MULTIFACTORS INTEGRATED FOREST FIRE DANGER RATING SYSTEM IN CHINA'S BOREAL FORESTS*

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ABSTRACT

Hundreds of field experiment fires, large sample compared analysis between historical fire statistics and meteorological factors provide the data base for the system. By introducing the Fuzzy sets concept, and the study of the meteorological factor affected fire occurrence and development, characteristic values and ritical values are designed to set up mathematical recognition models for forest fire danger rating. After several years practice and amending, the system has realized information collecting, computation and prediction automatically, and has been used in Heiloongjiang province, and is being adapted to other provinces in China.

KEYWORDS: FOREST FIRE DANGER, RECOGNITION MODELS, PREDICTION METHODS

1. BASIC IDEALS

There are many factors affect the occurrence of forest fires. However, the meteorological factors and weather condition are the most important ones especially in affecting the daily fire danger and seasonal fire danger. Therefore, study of the cause and effect relations between meteorological factors and fire occurrence is the critical step in setting up the fire danger index system and forest fire prediction system.

Fig. 1 shows the 450 field experimental fires. It reflects that there is a correlated fuzzy relation between fuel bed moisture content and ignition probability. In Fig. 1, if the shadows of ". " is set R, ignition probability set is U, fuel bed moisture content set is X, then, set R is, in fact, a mapping of set X to set U. Here:

$$U = F(X) \quad (1)$$

is actuarially a mathematical model of the affecting factor set X

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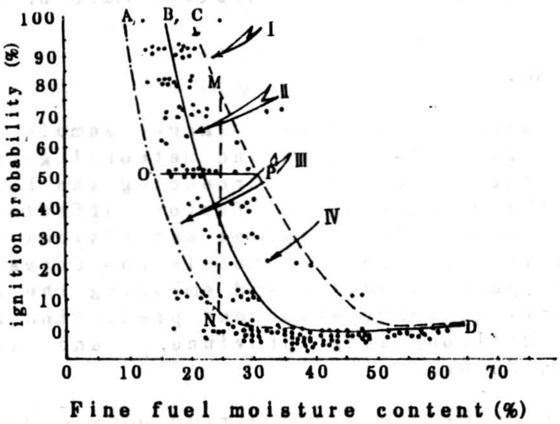
* The following people have contributed to the system: Liu Haitang Wei Lijie Liu Futang Wei shixian, Wang Mingru, Liu kunsheng Wang Donghong, Gao Xinglong

o fire danger contribution.

Again in Fig. 1, if we equally divide the fuel moisture content(0–00%) into several intervals, then account the number M of "." epresenting ignition probability< 5% and the number of N of "." epresenting ignition probability >50% fall into each interval, uppose the total "." number in each interval is W, therefore, the elative frequency $U_m = M/W \times 100\%$ reflects the effects of fuel bed's oisture which will led to the uneasy ignited situation; $U_n =$ /W× 100% reflects the degree of easy ignited fuel bed caused by its ryness. Let's have a look of Fig. 2; the dot line curves represent he two U's value which are got from the field fire experiments onducted in the spring of 1984; the solid lines are the expected alues of the two U. The experiments and statistics has shown that he contribution curve in Fig. 2, reflecting the general elationship between the factor set causing a fire and the fire danger et. This relationship can be better described by the fuzzy set theory.



I Weather condition most favorite the fire occurence

II Average weather condition

III Weather condition not suitable for fire occurrence

IV --- "." means the test ignition probability in 1984 spring

Fig. 1 Correlation curve between ignition probability and fine fuel moisture content

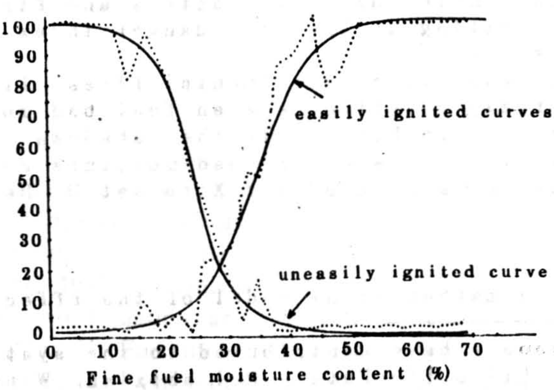


Fig. 2 Ignition probability vs fuel moisture content

2. THE INTEGRATED RECONGNITON MODELS

We have analyzed more than 3,000 fire's statistics and 120,000 weather recording data, and 12 weather factors were selected for fire danger rating. According to the general relationship showed in figure 2, we first set up the A recognition model which is decided by the single weather factors, in this case, if the fire danger index increase with the increment of a factor value, we adopt the equation:

$$U_i = \begin{cases} \dfrac{1}{1+[A_i(C_i-X_i)]^{B_i}} & \text{when } X_i<C_i \\ 1 & \text{when } X_i>C_i \end{cases} \qquad (2)$$

if the fire danger index decrease with the increasement of factor value, we adopt the equation:

$$U_i = \begin{cases} \dfrac{1}{1+[A_i(X_i-Ci)]^{B_i}} & \text{when } X_i>C_i \\ 1 & \text{when } X_i<C_i \end{cases} \qquad (3)$$

Here: U_i——Single factors contribution to fire danger (0, 1) or (0, 100%)
X_i——Weather factor recordings or predicted values
A_i, B_i, C_i——References
i ——12 weather factors

In reviewing the historical fire and meteorological statistics, we found that every selected factor has 3 basic critical values: no fire occurrence value R_{io}; value $R_{io.5}$ is when the ignition probability obviously increasing; value R_{i1} is when there is large number of fire occurred. The key for setting up the single factor recognition model is to determine the three critical values for each factor, then to fit the A_i, B_i and C_i. Here:

$$C_i = R_{i1} \qquad (4)$$

$$A_i = \left| \frac{1}{R_{i1}-R_{io.5}} \right| \qquad (5)$$

$$B_i = \frac{Lg19}{Lg\,|A_i(C_i-R_{io})|} \quad \text{or}$$

$$B_i = \frac{Lg99}{Lg\,|A_i(C_i-R_{io})|} \quad \text{or}$$

$$B_i = \frac{Lg199}{Lg\,|A_i(C_i-R_{io})|} \qquad (6)$$

The purpose we select three equations to calculate B_i is to make B_i better reflect the effects of each factor to fire danger.

Table 1 lists the 12 factors selected and the A_i, B_i, and C_i accordingly. Thus, from Table 1 and equation (2) and (3), we can get the single factor's contribution Ui to fire danger respectively.

As we know that a forest fire is the resultant caused by many factors, single factor's contribution can only reflect one point of total fire danger. For this reason, we divide the weather factors into two groups to calculate their fire danger contribution by group. First, put the weather factor collected before 08 clock of the prediction day in set $X_Q = \{X_6, X_7, X_8, X_9, X_{10}, X_{11}, X_{12}\}$ which represents their fire danger contribution and to calculate integrated recognition set U_Q. Secondly, put the weather factors collected from the prediction day in set $X_J = \{X_1, X_2, X_3, X_4, X_5\}$, and to calculate the integrated recognition set U_J. Thus, B recognition model composed of two equations:

$$U_Q = F(U_i) = (U_6+U_7+U_8+U_9+U_{10}+U_{11}+U_{12})/7 \quad i=6-12 \quad (7)$$

$$U_J = F(U_i) = (U_1+2U_2+U_3+U_4+U_5)/6 \quad i=1-5 \quad (8)$$

[H]ere: U_Q——previous high fire danger index
U_J——The day's high fire danger index

Table 1 Factors references in the A recognition model

	U_i		X_i	A_i	B_i	C_i	Equation
U_1	X_1 decided high fire danger contribution	X_1	precipitation (mm) 8 a.m-14 p.m	2	3	0	(3)
U_2	X_2 decided high fire danger contribution	X_2	temperature (℃) 14 p.m	1/5	4	20	(2)
U_3	X_3 decided high fire danger contribution	X_3	day temperature difference (℃)	1/10	6	25	(2)
U_4	X_4 decided high fire danger contribution	X_4	air humidity (%) 14 p.m	1/10	3	15	(3)
U_5	X_5 decided high fire danger contribution	X_5	10-12M wind speed (m/sec.) 14 p.m	1/12	14	17	(2)
U_6	X_6 decided high fire danger contribution	X_6	precipitation (mm) 24 hrs. before 8 a.m	1	3	0	(3)
U_7	X_7 decided high fire danger contribution	X_7	precipitation (mm) 72 hrs before 8 a.m	1/2	3	0	(3)
U_8	X_8 decided high fire danger contribution	X_8	previous 3 day's mean air humidity (%) 14 p.m	1/10	3	20	(3)
U_9	X_9 decided high fire danger contribution	X_9	previous 3 day's temp. accumulation (℃) 14 p.m	1/20	7	60	(2)
U_{10}	X_{10} decided high fire danger contribution	X_{10}	days accounted for precipitation <5mm	1/20	17	30	(2)
U_{11}	X_{11} decided high fire danger contribution	X_{11}	days accounted for precipitation <3mm	1/22	17	30	(2)
U_{12}	X_{12} decided high fire danger contribution	X_{12}	days accounted for precipitation <0.5mm	1/2	3	8	(2)

Thinking about the complicated relation ships between factors and [t]heir multiple effects to fire occurrence, we developed the C [i]ntegrated recognition model as the following:

$$G = \begin{cases} [U_J + U_Q(U_J+0.3)]/2 & \text{when } U_J \text{ or } U_Q < 0.5, \text{ or both } U_J \text{ and } U_Q < 0.5 \\ (U_J+U_Q)/2 & \text{when } U_J,\ U_Q > 0.5 \text{ and } U_J < U_Q \\ U_J & \text{when } U_J,\ U_Q > 0.5 \text{ and } U_J > U_Q \end{cases} \quad (9)$$

[H]ere: G——High fire danger index determined by whole weather factors, the simple integrated index

[S]o far by the previous discussion, we can get the primary fire danger [r]ating system in description set S = {0, 1, 2, 3, 4, 5, 6} which contain 7 [f]ire danger rating classes. It can be easily converted into 5 classes [n]ormally used, see Table 2.

The system is further revised by three climate phenomena: snow cover, [p]henological season, and the special meteorological factors.

The snow cover set B = {1, 0.5, 0} represents three conditions: when B=1, [a]ll the prediction area covered by snow, when B = 0.5, only northern [a]spect of slopes covered by snow, no snow in the southern slop, when B = 0, Both the northern and southern aspects no snow covering.

Table 2 Initial fire danger rating recognition classification

No.	Factor set Vi = {G, B, R}	S_i Classes (7)	5 Classes
1 2 3	G<0.05 $R=R_1$ B=1	(0) safe	1 (can't be ignite)
4	0.25>G>0.05	(1) relative safe	
5	0.50>G>0.25	(2) difficult to ignite	2 (difficut to ignite)
6 7	0.70>G>0.50 G>0.70 but B=0.5	(3) could be ignite	3 (could be ignite)
8	0.90>G>0.70	(4) easy ignite	4 (easy ignite)
9	1.00>G>0.90	(5) danger class	5 (very easy ignite)
10	G>0.90, $R=R_2$	(6) alarming	

The phenological season revising reference set is:

$$Z=\{Z_{spg}, Z_{fal}\}, \text{ and}$$

$$Z_{spg}=1-0.02t \quad (10)$$

$$Z_{fal}=1-(m^{-m/20}\times n^{-n/200}) \quad (11)$$

Here: Z_{spg}——spring phenological revising reference

Z_{fal}——fall phenological revising reference

t ——accumulating days in the spring since the end day of the min. temperature < 0 ℃

m ——accumulating days in the fall since the first frost occurred

n ——accumulating days in the fall since the end day of the average temperature > 15 ℃

The special weather factor critical set is $R=\{R_1, R_2\}$, Here: R_1 is the condition of precipitation between 8 a.m. to 14 p.m. $X_1>3$mm; R_2 means the 14 p.m temperature $X_2>25$ ℃ and the wind velocity $X_s>$ 10m/sec..

The D recognition set V={G, B, R, Z} is the final prediction model for the system. In practice, it can be fulfilled in two steps.

First, the initial recognition by factor set $V_1=\{G, B, R\}$. The general description is listed in Table 2. From this step we can get the initial fire danger S_i. Secondly, revise the Si through the phenological Set Z.

$$S=S_i\times Z \quad (12)$$

Thus, we get the final fire danger ratings of S.

3. THE PREDICTION CHART

The system has realized the receive of weather readings, telex code recognition, analysis of weather factors and the fire danger rating calculating automatically and digitally. Whole works can be

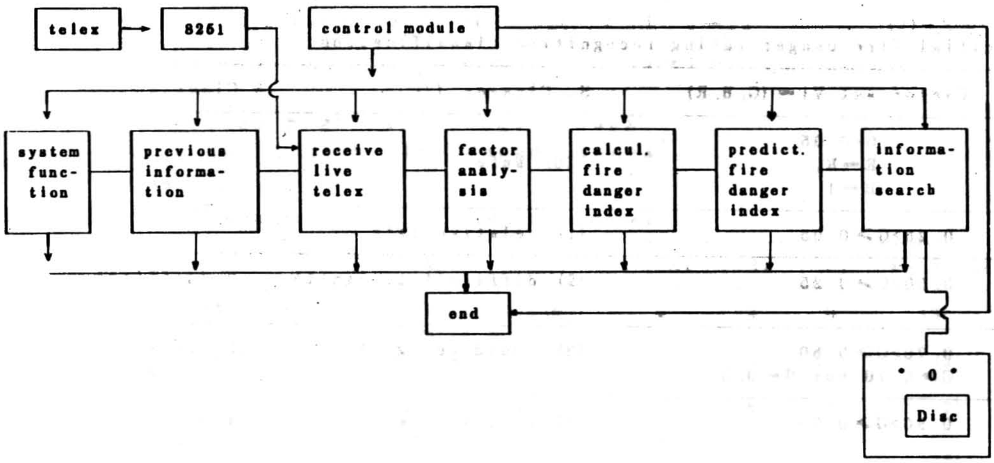


Fig. 3 Basic structure diagram of the system

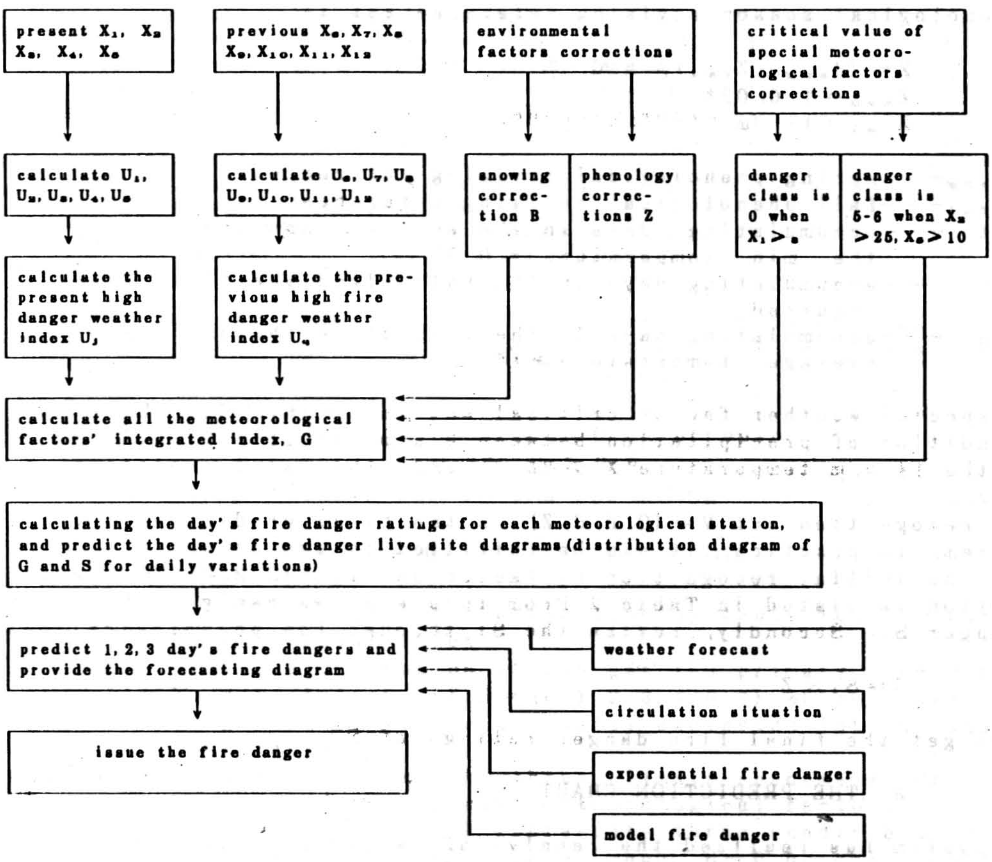


Fig. 4 Flow chart for fire danger calculation

finished by IBM and APPLE-II microcomputers. BASIC is the computer language used, Chinese DOS is the basic supporting system and the main menu controlled operation makes the works more convenience. Fig. 3 illustrated the basic structure of the system. Fig. 4 is the fire danger prediction processing chart. Fig. 5 shows the result of man-assistant computer prediction chart for future 1 to 3 day's fire danger ratings.

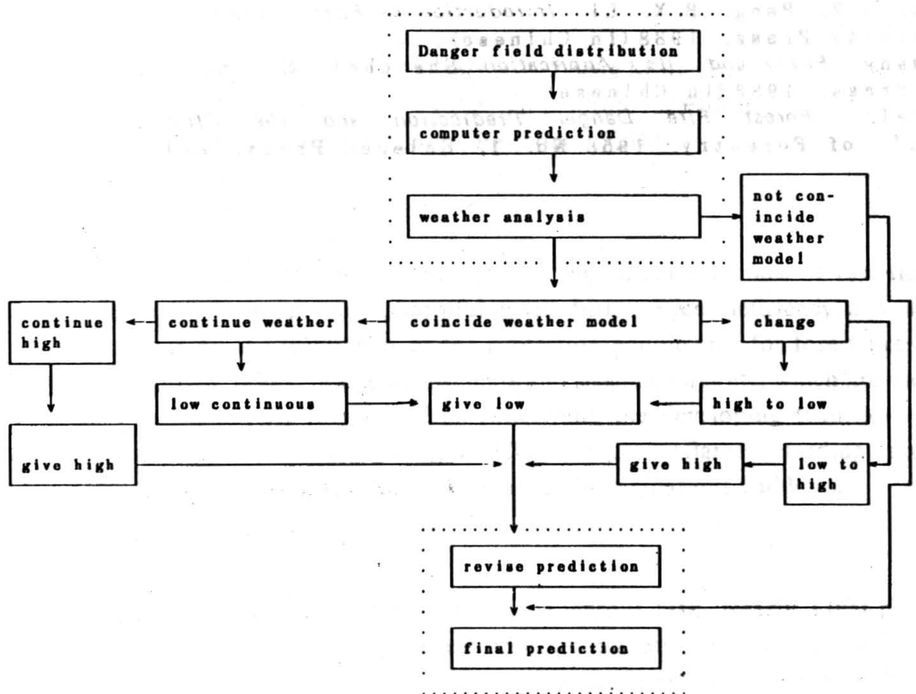


Fig. 5 Fire danger prediction flow chart

4. THE ACCURACY OF THE FIRE DANGER PREDICTION

Since the application of the system started in the spring of 1984, the system has worked very well. The prediction accuracy for short term fire danger is over 76%. The prediction accuracy for continues high fire danger period and the continued low fire danger period reaches about 90%. The forest fire weather index system can better divided the weather condition into high fire danger and low fire danger. We have tested the system by using the 1966 to 1983 fire seasons' data, 92% of fire occurred during this period are matched to the 4th and 5 th class of this system, and almost all large fires occurred in the predicted 4th and 5th fire danger classed. The special example was that the 1987's "May 6" fire, we had predicted the very high fire danger weather 3 days before May 6th.

From several years professional practice, we have reason to believe that the system has the advantage to be large scale applied in meteorological service for fire danger ratings. So far, despite the application in Daxinganling region, the system has be extended in Heilongjiang province, and will be adopted to many provinces and regions in China.

REFERENCES

1. Wang Zhengfei, T. Y. Zhu, J. W. Zhu, Q. W. Cui, *Forest Meterology*, Charpter 9. Chinese Forestry Publication Press, Beijing. 1985 (In Chinese).
2. Wang Zhengfei, X. X. Wang. *Meterology and Forestry Fire.* Soil Research Institute, Academina Sinica of China. Vol. 1, 1958. Science Publication Press. Beijing. (In Chinese).
3. Aoyang Mian, Z. Z. Peng, B. X. Li, *Introduction to Fuzzy Mathematics.* Wuhan University Press. 1988 (In Chinese).
4. Wang Peizhuang. *Fuzzy and its Application.* Shanghai Science and Technology Press, 1983 (In Chinese)
5. Wang Zhengfei. *Forest Fire Danger Predicction and the Climate Condition.* Bull. of Forestry. 1958 No. 1, Science Press, Beijing(In Chinese)