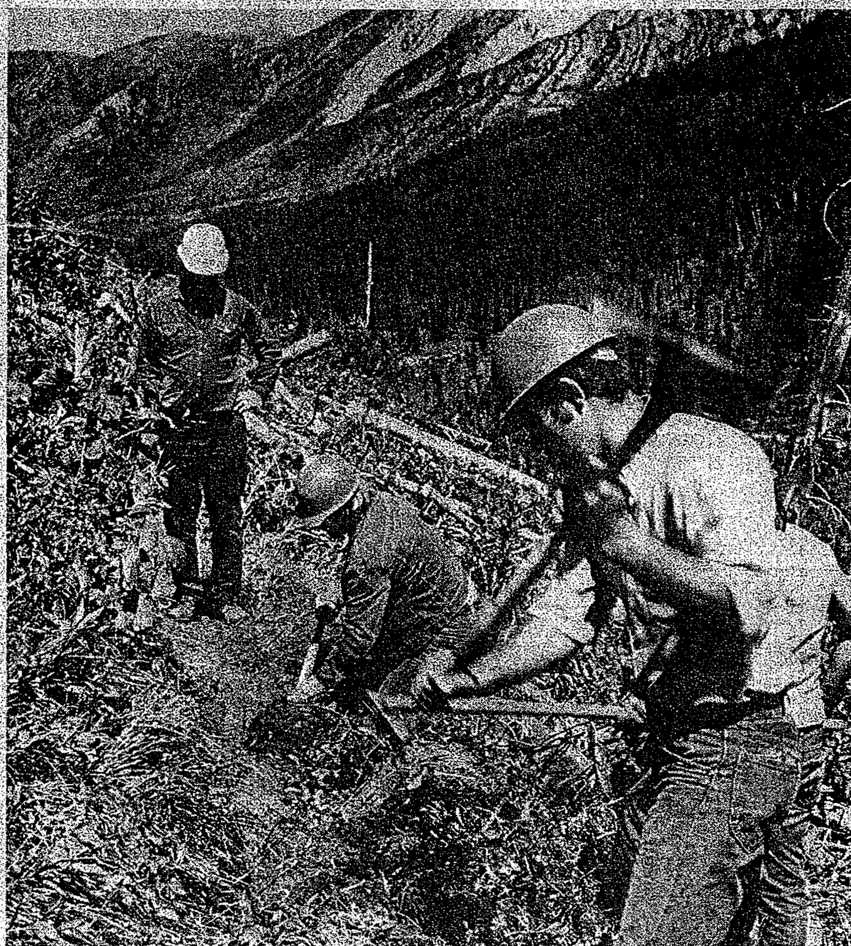
Fisheries and Environment Canada
Forestry Service
Pêches et Environnement Canada
Service des forêts

Handcrew fire-line construction: A method of estimating production rates



P.J. Murphy and D. Quintilio

Northern Forest Research Centre • Edmonton, Alberta • Information Report NOR-X-197

Handcrew fire-line construction: A method of estimating production rates

by

P.J. Murphy

D. Quintilio

Information Report NOR-X-197

January, 1978

Northern Forest Research Centre

Canadian Forestry Service

Fisheries and Environment Canada

5320-122 St

Edmonton, Alberta

T6H 3S5

Murphy, P.J.[1] and D. Quintilio. 1978. Handcrew fire-line construction: A method of estimating production rates. Fish. Environ. Can., Can. For. Serv., North. For. Res. Cent. Inf. Rep. NOR-X-197.

ABSTRACT

Trained handcrews were observed while building fire-line in common forest cover (fuel) types of Alberta, the Yukon, and the Northwest Territories in order to determine average production rates. A method of estimating fuel resistance of forest stand components, ie., tree cover, brush, deadfall or slash, and duff was devised and tested. Resistance index values for individual stand components are correlated directly to fire-line production rates. Fire control staff can use appropriate resistance index values according to a particular stand makeup, total the values, and predict the fire-line production for the overall fuel complex. A modular design enables addition of envircnmental influences as necessary.

Résumé

Des équipes de travaux manuels entraînées furent observées pendant qu'elles construisaient une ligne d'arrêt en des types (combustibles) de couvert forestier communs de l'Alberta et des Territoire du Nord-Ouest et du Yukon afin

[1] Professor and Chairman, Department of Forest Science, The University of Alberta.

de déterminer les taux moyens de production. Une méthode d'estimation de la résistance combustible des différents éléments d'un peuplement forestier, i.e, couvert forestier, brousse, arbres morts ou rémanents, et litière, fut conçue et essayée. L'indice de résistance des éléments individuels d'un peuplement a des valeurs en corrélation directe avec les taux de production des lignes d'arrêt. Le personnel de répression des feux peut assigner des valeurs d'indice de résistance à un peuplement de formation particulière, totaliser les valeurs, et prévoir l'efficacité (taux de production) de la ligne d'arrêt convenant au complexe combustible global. Un design modulaire permet l'addition d'influences du milieu si nécessaire.

CONTENTS

	PAGE
INTRODUCTION	1
FUEL RESISTANCE TO HANDTOOLS	2
STUDY METHOD	4
RESULTS	9
Fuel Resistance	9
Rates of Line Çonstruction	15
DISCUSSION	20
ACKNOWLEDGMENTS	23
LITERATURE CITED	24
APPENDIXES	25

I Fireline construction rates by resistance factors - Detailed Forest Inventory - Alberta Forest Service - (English Units)

II Fireline construction rates by resistance factors - Phase 3 Inventory - Alberta Forest Service - (English Units)

III Conversion of Index to production rate - (English Units)

INTRODUCTION

Trained men properly equipped with handtools are an important element of fire control in Canada. Handcrews are utilized during the critical initial attack period and in the sustained campaign fire operation. In both cases a knowledge of fire-line building rates is necessary in planning for efficient use of manpower. To date, handcrew strategy in Canada has been dependent on estimated production rates by experienced field personnel and to some extent on published U.S. Forest Service information (Storey 1969, Lindquist 1970, Ramberg 1974).

In 1973 a need was expressed for quantitative fire-line production rates for trained handcrews working in Boreal Forest (fuel) types. The information collected would be used to improve manpower allocation on initial attack and campaign fire operations and as input for current simulation modelling (Quintilio and Anderson 1976, Davis and Irwin 1976). This study was subsequently designed and implemented to (1) develop a system for describing fuel resistance to handtools and (2) determine fire-line building rates for broad fuel-resistance classes.

Initially, an attempt was made to observe crews working on going wildfires; however, the logistics and random choice of forest cover types proved unsatisfactoryand a systematic procedure was developed to measure fire-line construction of typical suppression crews in pre-selected areas.

FUEL RESISTANCE TO HANDTOOLS

There is very little available literature describing fuel resistance to handtools. References in agency manuals usually describe resistance in terms of fuel types--descriptive summaries of living and dead plant material associations. The U.S. Forest Service Firefighters Physiological Study conducted by Ramberg (1974) used the Bureau of Land Management [n.d.] fuel type descriptions as a basis. However, these totalled 201 descriptions, ranging from 10 in Alaska to 62 in the Colorado-Wyoming region. This approach seemed rather complex, and did not appear to be adaptable to the variations found in Canada.

During initial field work in 1973, it became evident that the line-building job involved four major resistance factors (Table 1). These included removing trees, removing brush, removing deadfall or slash, and digging a trench to mineral soil. It was decided, therefore, to observe crews working on the components separately and determine each component's contribution to overall resistance. We could then try to relate rates of line construction to various combinations of these factors. This, in essence, was the procedure used during the field seasons of 1974 and 1975.

Table 1.

RESISTANCE FACTORS

1. Removing trees

    falling
    bucking
    removing

    - varies with stand density and height class

2. Removing brush

    cutting
    removing

    - varies with density and height class

3. Removing deadfall or slash

    bucking
    removing

    - varies with pieces -- size and numbers or weight per unit area

4. Digging trench to mineral soil

    cutting sides
    loosening
    removing

    - varies with depth to mineral soil
    - affected by root resistance
      stoniness

STUDY METHOD

A total of 21 fuel types was sampled in 1974. Two of these were located north of Fort McMurray, the balance lying in the Slave Lake-Grouard-Swan Hills area. An additional 30 fuel types were sampled in 1975 for a total of 51. The 1975 sampling was conducted in the Bow-Crow Forest (20) and the Footner Lake Forest (10). Fire-line construction was performed by three experienced men in every case. (Fig 1)

In each fuel type a variety of data was collected describing the tree cover, brush cover, deadfall or slash, and soil conditions. A fire line was located by hanging up flagging for a distance of 100 m (5 chains). The line was then walked with the crew boss to discuss selection of the most appropriate tools and organization of his crew.

The first step normally consisted of removing the tree cover, if the fuel type required falling. This operation was conducted over a distance of 100 m, or for a work period of 20 min (whichever came first) in order to avoid psychological variables associated with crews attempting to achieve their own goals or filling in time. The second step consisted of removing the brush over the length of line cleared of trees. This was followed by removal of deadfall or slash and trenching to mineral soil. The latter three steps were also terminated at 20 min if the job had not been completed.

In every case, the study objectives were first reviewed and the crew was instructed to work at a production rate that they felt they could sustain over an extended period. The level of production was believed to be reasonably consistent throughout all stages of these trials. Maintenance of handtools was also stressed; tools were put into good shape before every trial.

Several assumptions basic to the methodology of the study are discussed below.

1) Psychological

There appears to be a real difference in rates of fire-line production depending upon whether it is initial attack with a chance for success or fire-line production on a campaign fire. In this study, rates are based on production that might be sustained over an 8-h shift on a campaign fire. In using the resulting tables, it should be understood that production rates would be a little higher in initial attack situations.

2) Units of Line Production

All rates of production were expressed in terms of lineal units per man-hour based on the number of men actually using tools. Lindquist (1970) expressed rates of line construction in California in terms of square yards per man-hour, which recognizes the effect of line width. This was an adaptation to the brush fuel types that are were predominant in that region.

It was decided in this study to build fire line as wide as necessary for that particular fuel type in order to hold a vigorous surface fire, and to measure the lineal rate. This criterion is a subjective one, but line widths were discussed with the crew boss and later with the fire control officer. Where the actual line appeared to be too wide or too narrow, a proportionate adjustment in rate was made in the computation.

Resistance to trenching was related to total depth to mineral soil. Trench widths were intended to be "shovel-wide", but averaged usually 35-40 cm.

3) Selection of Tools

The use of power saws can speed up line building, especially tree falling and bucking of large deadfall or slash. Fire control staff recognize this advantage, and power saws are commonly available where they are needed. It was assumed, then, that production would be achieved with whatever tools were suitable for that particular job. In some borderline situations, such as heavy brush or short tree cover, trials were conducted with both power saws and axes to provide comparative rates.

4) Crew Size

Smaller crews are believed to be more efficient because of closer supervision. In this study it was assumed that supervision would be adequate for whatever size of crew was used.

This is an important factor. In observations of the 25-

man crew building line, for example, the lead clearing squad invaribly moved ahead of the trenching squad, pointing out the importance of redistributing the workload among squads as the line progresses.

5) Working Time

The guidelines for rest breaks vary, but it was assumed that rest breaks and tool maintenance time would consume an average of 15 min every hour. Accordingly, all construction rates are expressed in terms of 45-min hours. The importance of rest and refreshment is discussed by Ramberg (1974). An attempt was made to obtain factors relating to fatigue, but without success.

6) Line Holding

No real indication of line holding requirements was obtained. The rates derived relate to line construction only. The fire boss would have to determine line-holding requirements on the basis of burning conditions. Line holding may be considered a part of line construction or as a separate function. In this study it was considered a separate function.

7) Hot Spotting and Cold Trailing

This technique is commonly used in the Boreal Forest as an alternative to constructing continuous trenched line to mineral soil. No reliable means of measuring rates using this method were determined. In using these tables, it must be recognized that hot spotting and cold trailing are generally faster than line trenching, so any errors should be on the safe side.

8) Training and Supervision

In determining fire-line production rates for this study it was assumed that there would be reasonable supervision and that crews would be proficient in the use of hand tools and construction of lines. It was evident among crews of all agencies that adequate supervision on the fire line is essential to obtain efficient handcrew performance.

9) Application

Line construction tables must be simple to apply in the field. On the other hand, they must also be responsive to or descriptive of fuel types to ensure a degree of uniformity in application. This approach has attempted to satisfy both requirements. Some further simplification may be possible as more data are obtained.

RESULTS

FUEL RESISTANCE

Actual average fire-line construction times for the various resistance factors are summarized in Table 2. These construction times were converted to relative values by dividing by a constant (.32) to reduce all values and then rounding off (Table 3). Where fuel-type categories were lacking in data, values were estimated and are indicated accordingly. (See Appendixes I and II for English measure conversions of Table 3).

Table 3 provides a matrix of index numbers that can be used to compare fuel-type resistance numerically. For example, a stand of trees with D density over 12 m in height, light brush under 2.5 m, light quantity of deadfall, and 15 cm of duff to mineral soil would have a resistance index of 4 + 1 + 1 + 13, or a total of 19. In contrast, an A density stand with no brush, no deadfall, and 2 cm of duff would have an index of 2. A crew should be able to build line at about 10 times the rate in the latter type.

Table 3 is structured so that index factors should be fairly simple to add to cover fatigue-related and environmental factors such as air temperature and topography if necessary. However, no quantification of these factors was possible in this study.

This method, then, provides a means of describing fuel resistance in specific terms that should make possible a more consistent interpretation. This approach should also make it possible to describe any combination of fuel-resistance factors, equating them in common numerical terms.

Some resistance-related points require specific comment.

1) Clearing Trees

Only the height and density class representing the cover type that will have to be removed should be selected. For example, in an A 4 stand there would normally be no trees to cut. However, if that stand had a B 2 understory, tree falling would be required, so the index figure for B 2 would be used.

2) Clearing Small Trees and Brush

a) Falling of trees over 12 m in height was done with a power saw, following normal practice. Brush and small trees under 2.5 m were normally cut with an axe or pulaski. However, for bush and trees in the 2.5 - to 12-m height range, either the power saw or axe/pulaski could be used. A total of 16 measurements was made in this category--8 with power saw and 8 with axe/pulaski. No significant difference could be shown in resistance between the two tools. Although chain-saw falling might be thought to be faster, one or two men are also needed for swamping behind the faller. With the axe/pulaski, all men are falling and swamping independently, which may account for the equivalent rate.

b) Only one brush type should be selected from the tables. For example, where there is a D density of both high and lcw brush, only the D density high brush index should be used, since it is the greater of the two.

3) Deadfall and Slash

Deadfall and slash quantities were estimated in terms of weight per unit area using the line intersect method (Van Wagner 1968). Total weights were correlated with the line-building effort (r=0.83), while a simple count of pieces >10 cm gave corelation coefficients of .91 for deadfall and .87 for slash.

A significant difference at the 1% level was noted between slopes for resistance to logging slash and deadfall (Freese 1967). Slash resistance is greater, probably because of the associated quantity of fine material that takes additional time to remove. The tables record separate indexes for these.

4) Trenching

a) Rocks

Rocks can increase resistance to trenching when there are many of them. It has been difficult to quantify this aspect, but some recognition appears warranted. The suggested (and estimated) guideline is to increase the Trenching Index by 50% if the soil contains over 60% rock.

b) Heavy Roots

The presence of heavy roots (defined as roots 5+ cm in in diameter) adds to trenching resistance. Where these are encountered in the heavy C-density stands, the index should be increased by 9.

c) V-trench

On steep slopes, V-trench is required on the lower edge of fires to catch rolling material. In the two tests we conducted (fuel type 75-14 and 75-15), there was no increase in resistance for V-trench over uphill trenching in the same type. Crew members commented that working into the slope and pulling the material downhill facilitated line building.

5) Slope

No measurable resistance due to slope up to 54% could be determined. Crew members commented that working upslope brought the work closer to them, and that gravity assisted in removing material from the line. The rate of line progression is such that uphill progress itself is not a strenuous activity compared to the energy expended in line construction.

Slope would undoubtedly have an effect if a crew were initially required to climb a great distance to get to work.

Table 2

AVERAGE FIRE-LINE CONSTRUCTION RATES BY RESISTANCE FACTORS

(man-minutes per metre)

1. TREES

STAND DENSITY	HEIGHT CLASS 1 (6-12 m)	2 (13-18 m)	3 (19-24 m)	4 (25-30 m)	5 (31+ m)
A 6 - 30%	nil (2)*				
B 31 - 50	0.75 (7)	0.47 (2)	nil (1)	nil (1)	
C 51 - 70		1.14 (4)	nil (2)	nil (2)	
D 71 - 100	2.46 (8)	1.26 (5)	1.30 (3)	1.44 (1)	

2. BRUSH

	HEIGHT 2.5 m and under	2.5-6 m
A 6 - 30%	0.32 (7)	
B 31 - 50	0.46 (6)	
C 51 - 70	0.74 (2)	0.60 (1)
D 71 - 100	0.88 (3)	1.50 (10)

3. DEADFALL OR SLASH

QUANTITY-PIECES 10+cm/30m

	DEADFALL	LOGGING SLASH
1 - 5	0.42	0.92
6 - 10	0.65	1.31
11 - 15	0.87	1.70
16 - 20	1.10	2.09
21 - 30	1.56	2.86
31 - 40	2.02	3.64
41 - 50	2.48	4.41
51 - 60	2.93	5.19

* figure in parenthesis indicates number of samples

4. TRENCHING

DEPTH (cm)	
2	0.50
5	1.61
10	2.88
15	4.15
20	5.43
25	6.70
30	7.97
35	9.24
40	10.51

Extensive roots 5+cm--add (3)

Table 3

RELATIVE FIRE-LINE CONSTRUCTION RATES BY RESISTANCE FACTORS (INDEX TABLE)

1. TREES

STAND DENSITY	HEIGHT CLASS 1 (6-12 m)	2 (13-18 m)	3 (19-24 m)	4 (25-30 m)	5 (31+ m)
A 6 - 30%	nil	(nil)*	(nil)	(nil)	(nil)
B 31 - 50	3	2	nil	nil	(nil)
C 51 - 70	(5)	4	nil	nil	(nil)
D 71 - 100	8	4	4	4	(4)

2. BRUSH

	HEIGHT 2.5 m and under	2.5-6 m
A 6 - 30%	1	(nil)
B 31 - 50	2	(1)
C 51 - 70	3	2
D 71 - 100	3	5

3. DEADFALL OR SLASH
QUANTITY-PIECES 10cm+/30m

	DEADFALL	LOGGING SLASH
1 - 5	1	3
6 - 10	2	4
11 - 15	3	5
16 - 20	4	7
21 - 30	5	9
31 - 40	6	11
41 - 50	8	14
51 - 60	9	16

* figures in parentheses are estimated

4. TRENCHING

DEPTH (cm)	INDEX
2	2
5	5
10	9
15	13
20	17
25	21
30	25
35	29
40	33

Extensive roots 5 cm+-- add 9
Rock resistance 60%+-- increase index by 50%

RATES OF LINE CONSTRUCTION

Once fuel-esistance index numbers for the four factors were developed, the next step was to prepare a working table relating index totals to fire-line construction rates. This was done by converting the actual time required for constructing line to equivalent rates, and relating them to the index numbers (Table 4). (See Appendex III for English measure conversion of Table 4.) In the examples cited earlier, the fuel type with a resistance index of 19 would likely result in a line production rate of 7 m/man-h while the fuel with resistance index of 2 would allow 70 m/man-h.

The index system was first tested against itself (Table 5). There were 38 fuel types in which all components were sampled. For each of these types two rates were compiled -- the actual measured rate, and the rate calculated by the index system. The mean index rate for the 21 types is less than the mean of the actual rates. This general situation probably results from selecting index figures on the conservative side in all borderline situations. Some of the individual differences can be explained in terms of smoothing of curves and averaging. A test for significance using a "t" test for paired observations (Freese 1967) in actual and index-derived rates indicated that the difference in means was not significant at the 1% level, and the correlation (r) value is .99.

The table of index rates was then compared to the 1973 and 1974 fire-line data obtained earlier in the study that had not been used to determine the index values (Table 6). Again, the mean rate determined by the indexes is less than the actual rate. The "t" test indicated that the difference in paired observations was not significant at the 1% level, and the correlation (r) value is .93.

Table 4

WORKING TABLE

- CONVERSION OF INDEX TO PRODUCTION RATES

INDEX	RATE (m/45-min h/man)	INDEX	RATE (m/45-min h/man)
1	140	36	
2	70	37	
3	47	38	
4	35	39	4
5	28	40	
6	23	41	
7	20	42	
8	17	43	
9	15	44	
10	14	45	
11	13	46	
12	12	47	
13	11	48	
14	10	49	3
15	9	50	
16	9	51	
17	8	52	
18	8	53	
19	7	54	
20	7	55	
21		56	
22		57	
23	6	58	
24		59	
25		60	
26		61	
27		62	
28	5	63	2
29		64	
30		65	
31		66	
32		67	
33	4	68	
34		69	
35		70	

Table 5

COMPARISON OF ACTUAL AND TABLE RATES

FUEL TYPE NO.	COVER TYPE	TABLE (m/45-min	ACTUAL h/man)
1-74	C4A	10	9
2	C 3 SwA	7	7
3	B 1 Sb	5	5
4	D 1 Sb	6	5
5	C 2 Sb	4	4
6	D 4 SwA	4	5
7	B 3 SwA	6	7
8A	Brush(Wi) 2.5-6m axe	6	6
8B	Brush(Wi) 2.5-6m powersaw	6	6
9	D 2y A	6	8
11	Old burn	8	9
12	C 3 P1	11	13
15	C 4 SwA	6	8
17	Brush(Wi) 2.5-6m	28	26
18	A 1 Pj	15	17
23	Old burn	11	13
25	D 2 A	5	4
26	D 3 Sw A	5	5
27	D 3 A	6	6
28	A 1 Pj	70	85
29	Brush(At) 2.5-6m	8	10
3-75	D 1 P1	10	9
4	D 1 P1	9	10
5	Brush(PL) 2.5-6m	14	11
6	D 2 P1	11	11
7	D 1 P1	8	9
8	D 3 P1	9	9
9	D 1 P1	6	6
10	B 1 FaP1	8	9
12-75	Logging slash	12	20
14	Logging slash	6	7
16	B 1 P1A	12	13
18	B 1 P1A	9	11
19	Logging slash	5	8
21	D 2 A	6	5
22	C 2 SwA	7	7
23	B 4 Sw	10	10
25	B 2 SwSb	9	10
MEAN		10	11

Test for significant difference

t(calc) = 2.18 t(01) = 2.70

No significant difference at the 1% level.

Table 6

COMPARISON OF OPERATIONAL RATES WITH TABLE RATES

(m/45-min h/man)

LOCATION	DATE	INDEX	TABLE RATE	ACTUAL RATE	CREW[1] SIZE	ATTA MODI
Lac La Biche Training	25 June 1973	19	7	9	20	T
Caribou Range Fire 21	27 June	18	8	8	9	I
Caribou Range Fire 21	28 June	6	23	43	4	I
Caribou Range Fire 21	28 June	6	23	49	5	I
Keg River Training	25 July	20	7	7	20	T
Keg River Training	26 July	20	7	6	22	T
Ft. Liard Fire 7	1 August	22	6	7	7	I
Ft. Liard Fire 7	2 August	22	6	3	14	L
Yukon Trial - Wi	27 August	27	5	5	10	T
Yukon Trial - Pj	27 August	5	28	34	6	T
Yukon Trial - Sb	28 August	31	5	6	6	T
High Prairie Training	25 July 1974	13	11	13	21	T
Keg River Training	15 July	13	11	9	21	T
Keg River Training	15 July	14	10	9	21	T
MEAN			11.2	14.9		

Test for significant difference

$t_{(calc)} = 1.59$ $t_{(01)} = 3.01$

No significant difference at the 1% level

1 Crew size refers to men with tools

2 I=Initial attack on uncontrolled fire

L=Line building on large fire

T=Training

DISCUSSION

Fuel resistance is the major factor affecting fire-line production rates in the Boreal Forest; fatique and heat are contributing secondary influences. These index tables provide a means for describing and comparing fuel resistance for handtools. The system is open-ended so that it can be adapted to other regions and fuel types as well.

The tables show where the high resistance factors are. For example, D density stands of trees requiring some falling have an index of 4, D density brush 2.5-6 m has an index of 5, and logging slash with 21-30 pieces 10 cm+ per 30 m has an index of 9. However, the major resistance factor is trenching; even a depth of 10 cm yields an index of 9, and depths of 30 cm run the index up to 35. In addition, the presence of heavy roots or stones in the soil adds an additional figure of 9 to 13 (estimated), respectively. These high indexes suggest the importance of trying to avoid such high-to-extreme types in line location wherever possible. Some reevaluation of trenching itself may be in order: considering the cold-trail and hot-spot techniques, or using power trenching equipment.

The calculation of probability factors and determination of the effects of temperature, fatigue, and possibly elevation will have to be determined in future studies. There may also be a difference in resistance to tree cover between decidious and coniferous species--

another factor that could be tested. Attempts should also be made to obtain data where figures were estimated and to obtain additional data where variation is evident.

The effect of fuel-type age was not determined. However, it is believed that site and disturbance factors such as propensity to build up deep duff or creation of blowdown would outweigh the age factor.

An attempt was made to relate tree-cover resistance to stand basal area. However, no correlation was evident. Number and proximity of trees appeared to be of greatest significance. The terminology used by Fahnestock (1970) in his keys for fuel appraisal was also kept in mind, but did not appear adaptable to describing resistance to handtools. Some of the size descriptions may be appropriate for simplifying slash resistance in future studies.

The study indicates the importance of supervision on the fire line to ensure that the workload is evenly distributed among crew members so all are contributing equally to the line-building effort. Since trenching is such a relatively difficult task, some rotation of duties among the squads is also indicated.

Ramberg (1974) points out the importance of the human welfare factors of rest and fluid replacement. Supervisors should ensure adequate but not uncontrolled rest breaks. Fluid replacement is important; beverages should be both available and palatable. Observations on the fire line indicate that crew performance declines perceptibly when welfare factors are disregarded. Included here should be proper food and camps as well. Ramberg also suggests that physical fitness should be a part of crew training.

ACKNOWLEDGMENTS

Thanks are extended to H. M. Ryhanen, Head of the Forest Protection Branch, Alberta Forest Service for supporting the overall study. Particular thanks go to Lorne Goff, Slave Lake Fire Control Officer, for his enthusiastic assistance in lccating suitable fuel types, advising on line quality and standards, and expediting the administrative details. Similar appreciation is extended to B. Brouwer, Athabasca Forest; M. Steistol, Footner Lake Forest; and L. Boulet and J. Hereford, Bow-Crow Forest. Brian Provo, Forest Technician with the Department of Forest Science at the University of Alberta, assisted greatly in organizing the Slave Lake field trials and measured and recorded much of the sample data. The authors are grateful to the staff of the Yukon and Northwest Lands and Forest Services who arranged for crews and transportation to wildfires.

LITERATURE CITED

Bureau of Land Management [n.d.]. Fuel type guides. 9 pp. Copies provided courtesy of E.W. Amundsen, Acting Director, USDA Forest Service, Equipment Development Centre, Missoula, Montana.

Davis, J.B. and R.L. Irwin. 1976. FOCUS: A computerized approach to Fire Management Planning. J. For. 74:615-618.

Fahnestock, G.R. 1970. Two keys for appraising forest fire fuels. U.S. Dep. Agric., For. Serv., Pacific Northwest For. Range Exp. Stn. Res Pap PNW-99. 26 pp.

Freese, F. 1967. Elementary statistical methods for foresters. U.S. Dep. Agric., For. Serv. Agric. Handb. 317.

Lindquist, J.L. 1970. Building fire-lines -- how fast do crews work? Fire Technol. 6:126-134.

Quintilio, D. and A.W. Anderson. 1976. Simulation study of initial attack fire operations in the Whitecourt Forest, Alberta. Environ. Can., Can. For. Serv., North. For. Res. Cent. Edmonton, Alta. Inf. Rep. NOR-X-166.

Ramberg, R.G. 1974. Firefighters physiological Study - project record ED & T 2003 - firefighting efficiency of man - the machine. U.S. Dep. Agric., For. Serv., Equip. Dev. Cent. Missoula, Montana. 33 pp.

Storey, T.G. 1969. Productivity and rates of substitution of line building forces in fire suppression -- a summary of existing data. U.S. Dep. Agric., For. Serv., Pac. Southwest For. Range Exp. Stn. Unpubl. Prog. Rep. 32 pp.

APPENDIX I

Relative fire-line construction rates by resistance factors

Detailed Forest Inventory - Alberta Forest Service - (English Units)

1. TREES

STAND DENSITY - crown closure -	2x	2y	3	4
	HEIGHT CLASS-feet (30' and under treat as brush)			
	31 - 45	46 - 60	61 - 80	81 over
A up to 30%	-	(-)*	(-)	(-)
B 31 - 70	3	2	-	-
C 71 - 100	5	4	4	5

2. BRUSH

DENSITY	HEIGHT 8' and under	HEIGHT 9 - 30'
A	1	(-)
B	2	2
C	3	6

3. BLOWDOWN OR SLASH

QUANTITY-PIECES 4"+/100'

	BLOWDOWN	LOGGING SLASH
1 - 5	1	3
6 - 10	2	4
11 - 15	3	5
16 - 20	4	7
21 - 30	5	9
31 - 40	6	11
41 - 50	8	14
51 - 60	9	16

4. TRENCHING

DEPTH (in.)	
up to 1	2
2	5
4	9
6	13
8	17
10	21
12	25
14	29
16	33

Extensive heavy roots (2"+) add (9)

Rock resistance 60%+ increase index by 50%

* numbers in parentheses estimated

APPENDIX II

Fire-line construction rates by resistance factors

Phase 3 Inventory - Alberta Forest Service - (English Units)

1. TREES

STAND DENSITY	HEIGHT CLASS 1 21-40'	2 41-60'	3 61-80'	4 81-100'	5 101+'
A 6 - 30%	nil	nil	nil	nil	nil
B 31 - 50	3	2	nil	nil	nil
C 51 - 70	(5)*	4	nil	nil	nil
D 71 - 100	8	4	4	4	4

2. BRUSH

	HEIGHT 8' and under	9 - 20 feet
A 6 - 30%	1	(nil)
B 31 - 50	2	(1)
C 51 - 70	3	2
D 71 - 100	3	5

3. Blowdown or Slash

QUANTITY-PIECES 4"+/100'

	BLOWDOWN	LOGGING SLASH
1 - 5	1	3
6 - 10	2	4
11 - 15	3	5
16 - 20	4	7
21 - 30	5	9
31 - 40	6	11
41 - 50	8	14
51 - 60	9	16

4. TRENCHING

DEPTH (in.)	
up to 1	2
2	5
4	9
6	13
8	17
10	21
12	25
14	29
16	33

Extensive heavy roots 2"+ add (9)

Rock resistance 60%+ increase index by (50%)

APPENDIX III

WORKING TABLE

Conversion of Index to Production Rate (English Units)

INDEX	RATE (chains/45-min h/man)	INDEX	RATE (chains/45-min h/man)
1	6.98	36	0.19
2	3.49	37	0.19
3	2.33	38	0.18
4	1.74	39	0.18
5	1.40	40	
6	1.16	41	0.17
7	1.00	42	
8	0.87	43	
9	0.78	44	0.16
10	0.70	45	
11	0.63	46	
12	0.58	47	0.15
13	0.54	48	
14	0.50	49	
15	0.47	50	0.14
16	0.44	51	
17	0.41	52	
18	0.39	53	
19	0.37	54	0.13
20	0.35	55	
21	0.33	56	
22	0.32	57	
23	0.30	58	0.12
24	0.29	59	
25	0.28	60	
26	0.27	61	
27	0.26	62	
28	0.25	63	
29	0.24	64	0.11
30	0.23	65	
31	0.23	66	
32	0.22	67	
33	0.21	68	0.10
34	0.21	69	
35	0.20	70	