集材機作業条件の統計的考察 II

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論 文

Statistical Analysis of Cable-Yarding Operations in Japan (II)
An Analysis of the Effect of Operational Conditions of Cable-Yarding Systems on Productivity by Means of the Quantification Theory

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SAKAI, Hideo & KAMIIZAKA, Minoru: **Statistical analysis of cable-yarding operations in Japan (II) An analysis of the effect of operational conditions of cable-yarding systems on productivity by means of the quantification theory J. Jap. For. Soc. 62: 331〜335, 1980** The effect of operational conditions on productivity is analyzed by the quantification theory with the same data used in the previous paper. It is recognized that payload is the most effective factor on volume yarded per day with cable-yarding systems. On national forests with clear cuttings, the size of setting, yield per unit area, undergrowth, and so on, follow. On private forests with clear cuttings, the soil condition, setting area, total volume yarded, lateral yarding distance, shape of setting, and so on, follow. It is clear that yarding distance has little effect on the volume yarded per day with the clear cutting system. In thinning or selection-cutting systems, payload, remaining trees, terrain of setting, and cable systems are the effective factors. It was recognized that complicated terrain or setting extending over both hillsides is favorable to some extent in cable-yarding operations in thinning or selection cuttings, and that the running skyline system is well suited for use in thinning and selection-cutting operations.

酒井秀夫・上飯坂実：**集材機作業条件の統計的考察（II）数量化理論による集材機作業の功程分析 日林誌 62: 331〜335, 1980** 前報の資料に数量化理論Ｉ類を適用して，種々の集材機作業条件が作業能率に及ぼす影響を分析した。集材機作業では１荷当り平均積載量が最も作業能率に影響を及ぼしていることが確認された。ついで，皆伐の場合，国有林では伐区の大きさ，ha 当り出材量，地表植生等と続き，民有林では土質，伐区面積，総出材量，横取距離，伐区の形等となった。また国・民有林とも集材距離の１日当り出材量に及ぼす影響が小さかった。間・択伐作業では，積載量，伐区内の地形，残存立木，索張方式が，作業能率に影響のある要因として抽出された。間・択伐作業では，伐区内の地形がある程度複雑か伐区が２山腹にまたがっている場合に作業能率がよく，また索張方式はランニングスカイライン方式が適していることも確認された。

I. Introduction

In the previous paper, the cable-logging practices in Japan were investigated, and their various operational conditions were analyzed. In this paper, the effect of these operational conditions on productivity is developed by the quantification theory using the same data analyzed in the previous paper. Although some conditions such as size of settings and yarding distances were investigated by MORIOKA(*2*), almost all conditions including qualitative conditions are analyzed in this paper. The electronic calculater, HITAC 8800, of the Computer Center, University of Tokyo, was used for the calculations of the quantification theory.

II. An Outline of the Quantification Theory

The quantification theory is a method to determine X_{ij}, which is a coefficient of category j of item i, by maximizing the correlation coefficient between A_k and $\bar{A}_k$ in the function (1) when A_k is given together with its reaction patterns of the items and the categories (*1*).

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Item	Category	Normalized score (-6 -4 -2 0 2 4)	No. of samples	Range	Partial cor. coe.	Interrelated factors
Payload (m^3/turn)	0 ~ 0.4		3	11.371	0.600	Forest management type, average stem volume
	0.4 ~ 0.8		35			
	0.8 ~ 1.2		67			
	1.2 ~		40			
Size of setting (δ)* (m)	0 ~ 150		41	7.641	0.400	Total volume, lateral yarding distance, etc.
	150 ~ 200		54			
	200 ~ 250		32			
	250 ~		18			
Yield per hectare (m^3/ha)	0 ~ 200		33	3.932	0.265	Forest road density, portion of saw timber
	200 ~ 300		64			
	300 ~ 400		27			
	400 ~		21			
Undergrowth	Dense		48	3.805	0.354	
	Medium		76			
	Sparse		21			
Double span sys.**	No		134	3.317	0.197	
	Yes		11			
Shape of setting (H)*** (m)	0 ~ 4		52	3.191	0.256	
	4 ~ 5		51			
	5 ~ 6.25		29			
	6.25 ~		13			
Logging method	Short-length		6	3.079	0.142	Manual prehauling
	Whole-stem		108			
	Whole-tree		31			
Number of crewmen**** (men)	0 ~ 2		15	2.992	0.298	Felling prior to yarding
	2 ~ 4		51			
	4 ~		79			
Cable system	Tyler		10	2.984	0.188	Horsepower of engine, change of skyline roads
	Endless Tyler		108			
	Falling block		23			
	Dunham or high lead		4			
Terrain of setting*****	Flat slope		45	2.784	0.217	Downhill or uphill yarding, location of setting on hillside
	1 valley 0 ridges		24			
	0-2 vs. & 1-2 rs.		51			
	More complicated		15			
	Extending over both hillsides		10			
Span on setting / total span	0 ~ 0.6		64	2.732	0.222	
	0.6 ~ 0.8		50			
	0.8 ~ 1.0		31			
Soil condition	Dry		20	2.689	0.171	
	Moderate		95			
	Swampy		30			
Cable clearance (m)	0 ~ 20		12	2.246	0.212	Average slope of setting, relative height in setting
	20 ~ 40		38			
	40 ~ 60		38			
	60 ~		57			
Piling	No		108	1.649	0.156	
	Yes		37			
Shelter belt	No		121	1.639	0.137	
	Yes		24			
Slope of span (degrees)	0 ~ 10		64	1.636	0.172	
	10 ~ 20		66			
	20 ~		15			
Yarding distance (m)	0 ~ 200		6	0.890	0.087	
	200 ~ 400		45			
	400 ~ 600		56			
	600 ~		38			
Logs drag	No		61	0.187	0.020	
	Yes		84			

Multiple correlation coefficient = 0.790

Fig. 1. Effect of operational conditions on productivity on the national forests with the clear-cutting system

* When shape of a setting is considered as a circle whose ratio of area to its circumference is the same as that of the setting, δ is the diameter of the circle.

** Aerial cableways are included.

*** H is the ratio of the setting area to its circumference(6).

**** Those who engaged in setting chokers, releasing chokers, and operating yarders are not included.

***** (5)

$$\bar{A}_k=\sum_i \sum_j X_{ij}\delta_k(i,j) \qquad (1)$$

where

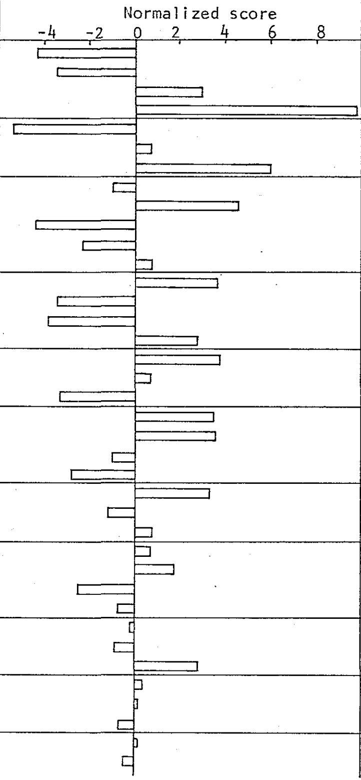
$\delta_k(i,j)=1$ if k belongs to (i,j)

$\delta_k(i,j)=0$ if k does not belong to (i,j)

k=kth sample

X_{ij} is a so called category score and is often used to estimate unknown A_k from its reaction pattern of the items and the categories. The accuracy of the estimation can be given by the multiple correlation coefficient. At the same time X_{ij} is available for investigating the degree of effects of the items on the outside value A_k by counting the ranges of category scores of each item or the partial correlation coefficients of the items. The greater the range or the partial correlation coefficient of the item, the greater the effect of it on A_k. The sizes of normalized category scores of the item, which depend on the choice of the items and the categories, indicate the tendency of the effect of them on A_k.

In this paper, we choose operational efficiency for A_k, and operational conditions for items. We represent operational efficiency by volume yarded per day, because volume yarded per day is less affected by the number of crewmen than volume yarded per man day especially when the number of crewmen is included in the items. As the main object is to investigate the effect of various operational conditions on productivity rather than to make a productivity function with coefficients of X_{ij}, such items, having a correlation coefficient of more than 0.3, are required to change their categories, or are eliminated gradually in consideration of their ranges of category scores and partial correlation coefficients in order to stabilize the category scores and the partial correlation coefficients (3). Such items as turns per day, net working days, region of the country, and ownership are eliminated also because they substantially express operational efficiency or because the mechanism of their effect on productivity cannot be explained.



Item	Category	No. of samples	Range	Partial cor. coe.	Interrelated factors
Payload (m^3/turn)	0 ～ 0.4	15	14.153	0.830	
	0.4 ～ 0.6	20			
	0.6 ～ 0.8	9			
	0.8 ～	11			
Soil condition	Dry	14	11.499	0.661	
	Moderate	32			
	Swampy	9			
Setting area (ha)	0 ～ 1	14	8.932	0.609	Terrain of setting, change of skyline roads, etc.
	1 ～ 2	13			
	2 ～ 4	8			
	4 ～ 6	7			
	6 ～	13			
Total volume yarded (m^3)	0 ～ 200	14	7.534	0.639	Number of crewmen
	200 ～ 400	12			
	400 ～ 600	14			
	600 ～	15			
Lateral yarding dis. (m)	0 ～ 40	12	7.148	0.588	
	40 ～ 80	24			
	80 ～	19			
Shape of setting (H)* (m)	0 ～ 4	9	6.456	0.529	
	4 ～ 5	8			
	5 ～ 6.25	25			
	6.25～	13			
Yarding distance (m)	0 ～ 200	8	4.558	0.401	Cable system
	200 ～ 400	31			
	400 ～	16			
Cable clearance (m)	0 ～ 20	9	4.333	0.404	
	20 ～ 40	21			
	40 ～ 60	14			
	60 ～	11			
Under-growth	Dense	10	3.741	0.369	Average stem volume
	Medium	34			
	Sparse	11			
Span on setting / total span	0 ～ 0.6	32	1.018	0.120	
	0.6 ～ 0.8	9			
	0.8 ～ 1.0	14			
Unloading platform	No	40	0.676	0.084	Double span system
	Yes	15			

Multiple correlation coefficient = 0.923

Fig. 2. Effect of operational conditions on productivity on the private forests with the clear-cutting system

* H is the ratio of setting area to its circumference(6).

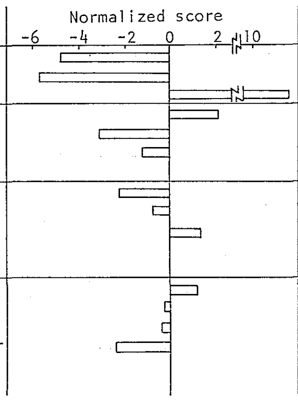
III. Results

The quantification theory was applied to 145 settings on the national forests with the clear-cutting system, 55 settings on the private forests with the clear-cutting system, and 22 settings of national and private forest thinning or selection cuttings which did not lack data and were investigated in the previous paper. The results are presented in Figs. 1, 2, and 3. On the national forests with the clear-cutting system, payload is the most effective factor on the volume yarded per day, and size of setting, yield per unit area, undergrowth, and so on, follow. On the private forests with the clear-cutting system, where operational scales are different from those of the national forests, payload is similarly the most effective factor, and soil condition, setting area, total volume yarded, lateral yarding distance, shape of setting, and so on, follow. Yarding distance, log drag, and so on, do not have much influence on the volume yarded per day on either the national or private forests. On the national and private forests with thinning or selection cuttings (though the number of samples is insufficient) only the factors of payload, remaining trees, terrain of setting, and cable system were isolated, and the multiple correlation coefficient reached 0.864. Payload is the most effective factor as well as clear-cutting systems. The small λ of remaining trees is desirable to operational efficiency, where λ is the product of average D.B.H. and stand density (*4*) and means the stand density per unit length in consideration of the tree sizes. It was recognized that complicated terrain or setting extending over both hillsides is favorable to some extent in cable-yarding operations in thinning or selection cuttings and that the running skyline system is well suited for use in thinning or selection-cutting operations.

IV. Discussion

It was recognized that payload is the most effective factor on the volume yarded per day in cable-yarding operations. This is probably because the volume yarded per day is the product of payload and turns per day. Thus it seems important to plan for large payload capacity and to determine the optimum logging method (whole-tree, whole-stem, and short-length) in consideration of the size of trees and the horsepower of the yarding equipment since the actual payload is much influenced by them (*7*). Also, it seems necessary to develop more effective chokers and techniques of setting chokers to enlarge payload.

The quantity of forest resources such as setting areas, amount of logs, and yield per unit area also affects operational efficiency as was pointed out by MORIOKA (*2*). On the national forests with the clear-cutting system, the more size of setting or yield per hectare, the more volume yarded per day increases. But on the private forests with the clear-cutting system, not only the settings of more than six ha have large volume yarded per day but also those of one to two ha (Fig. 2). This result suggests that there exists a fine skill suited to harvesting small settings on the private forests. This skill is the same as that of the yarding-operation combination of a light yarder, a small setting, and a man-made forest, because most of the small settings on the private forests are in man-made forests (*7*). Since it is very difficult for small forest owners to improve their forest



Item	Category	No. of samples	Range	Partial cor. coe.	Interrelated factors
Payload (m^3/tyrn)	0 ~ 0.4	5	17.336	0.841	D.B.H., logging method, etc.
	0.4 ~ 0.8	10			
	0.8 ~	7			
λ of remaining trees* ($\times 10^{-4}$/m)	0 ~ 100	11	5.393	0.425	Stem volume, undergrowth, stand density, etc.
	100 ~ 150	6			
	150 ~	5			
Terrain of setting**	Flat slope	6	3.704	0.306	Setting area, shape of setting, change of skyline roads, etc
	1 valley 0 ridges	4			
	More complicated or Extending over both hillsides	12			
Cable system	Running skyline	8	3.590	0.208	Yarding distance, horsepower of engine, lateral yarding distance, etc.
	Double endless	4			
	Endless Tyler	8			
	High lead or Tyler	2			

Multiple correlation coefficient = 0.864

Fig. 3. Effect of operational conditions on productivity in national and private forest thinning or selection cuttings

* λ is the product of average D.B.H. and stand density of the remaining trees(*4*). ** (*5*)

Table 1. Average volume yarded per day per yarder horsepower

	Horsepower of engine					
	over 51 hp		21 hp～50 hp		under 20 hp	
	(m^3/day)	(settings)	(m^3/day)	(settings)	(m^3/day)	(settings)
National forests with the clear-cutting system	18.8*	(169)	12.9**	(1)	—	—
Private forests with the clear-cutting system	20.7*,***	(25)	16.0**	(23)	15.2***	(3)
National forests with the thinning or selection-cutting system	22.2	(10)	—	—	22.6	(1)
Private forests with the thinning or selection-cutting system	19.5	(2)	16.5	(3)	10.3	(6)

* and ** The hypothesis that both are equal is not rejected by statistical test.
*** The hypothesis that both are equal is rejected by statistical test.

resources and to enlarge their setting areas in a short period of time, they would best develop a larger payload capacity so as to increase productivity still more. The introduction of yarders with increased horsepower will help to enlarge payload capacity and to increase productivity (Table 1) (*7*), but this must be investigated carefully from an economic point of view considering the scale of forest management.

The reason why soil condition greatly affect operational efficiency on the private forests with the clear-cutting system and the reason why dry condition is unfavorable on both the national and private forests with the clear-cutting system have yet to be clarified. Although the former is partly due to the choice of items and categories, and the chance of the correlation with A_k, further investigations are required.

The shape of the setting affects productivity (Figs. 1 and 2). Here H is the ratio of the setting area to its circumference. H becomes smaller as the shape of the setting becomes more slender or more complicated(*6*). Settings with a small H have larger volume yarded per day because they can lay out the skyline roads along the slender settings, or because they change the skyline roads to shorten lateral yarding distances in case of complicated setting areas, especially on the private forests(*6*).

Settings extending over both hillsides are favorable to the volume yarded per day, as pointed out(*2*). Settings on flat slopes do not have high operational efficiency. Terrain of one valley and no ridges where the skyline roads can cover the setting area easily with adequate cable clearance has the largest volume yarded per day on the national forests with the clear-cutting system.

The Tyler and endless Tyler systems have less productivity despite their numerous advantages probably because they must be used under more difficult and widespread conditions than any other system.

On the private forests with the clear-cutting system, the shorter the lateral yarding distance, the larger is the volume yarded per day. It is recognized that too much cable clearance is unfavorable probably because lifting or lowering loads may occupy much time in such cases.

Although log drag, yarding distance, unloading platforms, and so on have less effect on the volume yarded per day, these factors cannot be ignored in the synthetic evaluation of yarding operations. Neither can soil disturbance, working safety, terminal operations, and rigging and dismantling be overlooked.

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The titles in parentheses are tentative translation from the original Japanese titles by the authors of this paper.

* Japanese with English summary
** Only in Japanese

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