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A Progress Report on Time Studies of the Fire Fighting Job

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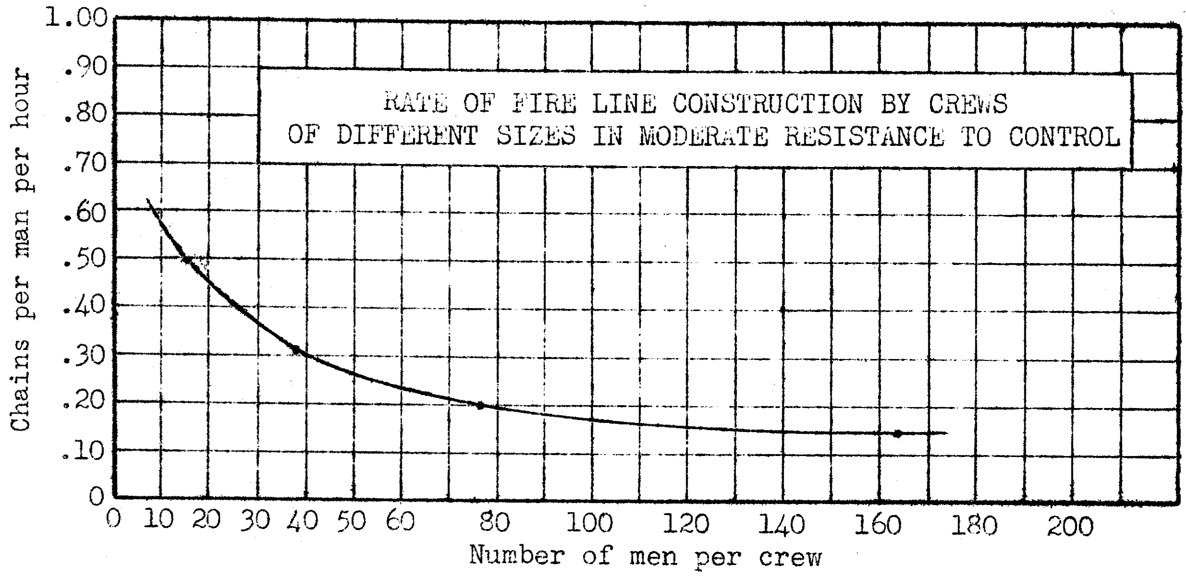

This graph indicates the following average rates of line production in crews of different sizes:

15 men produced 0.49 chain per man per hour.

30 men produced 0.36 chain per man per hour.

45 men produced 0.28 chain per man per hour.

60 men produced 0.23 chain per man per hour.

75 men produced 0.20 chain per man per hour.

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Fire fighting is still largely a hand-work job in the heavy cover and fuel conditions and rugged topography of the Douglas fir region, in spite of recent advances that have been made in the use of machinery. Controlling a fire in this region requires immense amounts of work per unit of fire perimeter, so that large numbers of men are required to attack all but the smallest fires. Therefore the per-man efficiency of the crews used in fire fighting is a vital concern. Under these conditions it becomes extremely important to determine how to use men most effectively, and therein lies the object of the study of which this is the progress report.

Long experience has taught the fire fighter that the most effective way to stop the spread of a forest fire is to rob it of fuel, and this is especially true in the heavier fuel types such as are found in the Douglas fir region. Thus the basic method of fire fighting in this region is the preparation of an effective break in the fuel mass ahead of the fire. Essentially this consists in cutting, clearing, and digging a line or trench through the fuel down to mineral soil along or parallel to the advancing edge of the fire. The width of this trench is not especially important because the trench itself does not stop the fire without additional work and attention. The completed trench must be patrolled to prevent fire from stealing across in rotten wood or roots or rolling across in live coals on steep ground; and all unconsumed fuel between the trench and the advancing fire should be burned out.

Although the trench itself, strictly speaking, does not stop the fire, nevertheless it is tremendously important to have such a trench and to have it correctly located and completely around the fire just as quickly as possible. Building the trench in heavy fuels, thick brush or thick stands of closely spaced reproduction requires a great deal of hand work to do the necessary clearing and to dig down to mineral soil. Indeed, clearing and digging the trench consumes a major portion of the fire-fighting time in the Douglas fir regioh.

The figures of output per man per hour of completed fire trench are astonishingly low. It is not at all uncommon to discover that when the total man hours worked to stop the spread of the fire as recorded on the fire report are compared to the total chains of line completed, rates of 0.05 to 0.10 chain (one chain equals 66 feet) per man per hour are pretty much the rule in the Douglas fir region.

Fire reports do not sharply segregate the time spent on trench building from time spent on patrol, mop-up, and other phases of fire fighting up to the time that trench building is completed; hence they tend to show rates that are too low. Nevertheless, since it is known that line construction consumes a major part of the fire-fighting job up to the time the trench is completed and the spread of fire is stopped, the low per-man production rates obtained from these records indicate a very low rate for this major operation.

Translated into fire-fighting costs, number of men required, and time necessary to surround a fire, these low production figures become tremendously important, especially on large fires. Thus if 10 miles of fire perimeter must be worked in 10 hours and the output is only 0.05 chain per man per hour, a crew of 1,600 workers is indicated. Recruiting, transporting, feeding, and supervising such a crew under fire-fighting conditions in the matter of a few hours is a colossal task, to say the least. Therefore it is but natural that considerable attention has been paid to ways and means of increasing the per-man production in fire fighting in order to reduce the number of men required.

This progress report summarizes the results of studies of per-man output in fire fighting obtained since the beginning of the study about 1935. Before presenting the results it will be necessary to explain the methods used.

Because of its importance and the large amount of time it consumes, the fire-line-construction job was singled out for study. Specifically, this includes such operations as clearing the line of brush, small trees, snags, vines, windfalls, rotten wood, and roots and digging a trench to mineral soil. It does not include such operations as burning out, backfiring, snag falling inside the line, patrol, or mop-up.

Actually it was not always possible to separate the operations as sharply as this because some burning out, backfiring, patrol, or mop-up may be done coincidentally with the line-construction job. All travel time to and from the fire line was eliminated. Rest periods of less than 30 minutes were included as working time. Supervisory overhead, water boys, etc. with the crew were included as workers. Packers, cooks, etc. not on the fire line were not included. The objective was to determine the number of men, the total number of hours worked on fire-line construction, and the total chains of fire line completed ready for mop-up in order to compute the output per man in terms of chains per man per hour.

Admittedly, the results are not very precise because of the many difficulties encountered in attempting to keep track of a crew of men strung out along an active fire over a constantly changing distance of one-fourth mile to one mile or more. Early in the study it was found that the best way to get worth-while records was for one trained man to devote all of his time to following the crew and making the necessary notes. The usual procedure was for this man to follow along behind the crew, pace each chain of completed line, and rate it as being either <u>low</u>, <u>moderate</u>, <u>high</u>, or <u>extreme</u> resistance to control according to the standard fuel-type classification used in the region, and to make note of the number of men and the hours worked. Thus the essential record of one shift or work period of one crew might have the following data:

30 chains rated <u>low</u>
<u>10</u> chains rated <u>moderate</u>
40 chains, total worked

10 men (including straw boss) worked 4 hours
or a total of 40 man hours.

Chains per man per hour = 1.00.

The chain-by-chain rating of the completed line is an essential part of the study because without some such system it would be impossible to compare the output of different crews. For example, by definition the 4 resistance-to-control classes have approximately the numerical relationship 1-2-4-8; <u>low</u> is unity, <u>moderate</u> is 2 times, <u>high</u> 4 times, and <u>extreme</u> 8 times as difficult as <u>low</u>. (Example: If 1 man can produce 1 chain of fire line in 1 hour in <u>low</u> he will produce about 0.50 chain in <u>moderate</u>, about .25 chain in <u>high</u>, and about 0.125 chain or less in <u>extreme</u> resistance to control.) Having rated each chain of line constructed by each crew, it is possible to compute a rough average rating of each crew's line and to compute approximately what the output per man per hour of the different crews would be if they were all working under uniform resistance-to-control conditions. For example, the data explained above would be recomputed as follows:

30 chains <u>low</u> = 30 x 1 = 30
10 chains <u>moderate</u> = 10 x 2 = <u>20</u>
50 ÷ 40 = 1.25.

The average resistance-to-control rating of this 40 chains of line is 1.25, with a production rate of 1.00 chain per man per hour. If the resistance-to-control rating were all <u>moderate</u> or 2.0, 0.62 chain per man per hour would be produced. (1.25:2::x:1.00.) The performance of this crew would be plotted in the figure (on the cover) as 10 men, 0.62 chain per man per hour, and would be comparable with the rate per man per hour of all the other crews similarly computed.

The data summarized in this figure were gathered on 40 units of fire line which were grouped as follows:

Eight crews of from 10 to 20 men (average 15 men) produced an average of 0.49 chain per man per hour.

Nineteen crews of from 21 to 55 men (average 38 men) produced an average of 0.31 chain per man per hour.

Seven crews of from 56 to 105 men (average 76 men) produced an average of 0.20 chain per man per hour.

Six crews of from 106 to 212 men (average 163 men) produced an average of 0.15 chain per man per hour.

The production rates obtained represent the work of many different kinds of crews--CCC's, loggers, and "pick-ups"--working under a wide range of conditions on the national forests and private lands of the Douglas fir region. Some of the data were collected by the administrative personnel of the national forests, but most of them were obtained by the research personnel of the Experiment Station. Most of the crews were organized according to patterns in vogue before the "one-lick method" was developed. In this discussion a crew is the total aggregation of men working on one unit of fire line regardless of the number of internal subdivisions into straw-boss or foreman groups. Each unit of line varied in length from 10 chains for the shortest to 196 chains for the longest with an average length of 69 chains.

In almost all cases each unit of line was worked in one shift or working period, and most of these working periods were from 3 to 10 hours in length. The data reveal only a very slight effect of length of working period; i.e., there is only a slight tendency for the lowest rates per man per hour to be associated with the longest shifts. Thus it appears that a somewhat more intensive study would be required to show the effect of fatigue. Probably the fact that most of the work periods were under 10 hours is the principal reason why these data do not yield very much information on the effect of fatigue.

Studies were also made of the reports on 1,564 fires controlled in the first work period by crews of from 1 to 30 men, and there again a strong tendency was revealed for output per man per hour to decrease as the number of men working on the fire increased, although the fire reports do not sharply separate time spent on fire-line production from other control work. This analysis also indicated that the longer the period worked the lower the rate of output per man per hour. More recently, time and production records obtained in the field by the record keeper of the experimental 40-man crew assigned to Region Six of the Forest Service (Washington and Oregon) on 19 units of fire perimeter were analyzed, and these indicate that after making the resistance to control roughly comparable (<u>moderate</u>), in the 11 cases where the crews working on line construction contained less than 18 men (10 to 17 men) they produced 1.31 chains per man per hour, but that in the 8 cases where the crews working under comparable conditions contained 18 or more men (18 to 29 men) they produced 0.93 chain per man per hour. These records, which were based upon the performance of one crew and measured under one standard procedure, are probably as comparable as any that have been collected in this region. They show a strong tendency for the output per man to decrease as the size of an individual crew increases, although they cover a comparatively narrow range in size of crew.

Examination of the figure (on the cover) reveals the most important fact uncovered by this study to date: Chains produced per man per hour decreases as the size of crew increases. Thus, 15 men produce at an average rate of 0.49 chain per man per hour, but 75 men produce only 0.20 chain per man per hour. If this is true--and there appears to be no reason to doubt but that some such relationship between size of crew and output per man does actually exist--it would indicate a principle that should be tremendously important in planning control work on a fire. The four elements of the fire control equation are: (1) time, (2) work to be done, (3) manpower, (4) cost. Time must be short to make the work successful. Work to be done is fixed for a given time and place. The number of men employed can be increased or decreased to meet the time and work requirements. How does this affect costs? Suppose there is one mile of line to build through cover with a resistance-to-control rating of <u>moderate</u>. Based on the output per man per hour shown in the figure, 15 men producing 0.49 chain per man per hour can produce one mile of such line in 10.9 hours and 75 men producing 0.20 chain per man per hour will do the same job in 5.3 hours. In this example it takes 5 times as many men and costs at least 5 times as much to cut the time in half. In figuring the cost of the 75 men full weight should be given to cost of the overhead, transportation, and camp facilities required for the larger crew. This is but one of innumerable problems of this kind that might be cited to show how an executive can use the effect of size of crew in deciding how much he can afford to pay in order to meet a given time specification or deciding when the number of men has reached the point of diminishing returns. It is also only one application of the principle that output per man per hour decreases as the size of crew increases.

It should be worth-while to speculate a little as to why size of crew has such a drastic effect on output per man per hour in fire fighting. Although it is common knowledge that nonproductive time tends to increase and output per man per hour tends to decrease with an increase in the size of crew on almost any kind of manual labor, nevertheless this tendency seems to be especially strong with fire-fighting crews. What is peculiar about the fire-fighting job that makes crew size so important?

The one outstanding characteristic of fire fighting seems to be the fact that the work is spread out over long distances. Thus the job is measured in terms of chains or miles of fire perimeter to be worked; and therein probably lies one special reason why size of crew affects fire-fighting efficiency over and above what might be expected as the normal effect of size of crew. Fire fighting involves a great deal of walking on the job as well as the actual work of chopping, clearing, digging, etc. to be done; and the more in the crew, the more men there are to walk over the same ground to do the same amount of work. If the walking time is thought of as being nonproductive time, an increase in the number of men going over the line increases the nonproductive time without any offsetting advantage in the productive work done per man. The amount of work to be done on a mile of fire perimeter remains constant whether it is attacked by 10 men or 50 men, but 50 men spend 5 times as much time walking as 10 men going over the same ground. Other nonproductive time, such as the time spent in waiting and resting, is also multiplied without any compensating gains when the size of the crew is increased.

The following examples will show how important the walking time may be:

Consider that the fire-fighting job on any one unit (chain, mile, etc.) of fire perimeter consists of two parts:

1. Walk one unit (nonproductive time).

2. Do the chopping, cutting, and digging work required to produce one unit of fire line (productive time).

Suppose the following is estimated to be the time required to do these two things on one mile of fire line in a <u>low</u> (resistance-to-control) fuel type:

1. Walk one mile, 30 minutes (including rests, stops, etc.).

2. Work 15 minutes per chain or 1,200 minutes per mile.

On this basis it is possible to compute and compare the rate of fire-line construction per man per hour in different-sized crews; for example, to compare a 10-man crew and a 60-man crew:

<u>10 men</u>

Walk 10 x 30 minutes = 300 minutes per mile.
Work 1,200 minutes per mile.
Total time, walk and work, per mile = 1,500 minutes = 25 man hours to produce 80 chains = 3.2 chains per man per hour.

<u>60 men</u>

Walk 60 x 30 minutes = 1,800 minutes per mile.
Work 1,200 minutes per mile.
Total time, walk and work, per mile = 3,000 minutes = 50 man hours to produce 80 chains = 1.6 chains per man per hour.

Under these assumed conditions the per-man production of fire line by members of a 10-man crew is twice the rate per man in a 60-man crew covering the same ground and doing the same amount of work.

Thus the large amount of walking on the job required in fire fighting seems to be an important factor in explaining why output per man drops rapidly as the size of crew increases. However, nonproductive time of any kind--waiting, resting, or loafing--works in a similar way to reduce per-man output as the size of crew increases. Large crews do not have any offsetting advantages to increase the efficiency of the individual crew members; furthermore, it is common knowledge that walking on the job is likely to be at a slower rate and that time spent in waiting, resting, or loafing is almost certain to increase with size of crew. Therefore these nonproductive time elements tend to pyramid; they increase in amount and they are at the same time multiplied by the number of men in the crew.

Applications of the Study

If it is true that the decrease in useful work as the size of crew increases is due principally to two elements, (1) time spent in walking on the job and (2) other nonproductive time such as waiting, resting, or loafing, the following conclusions and applications are pertinent:

1. Organizing a large crew into small units (e.g., straw-boss units of 8 or 10 men) or according to special patterns like the "one-lick method" may have a very worth-while effect in decreasing the nonproductive time due to waiting, resting, loafing, and other inefficiencies that tend to increase as the size of the crew increases and supervision is spread out thinner and thinner; but the internal organization of the crew cannot materially reduce the effect of walking as an important element of nonproductive time in fire fighting so long as all the men in the crew work from one end of the line to the other. Thus five 10-man crews working from the beginning to the end of a mile of fire line have just as much walking on the job to do as 50 men covering the same ground in one crew. However, if there were a road along the mile of line to be worked and each of the five 10-man crews could be transported to and work simultaneously upon one-fifth of the mile, then a very real saving in walking time on the job could be made by breaking the 50 men up into small crews because each man would have to walk only one-fifth of a mile while working.

2. The effect of size of crew will be most pronounced in fuel types having <u>low</u> or <u>moderate</u> resistance to control and less important in <u>high</u> or <u>extreme</u> resistance to control. Thus there is less loss in efficiency in working a large crew where there is a great deal of work to be done per unit of line than where there is very little work to be done per unit of line. This is true because the effect of crew size is most pronounced when the nonproductive time is large in comparison to the productive time. An example of how this might work out is shown by the following theoretical values computed as indicated in the table. (This table is not based on the data obtained in the study.)

Theoretical effect of size of crew on chains per man per hour of fire-line construction by resistance-to-control classes

Number of workers in crew	LOW Walk 30 min. per mile per man, work 15 min. per chain or 1200 min. per mile	MODERATE Walk 35 min. per mile per man, work 30 min. per chain or 2400 min. per mile	HIGH Walk 40 min. per mmile per man, work 60 min. per chain or 4800 min. per mile
	Chains per man per hour	Chains per man per hour	Chains per man per hour
10	3.2	1.7	.92
20	2.7	1.5	.86
30	2.3	1.4	.80
40	2.0	1.3	.75
50	1.8	1.2	.71
60	1.6	1.1	.67
80	1.3	.9	.60
100	1.1	.8	.55

3. Time is an important element in fire fighting and from the above it follows that the point of diminishing returns in saving time by increasing the size of the crew is reached with smaller crews in low resistance fuel types than in high resistance fuel types. An example of how this might work out is shown by the following theoretical values computed as indicated in the table. (The table is not based on the data obtained in the study.)

Theoretical effect of size of crew on the time required to construct one mile of fire line by resistance-to-control classes

Number of workers in crew	LOW Walk 30 min. per mile per man, work 15 min. per chain or 1200 min. per mile	MODERATE Walk 35 min. per mile per man, work 30 min. per chain or 2400 min. per mile	HIGH Walk 40 min. per mile per man, work 60 min. per chain or 4800 min. per mile
	Hours	Hours	Hours
10	2.5	4.6	8.7
20	1.5	2.3	4.7
30	1.2	1.9	3.3
40	1.0	1.6	2.7
50	.9	1.4	2.3
60	.8	1.2	2.0
80	.8	1.1	1.7
100	.7	1.0	1.5

This table indicates that in a low resistance-to-control type there is very little advantage from the standpoint of saving time in using more than 30 or 40 men in a crew, whereas in high resistance-to-control types substantial saving in time may be made by using crews of 60 or 80 men.

4. These tables of theoretical estimated values should not be taken literally; i.e., the values in the tables may not be the true values under actual field conditions. Under actual conditions other nonproductive time in addition to walking time on the job should be included in the calculations, and the total amount of nonproductive time per man would be increased as the size of the crew increases. These simple tables are given to show how the fire-fighting job can be broken down and analyzed. They indicate how local conditions and estimates of productive and nonproductive time might be used to obtain relative values that might have important implications for local use.

5. Since the effect of nonproductive time spent in waiting, resting, and loafing tends to increase with size of crew, it follows that good management and crew organization should strive to reduce all such nonproductive time to a minimum. Example of how a very simple item can run into important amounts of time: If men can stop at a spring and take one minute each to get a drink and fill their canteens, 10 men can all get water and be on their way after stopping for 10 minutes. Twenty men can easily take 20 minutes each for the same stop, and there is a very real probability that 50 men would all stop 50 minutes at the spring or much more than the 5 or 10 minutes each such a stop should take unless they are organized and supervised to eliminate just such time wasters.

6. How knowledge of the effect of size of crew can be applied to fire-fighting strategy is indicated by the following examples:

(a) It is more efficient to divide a crew into two parts and send each part around a fire in a different direction than to send all the men in one crew in one direction. (This holds true unless the behavior of the fire itself indicates that all the men should be concentrated on one side.)

Example: 100 men work in one crew around a fire with two miles of perimeter. From theoretical values above for <u>low</u> resistance to control it will take them 1.4 hours to work around the fire. By the same table, two 50-man crews working on two different sides of the fire should complete the same job in 0.9 hour, a saving of one-half hour.

(b) Wherever it is practical to do so men should be divided into small crews and transported by motor (not walked!) to as many small units of fire line as possible. Example: Suppose there are 10 miles of line to work on a fire in a <u>low</u> resistance fuel type. According to the above theoretical figures two 50-man crews each working half the perimeter will take 4.5 hours to surround the fire. (100 men in one crew would take 7 hours.) Ten separate 10-man crews, each transported to and assigned one mile and all working at the same time, could do the same job in 2.5 hours, a saving of almost half the time of two 50-man crews (and a saving of about two-thirds the time of one 100-man crew).

(c) Since the time spent in walking crews to and from the fire line is also nonproductive time and has a similar depressing effect on per-man output of productive work and is subject to the same effect of size of crew as walking on the job, it follows that any reduction of walking time to and from the fire by use of motor equipment or by camping on or near the fire line offers very real possibilities of increasing the effective per-man output of fire fighters.