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journal or publication title	三重大學農學部學術報告 = The bulletin of the Faculty of Agriculture, Mie University
volume	65
page range	9-15
year	1982-12-01
その他のタイトル	伐出作業システムにおける作業条件因子の類型化に関する基礎的考察 (I)
URL	<a href="http://hdl.handle.net/10076/3261">http://hdl.handle.net/10076/3261</a>

## Basic Studies on the Classification of the Conditional Factors of Operation in a Logging System (I)

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### I. Introduction

The purposes of this paper are to consider the significance of applying the cluster analysis method to the classification of the conditional factors of operation in the tractor skidding system, and to study the possibility of applying these results to the planning of a logging system.

In order to make a rational plan and a working system most suitable to the tractor skidding operation, it is most important and fundamental to estimate the proper labor productivity corresponding to the various conditions of the operation by using the predictable model of labor productivity<sup>1)</sup>. For this estimate, it is necessary in advance to investigate the conditional factors of operation which are involved in the labor productivity in the planned area of the operation. (The above-mentioned technical term "the conditional factors of operation" will be referred to hereafter as "the factors".) Each of the factors in the skidding system itself has its own characteristic; nevertheless, in order to make this investigation efficiently with limited time, labor, and expenditure, it would be more effective to use the classification method. By grouping those factors with common characteristics in regard to the skidding operation, we can choose the most suitable method of investigation according to the characteristics of each group. Therefore a classification of the factors in the tractor skidding system was attempted by applying the cluster analysis method<sup>2)3)</sup>. The possibility of applying the results of this analysis to the planning of a logging system was then investigated.

It is considered necessary to make these investigations, and to systematize a new technique of work study in order to improve the present logging systems. This paper is the first of a series of basic studies which are made to systematize the methods of research in regard to the logging systems.

### II. Analytical Methods

Cluster analysis is defined as a group of technical methods of analyzing objectively the structure of similarity between the data according to a definite algorithm. In this paper the hierarchical cluster analysis method, which agglomerates  $n$  factors in order, and which finally arranges them in one cluster, was adopted.

For the practical application of this analytical method, it is necessary to define concretely the index of the degree of similarity and the standard for evaluating the suitability of the cluster.

First, as an index of the degree of similarity, the absolute values of the correlation coefficient between the factors which are involved in the labor productivity of the tractor skidding operation were used. These values were calculated according to the formula of Pearson's product-moment correlation coefficient. Analytical data obtained through determining the best quantities for the categories of each factor were used, and the quantification theory<sup>4)</sup> (in which the outside criterion is given in terms of quantity) was applied to the results of investigation in 42 tractor skidding areas as shown in Table 1.

The reasons for using these methods may be summarized as follows:

(1) The purpose of study in the planned area of the operation is to investigate the factors in order to estimate labor productivity corresponding to the various conditions of operation, applying the predictable model of labor productivity. Therefore it is considered that the value of the correlation coefficient

cient between the factors and labor productivity as the outside criterion is one of the most important indexes which can objectively express the degree of similarity between them. This is because it expresses the intensity of correlation between the factors from the viewpoint of their effect on labor productivity.

(2) The characteristics of this system, which contains not only quantitative factors, but also many qualitative factors, should be considered. Therefore it is more effective to make use of the analytical data obtained by quantifying more correlations between the factors which are involved in labor productivity.

(3) There are interactions between the index of the degree of similarity and the criterion of clustering. Therefore it is satisfactory to consider that the absolute value of the correlation coefficient should be used as the index of the degree of similarity, because the value of the correlation coefficient can be either positive or negative depending on circumstances.

Next, as the standard to evaluate the suitability of the cluster, it was considered that the variation within the cluster should be as small as possible, and the variation between the clusters as large as possible. Therefore in order to satisfy this standard, the following criteria of clustering were set up:

The criterion 1: The cluster is made by agglomerating in order pairs of factors with the highest degree of similarity.

The criterion 2: The degree of similarity between the clusters is defined by the minimum value of correlation coefficient between the factors contained in each cluster.

Clustering was carried out according to these criteria by using the following matrix  $S$  composed of  $s_{ij}$ , which is the index of the degree of similarity between the factor  $i$  and  $j$ .

$$S = \begin{vmatrix} s_{21} & & & & & \\ s_{31} & s_{32} & & & & \\ s_{41} & s_{42} & \cdot & & & \\ \cdot & \cdot & \cdot & \cdot & & \\ \cdot & \cdot & & s_{ij} & \cdot & \\ s_{n1} & s_{n2} & \cdot & \cdot & & s_{n(n-1)} \end{vmatrix} \quad (1)$$

$$s_{ij} \geq 0 \quad (2)$$

The result of clustering can be clearly seen on the dendrogram.

The analytical data were obtained by investigating the tree length tractor skidding operation (containing the ground lead system and the sulky system) which was generally carried out as a normal operation based on the tractor skidding standards. This operation was also carried out under direct management in the selective cutting stands (natural forests) of the national forests within the province of the Hokkaido Regional Forest Office and the Obihiro Branch Regional Forest Office from 1975 to 1978. The skidding methods in this operation could be classified into the following three, mainly according to the stand density. This factor can be considered as the obstacle of this operation in the skidding area, because the operation was carried out in the selective cutting stands.

The skidding methods are as follows:

(1) The tractor directly advances into a position beside the skidding logs. After the choker man has loaded the logs, the tractor skids them.

(2) The tractor advances into an intermediate spot between the skidding road, made beforehand, and the side of the logs. After the prehauling operation has been done by means of the tractor-winch, the tractor then skids these logs.

(3) After the prehauling operation has been done by means of the tractor-winch on the skidding road, the tractor then skids the logs along the skidding road.

Results of this investigation are summarized in Table 1. The matrix of the correlation coefficient used in this analysis as the index of the degree of similarity is shown in Table 2.

Table 1. Summary on labor productivity and operational conditions in the tractor skidding system

Item	No. of skidding areas investigated	Labor productivity Y (m <sup>3</sup> /man-day)	Conditional factors of operation			
			Density of tractor skidding road X <sub>1</sub> (m/ha)	Total volume skidded X <sub>2</sub> (m <sup>3</sup> )	Average log size X <sub>3</sub> (m <sup>3</sup> /log)	Average skidding distance X <sub>4</sub> (m)
Results of investigation	42	8.659	107	979.152	1.334	300
		3.483~	32~	122.616~	0.560~	25~
		14.409	197	2,984.000	2.850	591
No. of category in case of quantification	—	—	3	3	3	3

Conditional factors of operation					
Stand density X <sub>5</sub> (No. of trees /ha)	Size of skidding area X <sub>6</sub> (ha)	Operating crew X <sub>7</sub> (No. of tractor/area)	Terrain index X <sub>8</sub> (%)	Type of tractor X <sub>9</sub>	Operational season X <sub>10</sub>
669	14.59	1 tractor set	58	Crawler type	Summer Winter
158~	1.20~	2 tractors set	17~	Wheel type	
2,242	47.06	3 tractors set	110	Mixed type	
3	3	3	3	3	2

- Notes: (1) In the results of investigation, the values written in the upper columns show average values. Those in the lower columns show minimum and maximum values.  
 (2) The conditional factors of operation are arranged in order of dimensions of the partial correlation coefficient to labor productivity.

Table 2. Correlation coefficient matrix as the index of the degree of similarity

	Y	X <sub>1</sub>	X <sub>2</sub>	X <sub>3</sub>	X <sub>4</sub>	X <sub>5</sub>	X <sub>6</sub>	X <sub>7</sub>	X <sub>8</sub>	X <sub>9</sub>	X <sub>10</sub>
Y	1.000	0.615	0.239	0.260	0.651	0.384	0.031	0.524	0.178	0.287	0.191
X <sub>1</sub>	0.615	1.000	0.074	0.093	0.410	0.060	0.083	0.183	0.131	0.345	0.073
X <sub>2</sub>	0.239	0.074	1.000	0.244	0.151	0.048	0.612	0.004	0.186	0.037	0.139
X <sub>3</sub>	0.260	0.093	0.244	1.000	0.079	0.316	0.265	0.028	0.124	0.237	0.293
X <sub>4</sub>	0.651	0.410	0.151	0.079	1.000	0.212	0.249	0.546	0.076	0.261	0.131
X <sub>5</sub>	0.384	0.060	0.048	0.316	0.212	1.000	0.175	0.355	0.244	0.421	0.267
X <sub>6</sub>	0.031	0.083	0.612	0.265	0.249	0.175	1.000	0.254	0.209	0.078	0.135
X <sub>7</sub>	0.524	0.183	0.004	0.028	0.546	0.355	0.254	1.000	0.120	0.332	0.063
X <sub>8</sub>	0.178	0.131	0.186	0.124	0.076	0.244	0.209	0.120	1.000	0.160	0.125
X <sub>9</sub>	0.287	0.345	0.037	0.237	0.261	0.421	0.078	0.332	0.160	1.000	0.018
X <sub>10</sub>	0.191	0.073	0.139	0.293	0.131	0.267	0.135	0.063	0.125	0.018	1.000

### III. Results and Discussion

The classification of the factors was repeated according to the above-mentioned criteria by using the analytical data shown in Table 2. By this means it was possible to identify the clusters. The result of clustering is shown in the dendrogram of Figure 1. Then the following considerations based on the result of clustering were given.

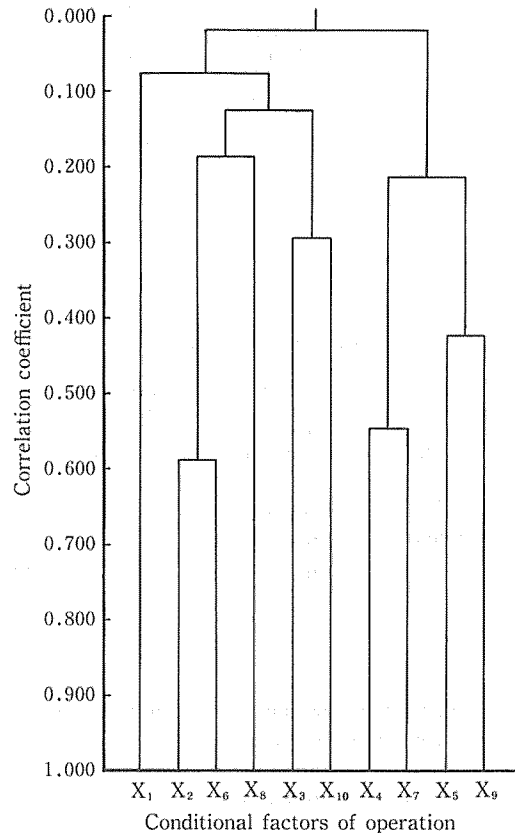


Figure 1. Dendrogram of the conditional factors of operation in the tractor skidding system

#### 1. Concerning the characteristics of factors classified as one cluster

In order to consider the meaning of the result of clustering, the following discussions were attempted.

First, the dendrogram of Figure 1 can be separated into two clusters,  $C_A$  and  $C_B$  by being cut at the level of two clusters.

$$C_A = \{X_1, X_2, X_3, X_6, X_8, X_{10}\} \quad (3)$$

$$C_B = \{X_4, X_5, X_7, X_9\} \quad (4)$$

Although the value of the correlation coefficient is quite small in the final step of clustering because cluster  $C_A$  is made up of six factors, it can eventually be considered that cluster  $C_A$  shows the common characteristics as the factors expressing the character of the skidding area. Likewise cluster  $C_B$  is made up of four factors, and it can be interpreted that cluster  $C_B$  shows the common characteristics as

the factors relating directly to the skidding method. Under cluster  $C_A$ , factor  $X_{10}$  expresses the seasonal aspect of the operation. This was investigated as the qualitative factor expressing whether there was snowfall on the skidding area or not: i. e. whether the operational season was in winter or summer. Under cluster  $C_B$ , factor  $X_5$  expresses the stand density. This has a side face of the factor expressing the character of the skidding area. But in this investigation, this factor means the reserved tree density as the obstacle of this operation in the skidding area, and it was investigated as the main factor which controls the above-mentioned three skidding methods.

Next, factor  $X_1$  is separated from cluster  $C_A$  by being cut at the level of three clusters. This factor expresses the density of the skidding road made in the skidding area. It can be interpreted that factor  $X_1$  is separated from cluster  $C_A$ , because it seems that this factor has a character as the base of the skidding area: i. e. the relationship of factor  $X_1$  to cluster  $C_A$  is different from that of the other factors, especially as the effects of the conditions of length and arrangement of the skidding road on the labor productivity of the skidding operation are different from those of the other factors in cluster  $C_A$ . In much the same way as these, if the numbers of the cluster are multiplied in order, each cluster in these levels comes to express more clearly the proper character of the factors contained in its cluster.

The investigation described above is a case study using the actual analytical data in the tractor skidding system by applying the cluster analysis method. It can be considered that the above study has demonstrated that the various factors with unknown or proper characters can be classified into some typical clusters with the common characteristics according to the objective criteria in response to need.

## 2. Concerning the possibility of application for the planning of the tractor skidding system

As has been mentioned before, in order to make a rational plan and a working system most suitable to the tractor skidding operation, it is necessary to estimate the proper labor productivity corresponding to the various conditions of operation by using the predictable model of labor productivity. Therefore a preliminary investigation of the factors which are necessary for this estimate must be conducted in the planned area of operation.

It seems that the dendrogram shown in Figure 1 clarifies the correlation between the factors, and indicates one of the useful criteria for judging the order and manner of this preliminary investigation of the factors. Concerning cluster  $C_A$ , the following practical procedures of this investigation based on the result of clustering can be considered, taking account of the character of each factor. These are: first, an investigation of the terrain index on a 1/5000 scale contoured topographical map; second, an investigation of the size of the skidding area and the total volume skidded, the average log size and the operational season in the planned area; third, an investigation concerning the density of the tractor skidding road to be made in the planned area, and the rational location and method for its layout, using the results of the above-mentioned investigations and some supplementary ones. These include the shape of the skidding road, which has a remarkable effect on both operational efficiency and safety during the tractor skidding operation, the rational distance, location, and method, with which the skidding road should be laid out, etc. In much the same way as cluster  $C_A$ , cluster  $C_B$  seems to suggest that the investigations of the average skidding distance and the operating crew, the stand density and the type of tractor to be adopted (containing the skidding methods) can be respectively carried out, taking account of the subject matters of the investigations in cluster  $C_A$ .

It seems that the result of analysis described above expresses quite well the rational procedures of the preliminary investigation which formerly have been considered empirically, and theorizes concerning them. Therefore it can be considered useful to utilize the above study for the effective planning of the preliminary investigation as one of the fundamental data based on the objective justification.

## 3. Concerning the possibility of application for the planning of a logging system

Forest management by the non-clear cutting method is one of the most important techniques of for-

est management in the future, but these technical systems are not established yet in the present situation. In this situation, it is particularly urgent to systematize the logging techniques. For this purpose, it is necessary first to investigate the mutual relationship between the specific index: for instance, labor productivity and the factors concerned in it in each working system, which composes a series of processes such as the felling, bucking, yarding, skidding, log-transportation, etc. Therefore being based on the results of the investigations described in this paper, it is considered to apply the cluster analysis method for the systematization of a logging system in forest management by the non-clear cutting method. It becomes possible to classify many factors, which have complicated relation to the specific index, into some kinds of cluster with common characteristics respectively according to the objective criteria such as the index of the degree of similarity, and to choose the typical factor out of each cluster by using the quantification theory in combination to each working system such as the felling, bucking, yarding, skidding and log-transportation. If these become possible, as the next step, the mutual relationships between the classified factors or each typical factor: i. e. the type of operational conditions and the logging systems to be adopted as the effective ones will be able to be concretely investigated according to the specific index. It can be considered that these points provide necessary fundamental data for the planning of the most suitable logging system as a series of the processes.

#### Acknowledgement

In preparing this paper, the author wishes to express his thanks to Dr. Isao Sasaki, Professor of the Kyoto University for many helpful suggestions. Thanks are also due to all of the staff members in the Hokkaido Regional Forest Office and the Obihiro Branch Regional Forest Office for providing the data for this investigation.

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

#### 摘 要

伐出作業システムにおける作業条件因子の類型化に関する基礎的考察 (I)

飛 岡 次 郎

数量化理論 I 類とクラスター分析の手法を、非皆伐施業のトラクタ集材作業システムにおける作業条件因子の類型化に適用することを考え、作業実績資料を用いた解析結果の伐出作業計画への応用の可能性について検討を試みた。

その結果、①労働生産性を外的基準とする作業条件因子相互間の相関係数(絶対値)を類似度の指標として、作業

条件因子をそれぞれ特性をもついくつかのクラスターに類型化しうることが一事例として示された。②クラスター分析の結果は、従来から経験的に合理的と考えられてきた作業条件因子の現地調査手順をかなりよく表し、これに対して一つの理論的根拠を与えるものと解釈できる。③作業条件のタイプと、そこに採用されるべき伐出作業方式との相互関係を具体的に検討しうることが示唆された。

なお、このような検討は各種の方法により実証的に行い、最も妥当な作業研究手法を体系化することが必要と思われる。