

FACTORS INFLUENCING THE DISCOVERY OF FOREST FIRES BY LOOKOUT OBSERVERS¹

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INTRODUCTION

In forest-fire suppression activities there are four generally recognized elapsed-time steps between the start of a fire and the time suppression forces actually begin working on it. These are (1) discovery time, (2) report time, (3) get-away time of the initial attacking force, and (4) travel time of attacking force. To attain the promptness of attack desirable—termed “hour-control requirements”—in any given forest cover type, it is necessary to keep the sum of these four elapsed-time steps less than the total allotted in the hour-control set-up.³

The discovery time of fires, under the type of detection system employed throughout the national forests of California,⁴ is subject to considerable variation, attributable to the varying physical conditions under which fires occur. This variation, unlike that in the other three elapsed-time steps, cannot be controlled by the protection organization. It is, however, desirable to measure the extent of the variations which occur and to associate them with their controlling physical factors in order that significant variations in discovery time may be estimated from the measurement of physical conditions under which fires occur.

The purpose of this paper is to present some measurements that have been made of the influence of certain factors on discovery time in the ponderosa pine (*Pinus ponderosa* Dougl.) type of northern California. While the quantitative experimental results obtained may not have direct application to other cover types or other forest regions, the trends established by the study may be of some value to all engaged in fire-control activities.

METHOD OF STUDY

In this study 200 actual test fires were set and allowed to burn from 10 to 30 minutes, depending upon their rate of spread, on the McCloud Flats of the Shasta National Forest during one fire season between July 1 and October 15.

Observations of the fires and quantitative measurements of the variables were obtained by two groups of observers. One, the ground crew, started and suppressed the fires and recorded weather and fuel data and the behavior of the fires. The perimeter of each fire was

¹ Received for publication September 20, 1937; issued April 1938.

² Maintained in cooperation with the University of California, at Berkeley, Calif.

³ SHAW, S. B., and KOTOK, E. I. THE DETERMINATION OF HOUR CONTROL FOR ADEQUATE FIRE PROTECTION IN THE MAJOR COVER TYPES OF THE CALIFORNIA PINE REGION. U. S. Dept. Agr. Tech. Bull. 209, 47 pp., illus. 1930.

⁴ BROWN, A. A. IMPROVING FOREST FIRE DETECTION IN CALIFORNIA. Jour. Forestry 33: 923-931. 1935.

plotted to scale at 2-minute intervals during the life of the fire. The second group consisted of a special observer on Black Fox lookout in the center of the area in which the fires were set and cooperating lookout observers on four other lookout points from each of which most of the area was directly visible. Each test fire set thus represented from two to five separate and independent discoveries. The special observer on Black Fox recorded the position of the sun at the start of each fire, a description of the background against which the smoke appeared, visibility conditions as indicated by visibility-meter ratings of natural objects in the landscape,⁵ and discovery time. The cooperating lookouts recorded a description of backgrounds, general estimations of visibility conditions, and discovery time. Radio communication was maintained between the ground crew and Black Fox, and all lookout observers were notified in advance of the location and time of start of each fire. No attempt was made in this study to check the personal efficiency of the different observers.

The fires were confined mainly to pure ponderosa pine needles. This type was selected as being the most uniform in fuel character and the one in which the fires could be most easily suppressed. Analysis of the data pertains only to the pure pine type.

EFFECT OF FACTORS ON DISCOVERY TIME

Collection of field data was limited to fires that spread immediately upon ignition. The time in which an incipient fire in the form of a smoldering campfire or rotten log will actually start to spread and produce smoke is governed more by chance than by any measurable physical factors. Lookouts can normally be expected to discover only such fires as are spreading and have produced a definite column of smoke.

The important physical factors which influence the time from the start of spread of fires to their possible detection by lookouts are: (1) Atmospheric obscurity, (2) background against which the smoke is seen, (3) distance of the lookout from the fire, (4) relative position of the sun with respect to the observer's line of sight, and (5) relative behavior of the fire governing the rate at which smoke is produced and rises—this last being dependent upon the combined influences of wind velocity, moisture content, and nature and distribution of the fuel. The correlation of fire behavior with these governing factors is being undertaken as a separate project and has not been treated in the study of discovery time. In the collection of the field data, quantitative measurements were made of each of these factors for every discovery recorded, with the exception of background. This factor was described by its composition and appearance to each observer. The effect of topographic shadows upon discovery time was not considered, since they play a very minor role in the detection problem in northern California.

ATMOSPHERIC OBSCURITY

The degree of atmospheric obscurity was measured in terms of the clearness with which objects in the landscape could be seen. Because of suppression of many of the fires before they could be discovered by all the lookouts under poor atmospheric visibility conditions, data on

⁵ BENNETT, M. G. A VISIBILITY METER. Jour. Sci. Instruments 8: 123-126, illus. 1931.

the influence of atmospheric obscurity are incomplete. Analysis of all the discoveries recorded, however, shows little quantitative relationship between the visibility of natural objects in the landscape and discovery time. This indicates that the concentration of particles in the atmosphere has a different effect upon the visibility of a smoke column from that upon the visibility of the landscape. Further work is required to find a more satisfactory method of measuring the degree of atmospheric obscurity as an influence on fire detection.

In order to simplify the analysis of the remaining factors, the range of atmospheric visibility encountered was divided into three broad classes based on visibility-meter ratings, and only those discoveries were used that fell within the upper class, representing excellent to moderate atmospheric transparency. This group constitutes approximately 86 percent of the observations made.

BACKGROUND

Green ponderosa pine timber, brush fields, mixtures of brush and timber in various proportions, and open flats covered with dry grass made up the backgrounds against which the test-fire smokes were observed. These were segregated into two classes to which differences in discovery time could be definitely attributed. The first and larger group includes the dark-colored backgrounds of brush, timber, and mixtures of the two. The data show no differences in discovery time caused by differences in background within this group.

The light-colored backgrounds of dry grass comprise only a very small portion of the experimental data and are insufficient in number to permit of detailed analysis. A summary of the data reveals quite definitely, however, that, under the same weather and fuel conditions, discovery time of smokes observed against backgrounds of dry grass is longer and much more erratic than that against the darker backgrounds of brush and timber.

A brief consideration of the factors controlling the intrinsic visibility of objects explains this. An object is visible to an observer because of contrasts in either brightness or color between the object and its background, or because of a combination of the two contrasts.⁶ When either type of contrast is of a low degree, the other must be of a much higher degree, to cause the object to be visible. Smokes observed against brush and timber backgrounds are always brighter than their backgrounds and normally present a strong contrast in both brightness and color. Even when one type of contrast is low, the other is usually sufficiently strong to make the smoke visible. Smokes observed against the sky or dry-grass backgrounds, on the other hand, may be either somewhat brighter or less bright than their backgrounds or of the same brightness as their backgrounds, resulting in a low degree of contrast. This, combined with low color contrasts between smokes and light-colored backgrounds, causes such smokes to have a relatively low degree of visibility. Under these conditions such a fire, considerably prolonged, may not be discovered until the smoke column becomes large enough to appear against an adjacent darker background or to become visible through its increased size and

⁶ NETTING, P. G. THE VISIBILITY OF RADIATION. A RECALCULATION OF KÖNIG'S DATA. U. S. Bur. Standards Bull. 7, 235-238. 1911.

REPORT OF STANDARDS COMMITTEE ON VISUAL SENSITOMETRY. Jour. Optical Soc. Amer. 4: 55-79, illus. 1920.

changing brightness with increase in volume and density. Analysis of the remaining factors is confined to smokes showing against dark backgrounds.

DISTANCE

It is impossible to isolate completely the factor of distance between fire and observer. In a perfectly transparent atmosphere, the only effect of distance is to control the visual angle subtended by the smoke column at the eye of the observer. Within the limits of the experimental data, this effect is negligible when expressed in minutes of discovery time. Since the atmosphere is never completely transparent, however, the degree of transparency has an important influence on the apparent effect of distance upon discovery time.

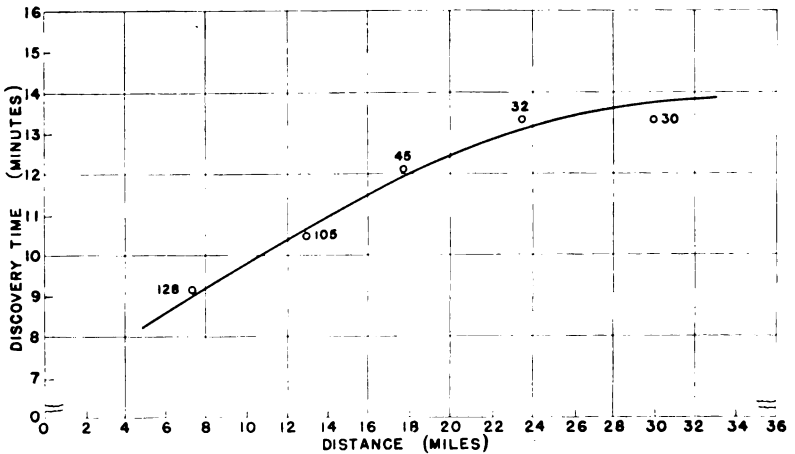


FIGURE 1.—Effect of distance upon the discovery time of pine fires under favorable atmospheric visibility. The figures on the curve indicate the number of observations taken.

The curve in figure 1, showing the increase in discovery time attributed to increases in distance, represents observations made under average good visibility rather than optimum conditions and therefore includes some effect of atmospheric obscurity. Within the limits of 15 miles, which is usually accepted as the maximum effective radius of vision of lookout observers, average discovery time may be considered as a straight-line function of distance under normal conditions. Distances greater than 20 miles, on the other hand, have a decreasing effect on discovery time because fires allowed to burn long enough to become visible at these distances normally begin producing smoke at a greatly accelerated rate. After this acceleration has begun, a large column of smoke is formed which becomes visible at relatively long distances within a very short time.

ANGLE BETWEEN SUN AND OBSERVER

Prior to analysis of the field data, a laboratory experiment was performed ⁷ to determine the effect of direction of illumination upon the visibility of a smoke column under controlled laboratory condi-

⁷BUCK, C. C., and FONS, W. L. THE EFFECT OF DIRECTION OF ILLUMINATION UPON THE VISIBILITY OF A SMOKE COLUMN. *Jour. Agr. Research* 51: 967-918, illus. 1935.

tions. From this experiment several conclusions were drawn, the most important of which was that the position of the light source (sun) with respect to the observer's line of sight, together with the concentration of particles in the smoke column, has a very definite effect upon the visibility of the smoke column. The results of this study materially aided in the analysis of this phase of the field data.

Following the trends indicated in the laboratory experiment, the effect of relative position of the sun upon discovery time was determined, as shown in figure 2.

This effect may be expected to vary somewhat with the degree of atmospheric obscurity. This in turn varies with position of the sun in the same manner as does the brightness of a smoke column, since the degree of variation in either is caused by the concentration of particles of suspended matter. The net variation in the visibility of the smoke column and its corresponding discovery time caused by variations in relative position of the sun is, therefore, determined by the relative concentrations of particles in the smoke column and in the atmosphere. Even under very adverse visibility conditions, however, in every observation made in the field with the sun behind the observer the discovery time of the fire was longer by at least a small margin than that of similar fires observed facing the sun.

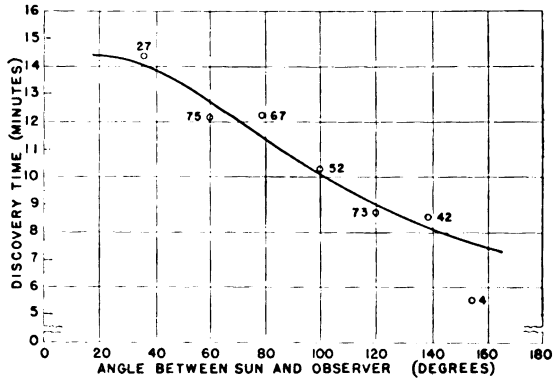


FIGURE 2.—Effect of relative position of the sun and observer's line of sight upon discovery time of pine fires under favorable atmospheric visibility. The figures on the curve indicate the number of observations taken. This is the angle with the smoke at the vertex and is the supplement of the angle measured at the observer between the sun and the smoke.

RATE OF SPREAD

Rate of spread is the principal element of fire behavior which influences the time required from the start of a fire for its smoke column to build up to the volume and density necessary to become visible to a lookout observer. Despite certain disadvantages, the unit of measure of this factor in the analysis was taken to be the average rate of spread for the first 8 minutes, since all fires were allowed to burn for at least this period. As a measure of rate of spread, average diameter, total perimeter, and area in square feet were all tried, but the last proved the most satisfactory in relation to discovery time. No usable relationship was found to exist between the size of a fire at any given moment and the size and density of its smoke column.

Figure 3 shows the average effect of the rate of spread of pine fires upon their discovery time under favorable atmospheric visibility. It will be noticed that discovery time decreases only slowly after rates of spread of approximately 40 square feet per minute are exceeded. This is due in part to the increased wind velocity responsible for the increased rate of spread, which undoubtedly has a marked influence

in keeping the smoke from rising above the timber crowns where it can be seen. Further, a rather definite minimum discovery time is determined by the failure of a fire to produce smoke for the first 1 or 2 minutes.

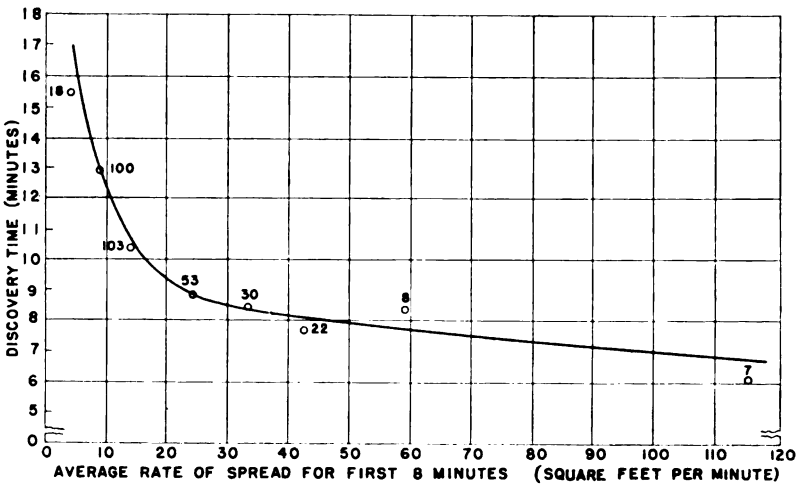


FIGURE 3.—Effect of average rate of spread upon the discovery time of pine fires under favorable atmospheric visibility. The figures on the curve indicate the number of observations taken.

COMBINED EFFECT OF RATE OF SPREAD, DISTANCE, AND POSITION OF THE SUN ON DISCOVERY TIME

To show graphically the combined influence of distance, position of the sun, and rate of spread upon discovery time, it is necessary either to make use of three-dimensional figures or to represent the influences of two of them with a single term. Analysis of the individual effects

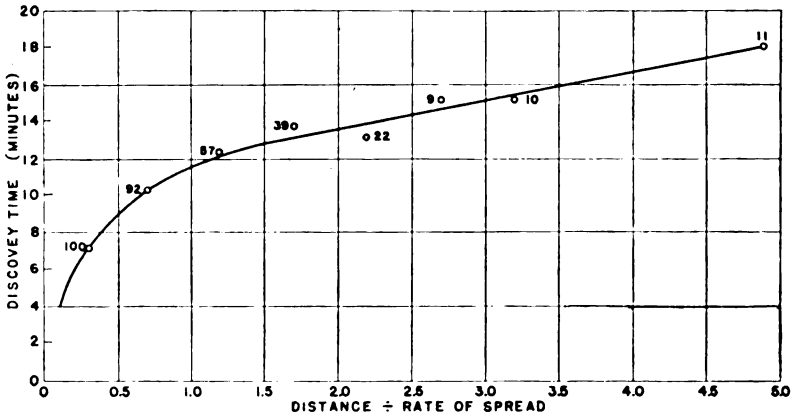


FIGURE 4.—Discovery time expressed as a function of the ratio between distance in miles and average rate of spread in square feet per minute for the first 8 minutes. The figures on the curve indicate the number of observations taken.

revealed that the latter method, involving the expression of discovery time as a function of the ratio between distance and rate of spread, could be used satisfactorily within the limits of the experimental data. This relationship is shown in figure 4 and indicates that under similar

conditions of position of the sun and atmospheric visibility, the discovery time of a fire 10 miles distant burning at an average rate of 25 square feet per minute for the first 8 minutes will be the same as that of a fire 20 miles distant burning at an average rate of 50 square feet per minute.

In figure 5, average rate of spread for the first 8 minutes and distance are represented on logarithmic scales in *A*. The ratio of distance to rate of spread is represented on a logarithmic scale by the diagonal lines in *A* which become the abscissae in *B*. Discovery time for different angles between sun and observer is plotted as the

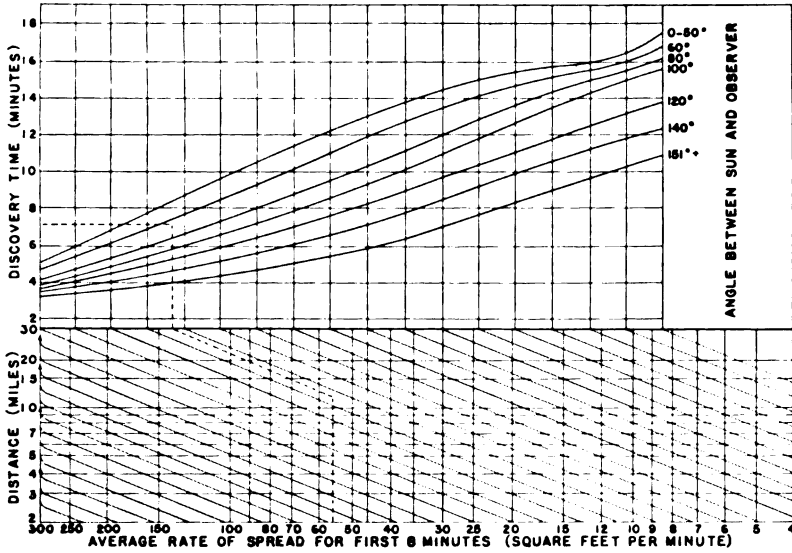


FIGURE 5.—Combined effects of average rate of spread, distance, and angle between sun and observer upon the discovery time of pine fires observed against brush and timber backgrounds under favorable atmospheric visibility. Example (shown by dotted line): Rate of spread 55 square feet per minute, distance 12 miles, angle between sun and observer 65°; discovery time 7.1 minutes.

ordinate in *B*. A total of 340 discoveries form the basis of this set of curves. Discovery time may be estimated from figure 5 in the manner illustrated by the broken line in the diagram.

Example: Rate of spread, 55 square feet per minute; distance, 12 miles; angle between sun and observer, 65°. Start at the value 55 on bottom scale and read vertically to distance 12 on lower left-hand scale; from this point follow upward to the left, parallel to the diagonal lines, to the heavy horizontal line, then vertically to the value 65° obtained by interpolating between the curves for 60° and 80°; discovery time is read on the upper left-hand scale opposite this point, 7.1 minutes.

A comparison of actual discovery times with estimated values from figure 5 indicates a relatively high degree of accuracy for observations during the middle of the day. Observations made at 7, 8, and 9 a. m. are more erratic. The heat from early morning fires is usually insufficient to puncture the inversion layer which characteristically persists in the experimental area from 15 to 30 feet above the ground at that time of day. The rising column of thin smoke from these early morning fires, upon striking the inversion layer, spreads out in

a horizontal plane and is soon dissipated. Discovery times of these fires may exceed the estimated values by as much as 10 minutes. Deviations of midday observations from the estimated values may nearly all be attributed to atmospheric obscurity. The experimental observations cover a range of distances from 3 to 33 miles and at the upper limits of this range even a slight haziness in the atmosphere undoubtedly has a detrimental effect upon discovery time.

SUMMARY

Better planning of protection organization developments and activities and better utilization of available man power are promoted by providing a more certain definition of elapsed-time allowances between start of fires and discovery than can be obtained from individual fire records. Solution of the discovery-time problem can contribute materially to this end. As a first step in this direction, the three discovery-time factors—distance, rate of spread, and position of the sun—were measured and their interrelation with respect to discovery time determined. The importance of these measurements, as shown in the accompanying charts, is that they form a basis for future work and at the same time may be used as trends indicating relative variations in discovery time which may be of value in present fire-control planning work. Their value will be enhanced materially as quantitative measurements are made of the effects of each of the remaining factors.