A MODEL FOR ESTIMATING OPTIMUM BENEFIT OF FIRE EXTINGUISHING

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ABSTRACT

In this paper, through analysis of an ideal fire area, an attemp was made to develop a theoretical model to obtain optimum fireman numbers with minimal damage and cost at putting out a forest fire, under such a supposed case as follows: homogeneous vegetation type, unchanged wind direction and velocity, smooth terrain, and in the meanwhile with a prerequisite which one fireman is a basic unit and one should fight fire head during extinguishments. The model can be expressed as the following transcendental equation:

$$ar^2\left[\frac{(N-2)\cdot sinA_{N-2}\cdot sin(\frac{\pi}{N-2})}{sin(A_{N-2}+\frac{\pi}{N-2})}-\frac{N\cdot sinA_N\cdot sin(\frac{\pi}{N})}{sin(A_N+\frac{\pi}{N})}\right]$$

$$=\frac{rb}{V_2}\left\{\frac{N\cdot\left[sinA_N-sin(A_N+\frac{\pi}{N})\right]}{sin(A_N+\frac{\pi}{N})}-\frac{(N-2)\cdot\left[sinA_{N-2}-sin(A_{N-2}+\frac{\pi}{N-2})\right]}{sin(A_{N-2}+\frac{\pi}{N-2})}\right\}+2C$$

Optimum fireman numbers and maximal benefits can be obtained by using the method of item—by—item iterative loop.

If the efficiency of various fire extinguishers and fire behaviors under various fuel types and topography conditions are quantified, the model can be applied to determine optimum benefit of fire extinguishing in various fire areas and with various measures during extinguishing procedures.

Key word: Benefit; Transcendent Equation; Extinguishing; Item—by—item Iteration Loop

INTRODUCTION

It is very important for forest f ire protection agencies to make exact decisions to minimize total forest losses and suppression cost caused by fire. Li Xien(1990)[1] suggested that economic idea in putting out forest fire should be further considered, that is to say, the unscientific and uneconomical tactics withlots of manpower and material in fighting fires should be changed as soon as a fire was taken place. We cannot deny this correct concept, even though the complishment of his idea might be restricted in distinguishing fires. Based on the economical idea, we have made further study and put forward a theoretical model that can be applied to extinguish forest fires so as to reach the optimum economical benefit.

ESTABLISHING THE MODEL

Different vegetation types, terrains, meterological elements and society factors result in different forest fire evironments, which have a deep influence on fire occurrence and spread. Therefore, diversities in fire behaviors and fire—slash were formed. There are not two forest fires which have the same fire—slash appearance because of different fire

—spread speed in various directions and the speed changed in the same directions as time goes on. However, various forms of fireareas occur generally with a small circle or near circle at the initial stage, so far as the fire development in plane area concerned. In this circumstances, the speed of fire spread and other factors can be determined, which provided a possibility for the model establishment.

Like other natural sciences, the model will be established in terms of the ideallest fire—spread types (uniform motion in different directions) or the ideallest fire environment (with similarity in any time and space), and then it will be extended to meet practices demand. Therefore, some supposed definitions are drawn as follows:

A. Homogeneous vegetation types, unchanged wind direction and velocity, even terrain.

B. One fireman as a basic unit of suppression and hold to the principle of fighting fire—head.

C. Total damage cost by forest fire including either the losses of forests (direct economic losses and indirect ecology benefit losses) or the cost put into fire suppression procedure.

1. Nonlinear Equation Establishment

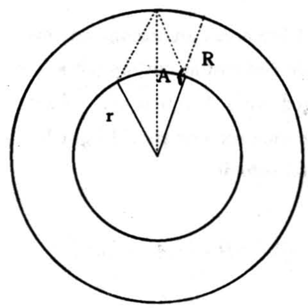

Fig. 1 Illustration of the fire area and fire slash.

Figure 1 shows an ideal fire area; the inner circle stands for fire area and the external circle for fire—slash. Their radius is r and R respectively.

According to Figure 1 and definitions mentioned above, we have $minQ = S_N \cdot a + N(b \cdot t_N + C)$ and following equation systems:

$$S_N = N \cdot r \cdot R \cdot \sin\frac{\pi}{N} - \pi r^2 \tag{1}$$

$$\frac{V_2 \cdot t_N + r}{\sin A} = \frac{r}{\sin(A + \frac{\pi}{N})} \tag{2}$$

$$A \leqslant Arccos(-\frac{V_2}{V_1}) - \frac{\pi}{N} \tag{3}$$

$$\Delta S \cdot a = (N \cdot b \cdot t_N + N \cdot C) - [(N-2)b \cdot t_{N-2} + (N-2)C] \tag{4}$$

$$t > 0, N > 0, \pi r^2 < S_N < \pi R^2, 90^\circ < A < 180^\circ$$

Where:

N=number of fireman.

Q=total damage of forest fire. (yuan)

S_N=damaged forest area when there are N fireman. (m^2)

ΔS=decresses forest area losses when there are N+2 fireman. (m^2)

V_1=rate of extinguishing. (m/h)

V_2=rate of fire—spread in the normal. (m/h)

a=forest losses. (yuan/m^2)

b=extinguishing cost per fireman. (yuan/h)

C=transportation cost. (yuan)

t=extinguishing time. (h)

A=angle between the radius and extinguishing direction. (degree)

2. Proof of the Nonlinear Equation Systems

Equation (1) and (2) are derived from the formula of triangle—area, circle—area and sinusoidal law. Equation (3), an inequality of anti—cose function, come from the basic formula $cos[180° - (A + \frac{\pi}{N})] \geqslant \frac{V_2 t_N}{V_1 t_N}$, and if N→∝, $A = Arccos(-\frac{V_2}{V_1}) - \frac{\pi}{N}$. In fact, when N>50, the formula can generally convert into $A = Arccos(-\frac{V_2}{V_1}) - \frac{\pi}{N}$ (error =0. 0064r). Equation (4) is a necessary and sufficient condition minimizing the total losses of forest fire. The forest fire damage will increase and manpower shortage will be occure if $\Delta S \cdot a > (N \cdot b \cdot t_N + N \cdot C) - [(N-2)b \cdot t_{N-2} + (N-2)C]$. If $\Delta S \cdot a < (N \cdot b \cdot t_N + N \cdot C) - [(N-2)b \cdot t_{N-2} + (N-2)C]$, it follows that extinguishing cost will increase and lead to increase in total losses. Only when $\Delta S \cdot a = (N \cdot bt_N + N \cdot C) - [(N-2)b \cdot t_{N-2} + (N-2)C]$, can the optimum extinguishing benefit be reached.

The conditional inequalities, t>0, N>0 and $\pi r^2 < S_N < \pi R^2$ exist certainly. The inequality 90°<A<180° also exist, because fire extinguishing will run along tangent if A=90°, so putting out forest fire except for underground—fire is impossible at all, let along A<90°. The vector—rate of extingushing will be zero if A=180°, this problem cannot be solved by the model.

3. Particular Solutions of the Nonlinear Model

Supposed that the radius of fire area is R_N with N firemen extinguishing, and radius is R_{N-2} with N—2 firemen extinguishing, and $R_N < R_{N-2}$. Equation (5) and (6) can be obtained according to sinusoidal law:

$$R_N = \frac{r \cdot sinA_N}{sin(A_N + \frac{\pi}{N})} \tag{5}$$

$$R_N = \frac{r \cdot sinA_{N-2}}{sin(A_{N-2} + \frac{\pi}{N-2})} \tag{6}$$

Accordingly, if N—2 firemen are replaced with N, the decreased area of fire area will be experssed as eqation (7):

$$\begin{aligned} \Delta S_{N-2 \to N} &= S_{N-2} - S_N \\ &= (N-2) \cdot r \cdot R_{N-2} \cdot sin\frac{\pi}{N-2} - N \cdot r \cdot R_N \cdot sin\frac{\pi}{N} \end{aligned} \tag{7}$$

Put equation (5) and (6) into equation (7), we have

$$\Delta S_{N-2 \to N} = r^2 \left[\frac{(N-2) \cdot sinA_{N-2} \cdot sin(\frac{\pi}{N-2})}{sin(A_{N-2} + \frac{\pi}{N-2})} - \frac{N \cdot sinA_N \cdot sin(\frac{\pi}{N})}{sin(A_N + \frac{\pi}{N})} \right] \tag{8}$$

From eqution (2), t_N and t_{N-2} can be presented respectively by:

$$t_N = \frac{r \cdot \left[sinA_N - sin(A_N + \frac{\pi}{N}) \right]}{V_2 \cdot sin(A_N + \frac{\pi}{N})} \tag{9}$$

$$t_{N-2}=\frac{r\cdot\left[\sin A_{N-2}-\sin(A_{N-2}+\frac{\pi}{N-2})\right]}{V_2\cdot\sin(A_{N-2}+\frac{\pi}{N-2})} \tag{10}$$

If N−2 persons were replaced by N persons for the same fire area, the increased cost (q) in suppression action can be given by:

$$\Delta q_{N-2\to N}=N\cdot b\cdot t_N-(N-2)\cdot b\cdot t_{N-2}+2C \tag{11}$$

When put equ. (8) and (9) into equ. (11), the fllowing equation can be obtained:

$$\Delta q_{N-2\to N}=$$

$$\frac{r\cdot b}{V_2}\left\{\frac{N\cdot\left[\sin A_N-\sin(A_N+\frac{\pi}{N})\right]}{\sin(A_N+\frac{\pi}{N})}-\frac{(N-2)\cdot\left[\sin A_{N-2}-\sin(A_{N-2}+\frac{\pi}{N-2})\right]}{\sin(A_{N-2}+\frac{\pi}{N-2})}\right\}+2C$$

If $\Delta S_{N-2\to N}\cdot a-\Delta q_{N-2\to N}=0$, the total damage of forest fire wiil reach minimum, namely the derived model is:

$$ar^2\left[\frac{(N-2)\cdot\sin A_{N-2}\cdot\sin(\frac{\pi}{N-2})}{\sin(A_{N-2}+\frac{\pi}{N-2})}-\frac{N\cdot\sin A_N\cdot\sin(\frac{\pi}{N})}{\sin(A_N+\frac{\pi}{N})}\right]$$

$$=\frac{rb}{V_2}\left\{\frac{N\cdot\left[\sin A_N-\sin(A_N+\frac{\pi}{N})\right]}{\sin(A_N+\frac{\pi}{N})}-\frac{(N-2)\cdot\left[\sin A_{N-2}-\sin(A_{N-2}+\frac{\pi}{N-2})\right]}{\sin(A_{N-2}+\frac{\pi}{N-2})}\right\}+2C$$

Where:

$$A_N=\mathrm{Arccos}(-\frac{V_2}{V_1})-\frac{\pi}{N}$$

$$A_{N-2}=\mathrm{Arccos}(-\frac{V_2}{V_1})-\frac{\pi}{N-2}$$

The model contains seven parameters V_1, V_2, a, b, c, r, N, which is knownable and relate to fire environment except for N. Provided these variables have i1, i_2, i_3, i_4, i_5, i_6 states, the model will have j solutions ($j=i_1\cdot i_2\cdot i_3\cdot i_4\cdot i_4\cdot i_5\cdot i_6$) which include various fire environments. Because the model is a transcendent equation, the optimum fireman numbers, maximum benefits and resultant suppression time (t), area of fire—slash (S), total losses of forest fire (Q) can be given by means of item—by—item interative loop on micro—computer.

ON APPLICATION OF MODEL

A. Variables with the model comprised mainly both fixed and unfixed parameters. It is necessary for the model to study the value of those parameters under various conditions, and then the given values form a data base for users.

B. The model only can be applied under such economic conditions, as relationships between the cost, efficiency of extinguishers and a fireman was determined, especially in different fire states.

C. The model is not involved in change of velocity in same direction. This problem needs further study.

REFERENCE

1. Li Xien, the investment put into forest fire suppression procedures, forest fire prevention, 25, (1990), 2, 17 (in Chinese).