service, etc.) influenced to the sales amount.

ACKNOWLEDGMENT

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