Bull. Tokyo Univ. For., 81, 95–105 (1989)

Profitable Logging Operation System in Thinning with a Truck-Crane

Hiroshi KOBAYASHI*, Masamichi ONO**, Toshio NITAMI*,
Yasushi MINAMIKATA*, Yasuo TAKAHASHI***, Shigeru KAWAHARA***
and Sadamoto WATANABE***

I. Introduction

The methods of logging that had been generally used in Hokkaido since the harvesting of logs in damaged forests caused by No. 15 typhoon in 1954, were tractor logging operations. This was because of the low cost of road construction on lands of low altitude with mild slopes. Recently, multi-storied forest management and the thinning of young forests have been practiced in Hokkaido. Logging operations with truck-cranes on forest roads have become remarkably efficient operations. This logging system is very important in thinning operations because it causes little damages in stands and to forest lands, and it is an economical method.

Under these circumstances in the Tokyo University Forest in Hokkaido, logging operation experiments in thinning a plantation of Norway spruce (*Picea abies* Karst.), where the road net work (63 m/ha) had been constructed the year before, were made from 25 August to 10 September, 1987 (NITAMI *et al.* 1988). In this paper analyzing the resulting data, we report the factors that influence logging operations and operation time (KOBAYASHI *et al.* 1988). Also, we constructed an logging operation system with a truck-crane including a road net work.

II. General investigation

1. Study sites

The study sites consist of three testing plots in Compartment 75, which is located in the south west part of the Tokyo Unversity Forest in Hokkaido. The compartment has an area of 78 hectare (Fig. 1). The average slope is 18.4 degree; its Terrain Index of Forest Utilization is 33.6, and it belongs to the "Medium class". The forest road density is 60.2 m/ha. The A-plot shown in Fig. 1 is in a young forest and is divided into A1 and A2 representing different logging distances. The B-plot is a forest where trees are more than 42 cm in D. B. H. (diameter at breast height). It is divided into B1, B2, and B3 plots having different logging distances. The C-plot is a forest having trees of 32–40 cm in D. B. H. and also is divided into C1, C2, and C3 plots. We had measured the D. B. H. and mapped the positions of the standing trees in advance for making table of standing tree volumes. The method of thinning was a "same-quality" thinning. The thinned trees of A-plot were between 12–20 cm and between 22–30 cm D. B. H., and those of B-plot were over 42 cm. Those of C-plot were 32–40 cm. From these data we calculated the area of the plots, their densities, standing tree volumes, thinned tree volumes, and the rates of thinning. The rates were about 10% on A-plot, about 35% on B-plot, about 25% on C1 and C2-plots, and about

* Department of Forestly, Faculty of Agriculture, University of Tokyo.
東京大学農学部林学科
** Osaka univeristy.
大阪大学
*** University Forest in Hokkaido, Faculty of Agriculture, University of Tokyo.
東京大学農学部附属北海道演習林

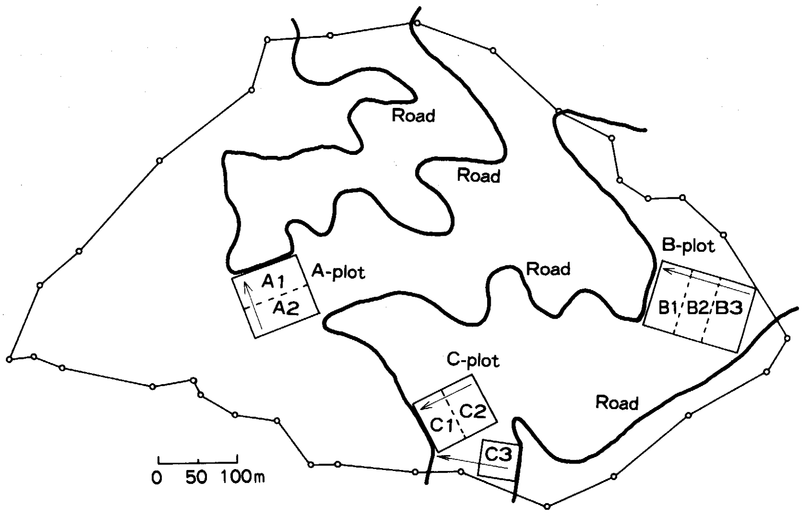

Fig. 1. Location of the testing areas in Compartment 75.

Table 1. Characteristics of the testing area

Plot	A-plot		B-plot			C-plot		
	A1	A2	B1	B2	B3	C1	C2	C3
Yarding distance (m)	0~50	50~100	0~50	50~100	100~150	0~50	50~100	100~150
D. B. H. of felled trees (cm)	12~30	12~30	42~	42~	42~	32~40	32~40	12~30
Number of felled trees	40	35	20	20	20	20	20	57
Area (ha)	0.42	0.42	0.50	0.50	0.50	0.25	0.25	0.27
Density of standing trees (1/ha)	535	323	186	120	196	396	304	388
Volume of standing trees (m^3/ha)	230	275	256	143	192	303	272	277
Volume of felled trees (m^3/ha)	11.35	10.74	38.64	33.70	33.59	17.03	17.61	29.30
Rate of thinning (number %)	18.0	26.1	21.5	33.3	20.4	20.2	26.3	63.3
Rate of thinning (volume %)	8.4	9.4	30.0	47.0	35.0	22.1	25.9	45.7
Average slope (degrees)	17.0			17.0			21.0	

45% on C3-plot (Table 1).

2. The skidding operation

In this logging operation, a truck crane (M-company MCY-1000) and a log loader (K-company D20) were used. With the former, we could skid with its two-drum winch using a skyline system and a high-lead system. Log-making was completed before skidding on every plot; these operations did not influence the skidding operations.

In this system, the logs were skidded first to the logging road, and then piled by the log loader along this road. Using the truck crane, we used the high-lead system with a boom

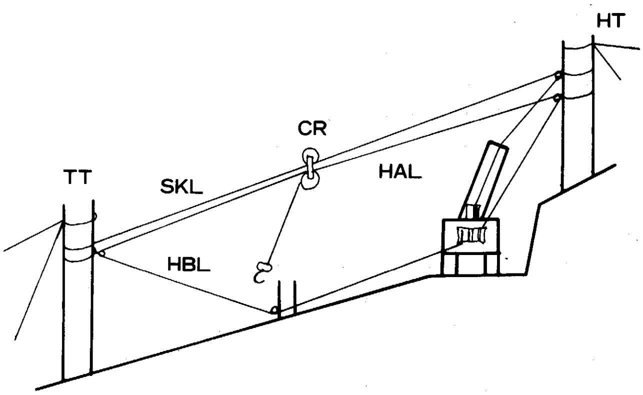

Fig. 2. Skyline-skidding system.
Legend: TT (Tail spar tree), HT (Head spar tree), SKL (Skyline), CR (Carriage), HAL (Haul line), HBL (Haul back line).

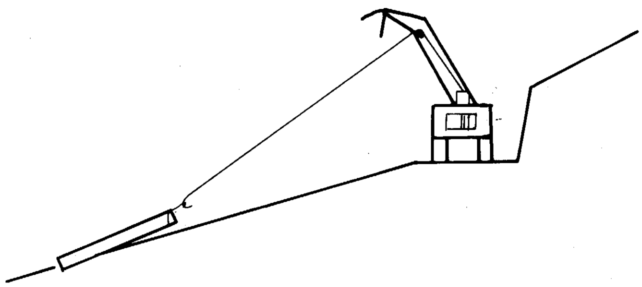

Fig. 3. Ground-skidding system.

winch in skidding small-diameter logs or for short-skidding distances. We used the skyline system with the two-drum winch in skidding large trees or for long distances. In this skyline system, we used a cable from the boom winch as a main line and cables from the two-drum winch as haul and haul-back lines in the falling-block system. Using the skyline system, we could decrease damage, avoid obstacles on the ground, and reduce the work of the choker-setter in hauling back, but it needed half an hour to set up and dismantle. The logs were ground-skidded on A- and B-plots and with the skyline system on the C-plot. Depending upon the diameters of the logs, we skidded them as tree-logs, tree lengths, and short logs (Fig. 2).

The ground-skidding was conducted with a truck-crane and a log-loader. Normally four men work with this system: a truck-crane engineer and a log-loader engineer to operate the machines, a chaser to unhook the logs at at the landing, and a chocker-setter out in the woods. First, the chocker-setter sets the chokers (or hooks the logs) and then signals the truck crane operator with a radio transmitter. The crane operator sounds his horn as a warning and yards the logs. When a turn of logs is caught in some ground obstructions, the choker-setter has to go and free the logs from them. After the logs reach to the road, they are unhooked by the chaser and piled with the log-loader. The choker line is returned to the woods by the choker-setter who must walk in the forst every yarding (Fig. 3).

In the skyline method, the number of workers are the same as in ground-skidding, but the added work of setting up and dismantling the equipment is required. The distance the choker-setter walks from the tail spar tree to the logs is less than what he walks in ground-skidding, and the times of delay with turns of logs are less than those in ground-skidding. The operational efficiencies were 37 m^3/day in maximum, 14 m^3/day in minimun and 21 m^3/day on average. The total log volume was 230 m^3. Our investigation was conducted as a multimoment time study of individual case for every logging distance and diameter of log. We also investigated the position of the standing trees and skidded logs.

III. Analysis of investigation data

1. Operational elements

The methods of truck-crane logging were a ground-skidding system and a skyline-skidding system. There are many kinds of operational elements in ground-skidding, but all operations do not necessarily occur with all work cycles depending on the terrain, yarding distances, and the conditions. We divided these operation into four main phases: namely, carriage out haul, choker-setting, carriage in haul, and unhooking as shown in Table 2 (SINNER 1973).

In this paper we analyze and calculate logging cycle times and form the equations and so we divide the factors as follows:

(1) The factors which varied in every measurement and directly influenced the operational time, were yarding distance, carriage capacity, number of logs carried, number of delays caused by ground and stand conditions covering hauling.

(2) The factors which depend on every plot, A, B, and C, were stand density, diameter trees in stands, type of logs (short log, log, tree length).

(3) The factors on the forest land are slope of ground, plant residue, and rate of thinning.

We used the multimoment time study method to observe the yarding operations. Work-cycle yarding was arranged into six regular and three irregular elements; regular elements were: carriage out haul, rigging out haul laterally, carriage in haul and unhooking. Irregular elements were reset, delay, moving, and resting times.

The average and variable time elements and factors of every plot are shown in Table 3.

Table 2. Operational elements in truck-crane yarding

			In forest	On road
Total operation	Main operation	Carriage out haul	Rigging out haul Carriage out haul	Bucking Piling Operating mechine
		Choker-setting	Chocker-setting Sending signals	Operating machine
		Carriage in haul	Freeing logs of obstacles Resetting chockers Setting guide blocks Sending signals	Operating machine
		Unhooking	Walking to the log Setting chokers	Resetting chokers Bucking Unhooking
	Sub-operation	Sub-operation	Checking logs	Moving of truck Preparation for next yarding
			Surplus time	Resting time Surplus time
		Regular resting time		

Table 3. Opertional times of yarding

Feature / Plot	A-plot Average	A-plot S. D.	B-plot Average	B-plot S. D.	C-plot Average	C-plot S. D.
I. Yarding distance: HL (m)	44.02	29.01	32.50	16.95	24.89	6.19
II. Number of logs in turn: MT	2.06	1.00	1.41	0.52	1.67	0.47
III. Number of delays for turn: NI	1.92	2.35	0.69	1.00	0.22	0.42
IV. Volume on carriage: VH (m^3)	0.40	1.90	0.44	0.18	0.30	0.17
V. Volume of a log: VM (m^3)	0.20	0.06	0.34	0.16	0.18	0.01
VI. Carriage in haul: TL (sec)	224.33	213.88	96.72	70.21	59.00	46.54
VII. Carriage out haul: TB (sec)	62.35	49.48	43.74	23.96	27.67	5.52
VIII. Choker setting: TF (sec)	32.20	21.23	24.26	19.02	19.22	7.69
IX. Unhooking: TO (sec)	96.78	85.42	32.01	25.62	66.00	46.26

Note: S. D.=Standard deviation

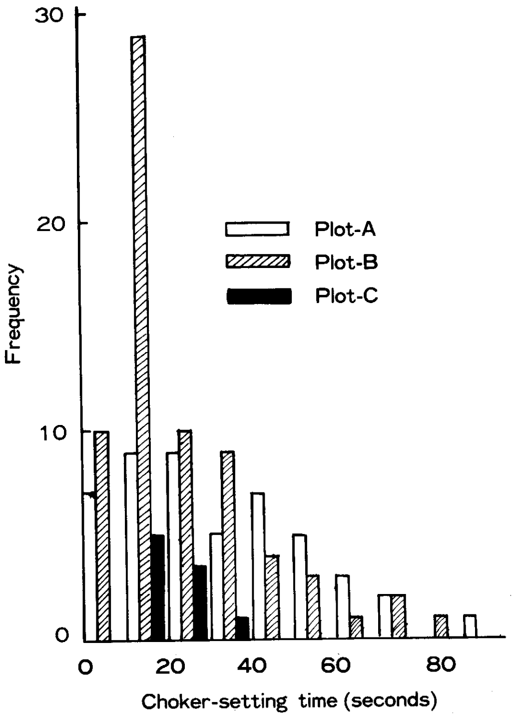

Fig. 4. Distribution of choker-setting times.

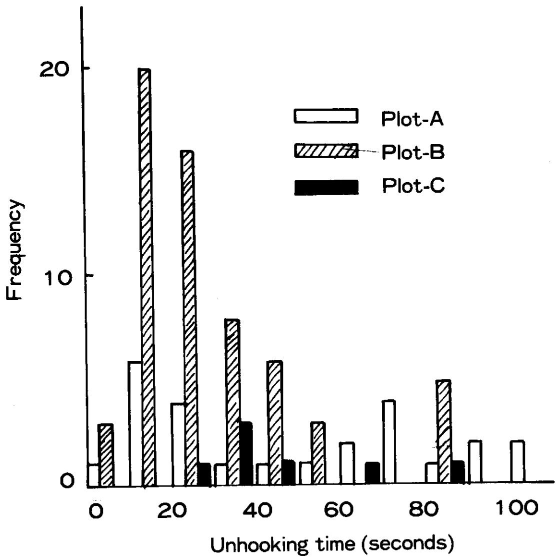

Fig. 5. Distribution of unhooking times.

Histograms of chocker-setting and unhooking times and carriage capacities are shown in Figs. 4, 5 and 6. In Table 4 and in the following regression equations, we show the correlation coefficient of high significance at the 0.01 level (**).

2. Relationships between time of operational features and other factors

1) Carriage out haul time

Table 4 shows the relationships between carriage out haul time (*TB*) and yarding

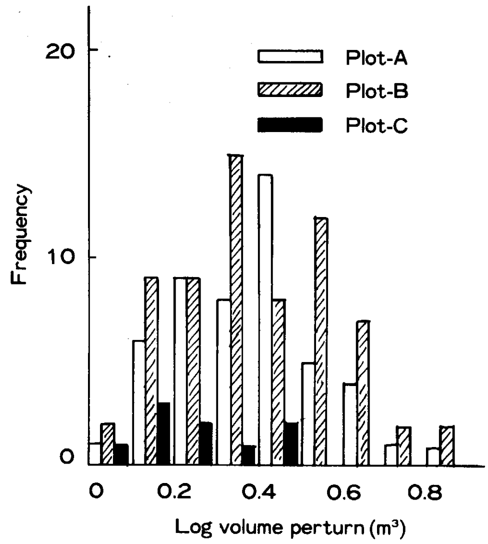

Fig. 6. Distribution of volume in turns of logs.

distance (*HL*). The relationship equations for yarding distance for the three plots are as follows:

A-plot $TB=1.55\,HL-5.87$ $r=0.91^{**}$ (1)

B-plot $TB=1.21\,HL-4.53$ $r=0.85^{**}$ (2)

C-plot $TB=1.09\,HL+2.23$ $r=0.92^{**}$ (3)

2) Chocker-setting

Table 4 shows that chocker-setting times (*TF*) do not relate to almost all other elements. Table 3 shows 32 seconds on A-plot, 24 seconds on B-plot, and 19 seconds on C-plot on average. The total average time is 27.1 seconds. So that we regard this time about 30 seconds.

3) Carriage in haul time

In Table 4 carriage in haul time (*TL*) relates most to the times of delay of turns (*NI*). It also relates to *HL*. Carriage in haul time (*TL*) involves the delay time of logs caught on obstacles. Thus, we analyze these two factors, *HL* and *NI*. We obtained the following relationship equations:

A-plot $TL=1.4\,HL+54.1\,NI+13.8$ $r=0.93^{**}$ (4)

B-plot $TL=1.4\,HL+84.7\,NI+5.3$ $r=0.88^{**}$ (5)

C-plot $TL=1.4\,HL+69.3\,NI+29.5$ $r=0.90^{**}$ (6)

In this case, *NI* relates mostly to *HL* (Table 4). Thus, we can formulate *TL* as a liner regression only of *HL*, as in the following equations:

A-plot $TL=6.12\,HL-45.25$ $r=0.83^{**}$ (7)

B-plot $TL=2.56\,HL-13.46$ $r=0.62^{**}$ (8)

C-plot $TL=5.98\,HL-89.87$ $r=0.80^{**}$ (9)

The coefficients of *HL* on every plots are different because of different stand densities.

4) Unhooking time

From Table 4, the unhooking time (*TO*) has little relationship to the number (*MT*) and volume (*VH*) of logs in a turn. This *TO* has more relation with the *MT* than with the *TF*.

Table 4. Coefficient of correlation among features

Feature	I	II	III	IV	V	VI	VII	VIII	IX
I. Yarding distance: HL (m)	-								
II. Number of logs in turn: MT	0.11	-							
III. Number of delays for turn: NI	0.38**	0.07	-						
IV. Volume on carriage: VH (m^3)	0.02	0.19	0.12	-					
V. Volume of a log: VM (m^3)	−0.02	−0.52**	0.08	0.70**	-				
VI. Carriage in haul: TL (sec)	0.85**	0.12	0.53**	−0.03	−0.07	-			
VII. Carriage out haul: TB (sec)	0.62**	0.10	0.90**	0.12	0.06	0.68**	-		
VIII. Choker setting: TF (sec)	−0.11	0.17	−0.12	0.13	−0.05	−0.17	−0.09	-	
IX. Unhooking: TO (sec)	−0.04	0.28*	0.09	−0.16	−0.32**	0.07	0.06	0.03	-

* Significant at the 0.05 level ** Highly significant at the 0.01 level

The average of TO is 90 seconds on A-plot, 60 seconds on B-plot and 30 seconds on C-plot.

5) The total cycle time

On these bases, we could obtain the total cycle time (TC). The TC can be obtained as the sum of TB, TF, TO, and TL as the following equation:

$$TC = TB + TF + TL + TO \tag{10}$$

But if we express this TC with HL only, we can obtain the following relationship equations.

A-plot $TC = 7.6\,HL + 77.8$ (11)

B-plot $TC = 3.8\,HL + 65.8$ (12)

C-plot $TC = 7.1\,HL - 2.4$ (13)

IV. The optimun logging operation system

We obtain an equation that can compute the operational efficiency of a day, using the above equations, by computing the cycle time from the following equation:

$$P = \frac{3600\,WV}{aHL + b} \tag{14}$$

where P: operational efficiency of a day (m^3),
V: volume of a carriage (m^3),
HL: yarding distance (m),
W: working hour in a day (hours), and
a and b: constants.

This equation shows that P increases in propotion to V. It also shows that P increases in inverse proportion to HL.

Thus when we try to yard logs in a planning area whose maximum yarding distance is greater than a certain level, we should erect a skyline at an interval and yard logs with a combining system of ground skidding and skyline skidding.

1. Logging model

As shown in Fig. 7, we use a logging model where Y (m) is the maximum yarding distance from the road and X (m) is the maximun lateral distance from the skyline. When we yard the logs from the point of the co-ordinates (x, y) with the ground-skidding system, we obtain the cycle time (T_z) with the use of following equation:

$$T_z = a_1 y + c_1 \tag{15}$$

where a_1 and c_1 are constants.

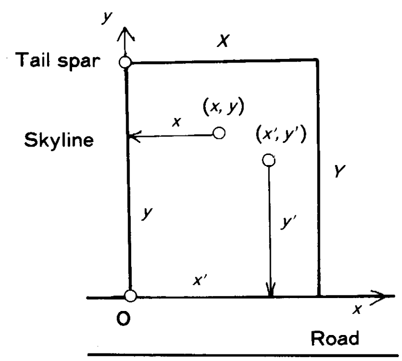

Fig. 7. Logging model.

On the other hand, when we yard the logs with a skyline, we can obtain the cycle time (T_s) from the following equation (16).

$$T_s = a_2 x + (1/v_0 + 1/v_1) y + c_2 \tag{16}$$

where v_0: the velocity of the loaded carriage,
v_1: the velocity of the empty carriage, and
a_2 and c_2: constants,

and if we use $b = 1/v_0 + 1/v_1$, the following equation can be formulated:

$$T_s = a_2 x + by + c_2 \tag{17}$$

if we assumed $a_1 = a_2 = a$, $c_1 = c_2 = c$, we can obtain the locus of the following equation from this equation:

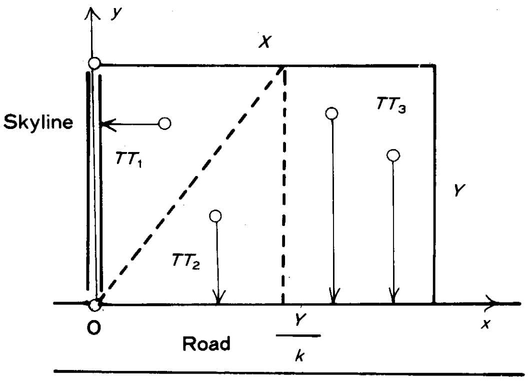

Fig. 8-1. Logging model ($Y<kX$).

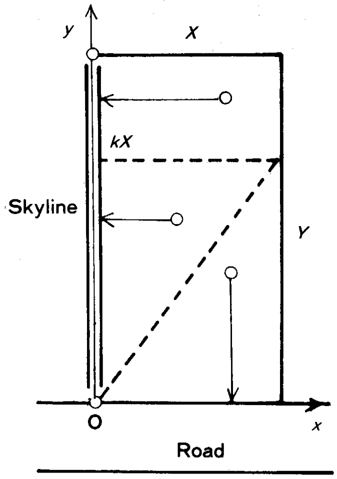

Fig. 8-2. Logging model ($Y>kX$).

$$T_s = T_z$$

$$y = \frac{a}{a-b}x \tag{18}$$

and if we express $k=a/(a-b)$, we formulate the following equation:

$$y = kx \tag{19}$$

Then in Fig. 8-1, we can divide it into two area where the one where the ground-skidding system is used better and the other where the skyline-skidding system is used better; at the border line: $y=kx$.

We calculated the total yarding time used in logging in the area expressed as XY (m[2]). We must consider two cases; the rectangle with $Y < kX$ and the rectangle with $Y>kX$.

1) In the rectangle with $Y<kX$ (Fig. 8-1), the total yarding operation time is the sum of the yarding operation time with skyline-skidding in the area (TT_1) and the yarding operation time with ground-skidding in the area (TT_2, TT_3). These values can be calculated by integrating with X and Y as follows:

$$TT_a = TT_1 + TT_2 + TT_3$$

$$= \int_0^Y \int_0^{Y/k} (ax+by+c)dxdy + \int_0^{Y/k} \int_0^{kX} (ay+c)dydx + \int_{Y/k}^X \int_0^Y (ay+c)dydx$$

$$= \left(\frac{a}{2k^2} + \frac{b-a}{k}\right)\frac{Y^3}{3} + \frac{a}{2}XY^2 + c\cdot X\cdot Y \tag{20}$$

2) In the rectangle with $Y>kX$ (Fig. 8-2), we can obtain the total yarding operation time (TT_b) from the following equation:

$$TT_b = \frac{b}{2}\cdot X\cdot Y^2 + \frac{a}{2}\cdot X^2\cdot Y - \frac{2ak+bk^2-ak^2}{6}\cdot X^3 + C\cdot X\cdot Y \tag{21}$$

From these bases, we can calculate the operational efficiency in a day.

$$P_1 = \frac{3600\ V\cdot w\cdot X\cdot Y}{TT_a + S} \text{ and } P_2 = \frac{3600\ V\cdot w\cdot X\cdot Y}{TT_b + S} \tag{22}$$

where $S = \dfrac{5000\ V\cdot K}{v\cdot q}$ with

P_1: The operational efficiency of a day in the case of ($Y<kX$),
P_2: The same as above in the case of ($Y>kX$),
v : The volume of the study site per ha(m^3/ha),

q : Rate of thinning,
V : The volume of a carriage (m^3),
K : Skyline setting time (seconds) and
w : Working hour in a day (hours).

From these equations, we can delineate the border line between ground-skidding system and skyline-skidding system. If the yarding distance (Y) is greater than Y_0 in the case of $dP/dX<0$, we had better use the skyline-skidding system. The value of Y_0 can be obtained with the following equation:

$$Y_0 = \frac{6as}{(a-b)^2} = \frac{3a \cdot K \cdot V}{(a-b)v \cdot q} \times 10^4 \tag{23}$$

2. Calculation of the operational efficiency of thinning with a truck crane

Example: Thinning the forest: $v=250$ m^3/ha, $q=0.3$.

If we use the truck-crane (MCY=1000), V, K, and b should be 0.4 cubic meter per carriage, 2,400 seconds, and 1.5, respectively, and we are inquiring of the break-even yarding distance (Y_0), more than which we had better use skyline system, using the Equation (23) on Plots A, B, and C.

The distances on the Plots A, B, and C are 42.8 m, 65.1 m and 44.3 m respectively. In this situation ($a=3.8$), we show a graph of the break-even points in the yarding distance, Y_0, for carriage volumes, v(m^3) in Fig. 9. This graph shows that the value of Y_0 increases with increase of the value of V. If the condition is $Y>Y_0$, the skyline system is more profitable. In this case, we would inquire of the optimal interval of the skyline solving the equation of $dp_2/dx=0$,

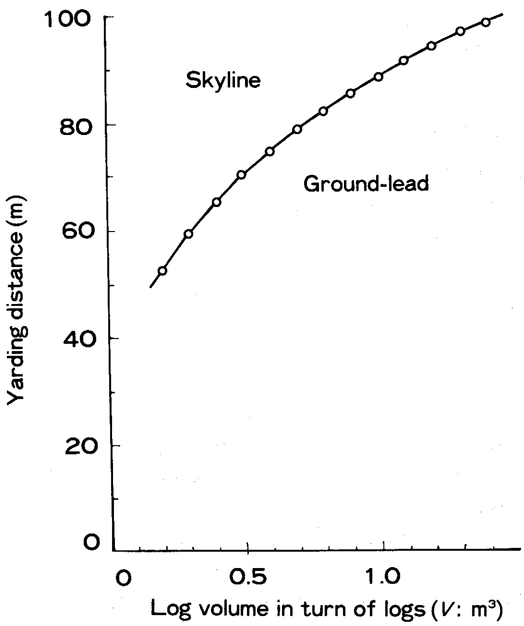

Fig. 9. Break-even points between skyline and ground-lead systems for yarding distance.

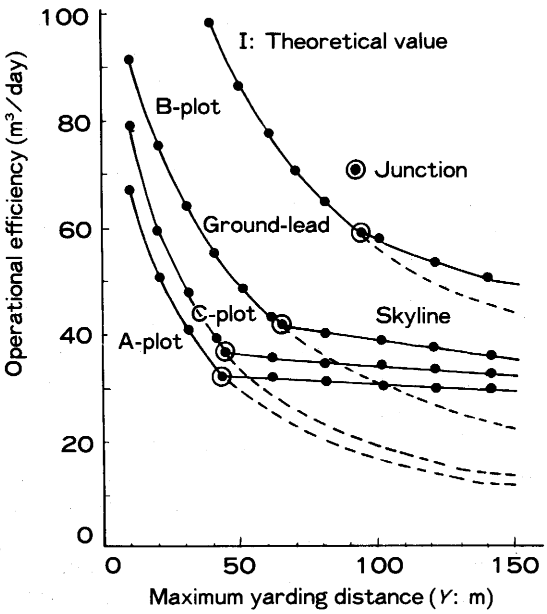

Fig. 10. Relationship between operational efficiency in a day and maximum yarding distance.

$$\frac{dp_2}{dX} = \frac{a^2}{3(a-b)} X^3 - \frac{a}{2} X^2 \cdot Y + S \tag{24}$$

This time, the optimal skyline interval is obtained as the value X_0.

3. The optimal operating-system

From the results obtained in the previous section we can show the optimum operating system in a given cutting area. The conditions of the area have been given as the value of X m and the logging distance Y m. First, we obtained the value v(m^3/ha): volume of the forest, q: coefficient of thinning, the value of the truck-crane, and a: the coefficient; then we can calculate the value Y_0 by solving Equation (23) with these values. The value Y_0 for the tested truck-crane is 40–65 m. If the value Y is smaller than Y_0, we should use the ground-skidding in this area. If the value Y is greater than Y_0, we should use the skyline-skidding system. We can select the optimum operating system from Equation (23) or from Fig. 9 and 10. Then we can obtain the operational efficiency P, for the maximum logging distance Y, from Fig. 10.

V. Conclusion

In this study we investigated the results obtained from a test logging conducted in thinning in Hokkaido with a truck-crane. The results obtained are follows:

The volume of the carriage did not influence the cycle time but influenced the efficiency. The factor that most influenced the efficiency was the time of delay caused by obstacles in yarding logs. It is very important to decrease the time of delay of turns of logs to increase the total efficiency. The differences between the ground-skidding system and skyline-skidding system, come from the yarding distances. Logging large logs is more efficient for distances over 60 m in using a cable crane. Small logs are moved more efficiently with the cable system at more than 40 m yarding distances. It is necessary to construct a forest-road density greater than 60–120 m/ha.

Acknowledgment

The authors thank the members of the Tokyo University Forest in Hokkaido for their help in the field work. This study was supported in part by a Grant-in-Aid for Scientific Research (C) No. 63560144, and (A) No. 61440097 from the Ministry of Education, Science, and Culture of Japan.

Summary

In the Tokyo Unversity Forest in Hokkido, logging-operation experiments in thinning with a truck-crane of a plantation of Norway spruce (*Picea abies* Karst.) were conducted. The average slope was about 20 degree. The logging operation used both a skyline system and a high-lead system of skidding. A time study of the entire skidding operation was made. The relationship between operational features and other factors such as yarding distances, was analyzed. The times of carriage out haul and carriage in haul were influenced by the yarding distance. Especially, the time of carriage in haul was influenced by the number of delays of turns of logs. Ground-skidding is best for yarding for short distances and skyline-skidding is better for long distances because the time for setting up and dismantling the skyline takes much time. From these results, we can obtain a profitable logging operation system in thinning with the use of a truck-crane.

Key words: logging operation system, thinning, truck-crane, skyline-skidding system, ground-skidding system

References

KOBAYASHI, H. *et al.*: Studies of logging system in the method of forest stand management (I)—Experimental logging with a truck-crane—. Trns. Jpn. For. Soc. 99 th, 675–676, 1988 (in Japanese).

NITAMI, T. *et al.*: Studies of logging system in the method of forest stand management (II)—Labor and Machine Investment and Work Efficiency on Forest Conditions—. Trns. Jpn. For. Soc. 99th, 677–678, 1988 (in Japanese).

SINNER, H. U.: Simulating skyline yarding thinning young forests. Proceeding of IUFRO Meeting in Freiburg, West-Germany, 82–106, 1973.

(Received January, 30, 1989)

間伐作業におけるトラッククレーンによる適正搬出システム

小林洋司・小野正道・仁多見俊夫・南方　康
高橋康夫・河原　漠・渡辺定元

要　旨

北海道演習林のヨーロッパトウヒの人工林において平均傾斜20度前後の試験地を設定し，トラッククレーンによって搬出作業を行った。集材作業は，索張りを用いる方法と地曳きによる方法である。搬出作業について時間観測を行い，各作業要素と集材距離などの因子との関係を分析した。引き戻し時間，引き寄せ時間は，集材距離と高い相関を示した。また地曳きによる集材は，短距離集材に適する反面，索張りによる集材法は，架設，撤去の時間がかかり，短距離集材には不適切である。このさかいとなる搬出方法を求めた。これらの結果とモデルによって作業功程算出式を求め，トラッククレーンによる適正搬出システムを求めた。

キーワード：集材作業システム，間伐，トラッククレーン，架線集材，地曳集材