Analytic Hierarchy Process (AHP)-Based Multi-Attribute Benefit Structure Analysis of Road Network Systems in Mountainous Rural Areas of Japan

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ABSTRACT

A number of people have studied the problem of measuring the multi-attribute influence derived from the presence of road networks in mountainous areas. I have briefly examined this concept within the framework of the analytic hierarchy process (AHP). I assumed that this influence is a function of several factors. I considered three such supra-functional factors: (1) promote long-term sustainable forest production and resource protection; (2) improve comprehensive timber production infrastructure; and (3) improve settlement infrastructure in rural areas. I studied a multi-attribute benefit structure of forest road networks in the hierarchy form. By pairwise comparison matrix according to all the criteria of the proposed hierarchy, the final eigenvectors and the composite weights have been arrived at. The AHP-based approach should be repeated to identify the benefit structure of road network systems and to improve the development strategy in mountainous areas.

Keywords: *AHP, forest roads, decision-making, benefit structure, rural development.*

INTRODUCTION

In mountainous areas the forest has a significant role to play in the lives of the people: number of municipalities -- 1793 (55% of the national total 3246); land area -- 68% of the national total; and forest area -- 81% of the national total. The life style is closely linked with the community and heavily dependent upon agriculture and forestry. People in these areas have utilized the forest in various ways and through the process managed the forest appropriately. As the single largest resource in terms of area, it has greatly contributed to local economies. Wood-related local industries have been developed and income opportunities have been provided because of the proximity of the forest to rural populations.

In recent years, proper forest management has become difficult due to depopulation in rural areas, and it is feared that land conservation may be adversely affected as this trend continues. Depopulation has emerged clearly as a common problem in rural areas. Between 1960 and 1985 there was approximately a 20% decrease in rural populations, especially in the younger generation, whereas there was a 30% increase in the national population. The population density gap was widened in comparison with cities in terms of industries, income, and living infrastructure. It is, therefore, important to position these fragmented areas as forest-based rural communities which can utilize the forest in multiple ways for rural development and manage the forest in an appropriate manner, and to improve fundamental conditions which facilitate steady growth.

To reverse this trend it is necessary to create new living spaces in rural areas, taking advantage of the forest as an environment and enhancing the awareness of the public through direct contacts with forest culture. Furthermore, an integral approach for securing income opportunities and improving the quality of life is needed for the purpose of restructuring forest-based rural communities as a place for settlement. To provide mobility and accessibility to rural locations, adequate road network infrastructure in these areas is therefore a prerequisite for rural development strategies.

This study focuses on the complex socioeconomic problem of measuring the multi-attribute influence derived from the presence of forest road networks in mountainous rural areas of Japan and the methodological considerations for preparing evidence toward the selection of rural development strategies (Figure 1). Specifically, this study attempts to offer an analysis of multi-attribute benefit structure of forest road network systems within the framework of the analytic hierarchy process (AHP), and estimate the final eigenvectors and the composite weighted priorities by pairwise comparison matrix with all the criteria of the proposed hierarchy.

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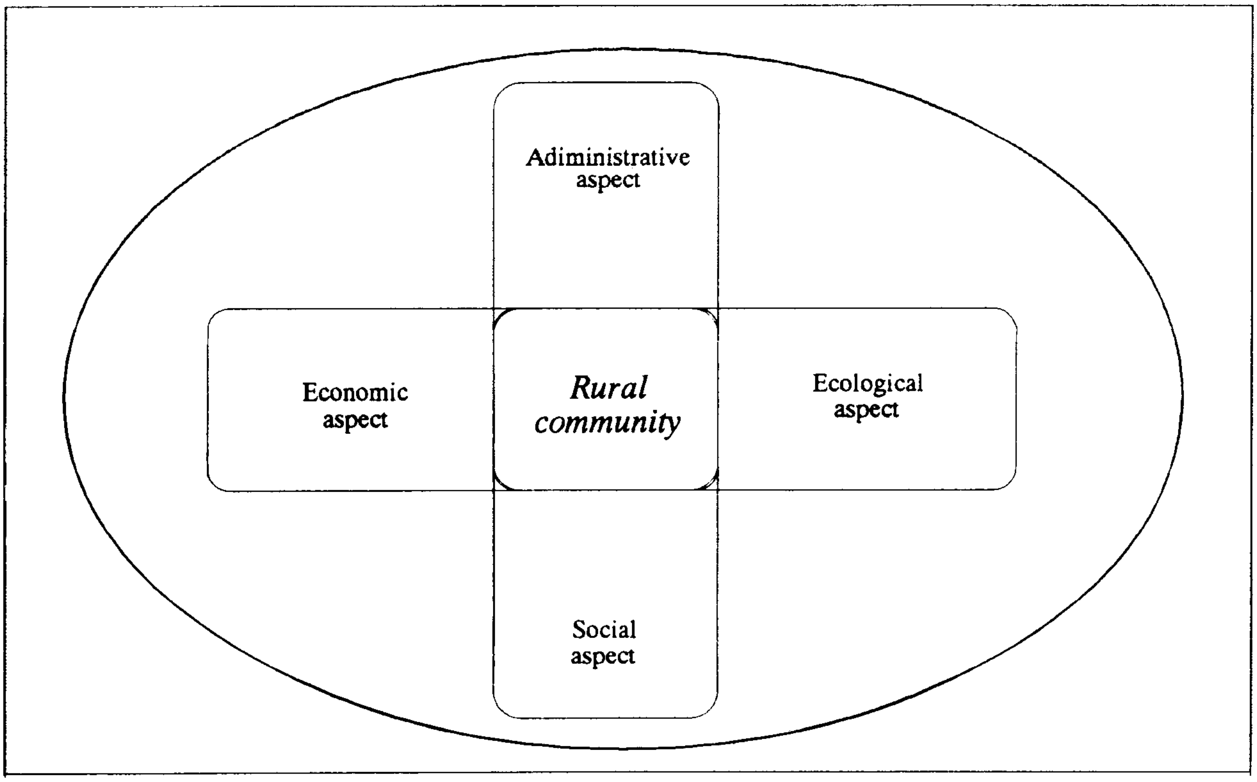

Figure 1. Schematic form of multiple benefit tradeoffs with presence of road network in mountainous rural community.

ROAD NETWORK DEVELOPMENT IN MOUNTAINOUS RURAL AREAS OF JAPAN

The Japan Forest Agency (JFA), which has jurisdiction over the construction of forest roads, has prepared development plans for many different purposes: (1) local skeleton forest roads to improve access to regional and local forest areas; (2) general forest roads to improve transport services to forestry management; (3) cross-ridge forest roads to join several management units such as drainage areas; (4) super forest roads to access remote mountain forests and rural communities; and (5) specific territorial forest roads to develop the area with a high ratio of plantation forests intensively.

The total length of the national forest road network for vehicle traffic is currently about 41 714 km and the road density in production forests is about 5.45 m/ha. The road network in private forests is estimated at about 75 878 km with density of 4.37 m/ha. The road density including public roads in all the forests is more than 12 m/ha [5]. Public roads occupy more than 60% of all the road networks in forest areas because major parts of these public roads were once constructed as forest roads (Table 1).

The long-term development plan by JFA sets its target value of road density at 20 m/ha. The estimated figure is generally less than that for mountainous terrain in European countries. The major reasons for these differences are thought to be: (1) higher road construction/maintenance costs due to topographic and climatic conditions; (2) the priority of cable to vehicle in logging system alternatives; (3) environmental concerns for soil, water and aesthetics push towards road and harvest systems; and (4) forest road funding is becoming a controversial political issue (Table 2).

Table 1. Development of forest road network in Japan (resources:JFA).

Year	Total length	Total density	National forest	National forest	Private forest	Private forest
	Km	m/ha	Km	m/ha	Km	m/ha
1975	82655	3.31	32503	4.25	50152	2.89
1976	84298	3.37	33081	4.32	51217	2.95
1977	86333	3.45	33797	4.42	52536	3.03
1978	89691	3.59	34351	4.50	55340	3.19
1979	92239	3.69	35064	4.58	57175	3.30
1980	94786	3.79	35680	4.66	59106	3.41
1981	97741	3.91	36486	4.77	61255	3.53
1982	99889	4.00	36935	4.83	62954	3.63
1983	101527	4.06	37497	4.90	64030	3.69
1984	103775	4.15	38065	4.98	65710	3.79
1985	105899	4.24	38653	5.05	67246	3.88
1986	108219	4.31	39173	5.12	69046	3.98
1987	110041	4.40	39767	5.20	70274	4.05
1988	112092	4.48	40215	5.26	71877	4.14
1989	114146	4.57	40793	5.33	73353	4.23.
1990	116073	4.64	41315	5.40	74758	4.31
1991	117592	4.70	41714	5.45	75878	4.37

Table 2. Forestry-related general account budget (unit: million yen, resources: JFA).

Items	1986	%	1991	%
Improvement of forest resources	10002	2.7	8396	1.8
Forest road construction	80511	21.8	97579	20.8
Afforestation	40317	10.9	48948	10.4
Promotion of thinning	9089	2.5	7476	1.6
Research and extension	11151	3.0	11974	2.6
Forest structures improvement	21722	5.9	20926	4.5
Improvement of forestry production	4839	1.3	4013	0.9
Promotion of forest owner's association	179	0.1	268	0.1
Land conservation projects	164604	44.7	202482	43.2
Reconstruction after disasters	19655	5.3	47997	10.3
Forestry financing	432	0.1	760	0.2
Other	6136	1.7	16919	3.6
Total	368637	100	467737	100

AHP-BASED MULTI-ATTRIBUTE BENEFIT STRUCTURE ANALYSIS OF ROAD NETWORK SYSTEMS

A Formal Approach by the AHP

The Analytic Hierarchy Process (AHP) allows one to achieve a powerful economy of thought by bringing all the factors together in a hierarchical decomposition of the system, with the objectives and functions represented in the higher levels and the structure represented in the lower levels. The AHP treats different components of a system and their interactions as a whole and allows for feedback. One uses judgements or other data to make careful quantified tradeoffs among the relative criteria. This sets out an accurate assessment of an overall position [9]. The AHP is basically designed to: (1) set priorities for the elements in each level of the hierarchy according to their impact on the criteria or objectives of the next higher level; (2) structure multi-person, multi-criteria, and multi-time-period problems with uncertainty and risk hierarchically.

The AHP is being used widely in corporate planning, in the government for resource allocation purposes, and, more widely, on an international scale in the developing countries to determine priorities for transport, industrial and agricultural infrastructure, and to prioritize the natural resources for investment, except for a very few examples of benefit-cost analysis applied to forestry investment decision-making [7, 3, 1, 10, 11].

Application as an Instructive Example

Several authors have studied the problem of measuring the multi-attribute influence derived from the presence of road networks [2, 4, 6]. I have briefly examined this concept (Figure 2) within the framework of the hierarchies and priorities by the AHP model. More details of this study are shown in references [8, 12].

I assumed that influence is the supra- and subfunction of several factors. I considered three such supra-functional factors: (1) promote long-term sustainable forest production and resource protection; (2) improve comprehensive timber production infrastructure; and (3) improve settlement infrastructure in rural areas.

The proposed hierarchical benefit structure from the presence of road networks is shown in Figure 3. A consensus of the criteria of the hierarchy was achieved by brainstorming and/or the Delphi process with the cooperation of administrative staff, rural communities, and forest owners in the study areas. The causal factors which affect the benefits include the availability of capital, labor, land, skill, and natural resources, and conceptually fall into three categories: economic, social, and environmental. They mainly consist of the benefits derived from the time, the cost, the space saved, and the safety, and the comfort in improving the inadequate existing transportation infrastructure in mountainous rural areas.

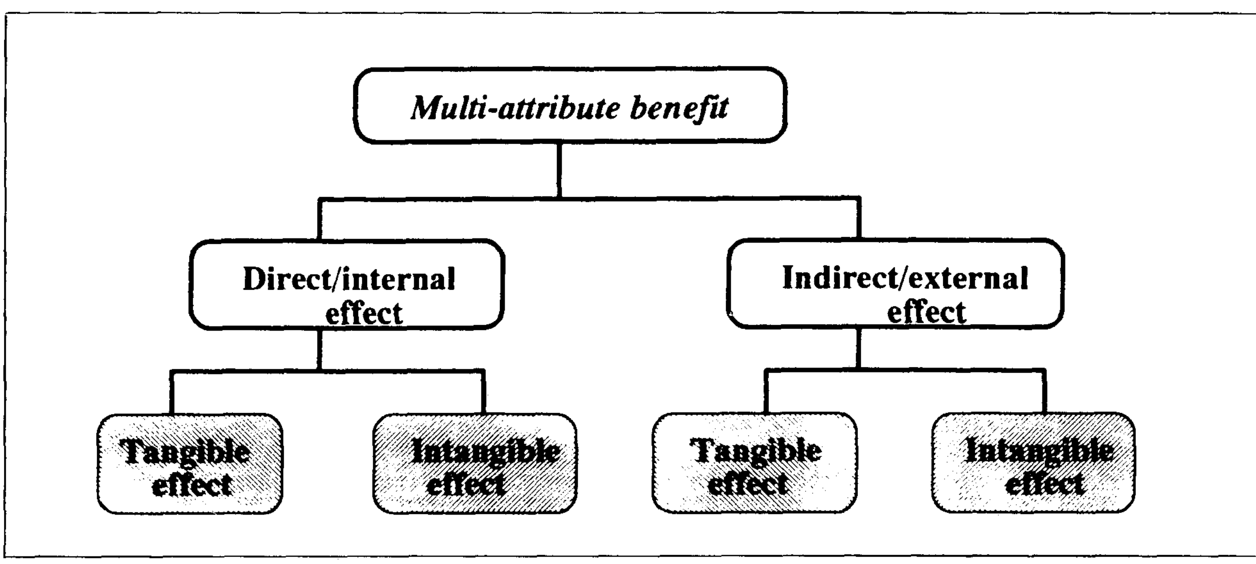

Figure 2. The hierarchy of benefit structure.

A1 Promote long-term sustainable forest production/resource protection

- A11 Stabilize domestic timber demand/supply
- A12 Improve quality of forest stands:uneven-aged,mixed,prolong-cutting etc.
- A13 Control overall adiministrative resource management plans

B1 Improve comprehensive timber production infrastructure

- B11 Increase productivity of harvest activities
- B12 Improve labor circumstances

B111 Reduce production cost
B112 Increase gross profit potential
B113 Promote capital and technical investment inputs
B114 Improve organizational structure of production sectors
B115 Extend multi-use products from forestry
B121 Reduce required commuting time
B122 Reduce physical work/walk load
B123 Provide adequate safe and health care to workers
B124 improve operaional phases in space,time,machine allocation
B125 Create year-round operations
B126 Increase available employment opportunities
B1111 Reduce planting,weeding and thinning costs
B1112 Reduce harvest/transportation costs
B1113 Improve landing/yarding facilities
B1121 Increase managed land/stumpage prices:property values
B1122 Increase gross timber production: final cutting/thinning
B1123 Improve log conversion/sale manner
B1124 Produce high quality/value timber
B1125 Improve stagnated stand by reforestation
B1131 Restructure harvesting methods/equipments
B1132 Improve openning up infrastructure with fine feeder roads
B1133 Improve nursery practices/tending techniques
B1141 Increase cooperative use of machines,equipments and facilities
B1142 Coordinate joint activities in forest operations
B1143 Improve timber-sale and marketing manner
B1144 Institute land-use reform and regulation
B1145 Improve structure of forest owner's association/contractors
B1151 Extend multiple-product forestry: agroforestry,silvipasture managements
B1152 Increase recycling and reuse of materials: stump,bark,twings.leaves
B1153 Exploit merchantable crops: indigenous plants and shrubs etc.

C1 Improve settlement infrastructure in rural areas

- C11 Provide mobility and accessibility to rural populace
  - C111 Supplement extra traffic to urban area
  - C112 Supplement internal traffic in rural area
- C12 Provide adequate restoration care to natural disasters
  - C121 Improve land conservation works
  - C122 Serve forest disasters: plant pest,fire etc.
  - C123 Improve fire and water disaster salvage services
- C13 Promote forest amenity and outdoor recreation activities
  - C131 Provide trafficability to forest areas
  - C132 Accelarate recreational activities for rural populace
  - C133 Widen communication opportunities between rural and urban areas

Figure 3. The proposed hierarchal benefit structure from the presence of forest road network.

The major purposes of this application are to identify potential problem areas and the policies/objectives of each actor that will affect development planning: what changes in policies are needed to achieve a desired future as contrasted with the current projected future? and what will be the corporation's future if the planning policies of the decision-maker remain as they are now and the results of other external actors and forces continue unchanged (Figure 4)? The actors here are prefectural district officers (6 bureaus: PDO), municipal officers (14 municipalities: MO) and indigenous private forest owners (13 holders: PFO) in Mie Prefecture (Figure 5).

The efficiency of a hierarchy may be defined to be the ratio of the number of direct pairwise comparisons required for the entire set of elements involved in the hierarchy, as compared with the number of pairwise comparisons resulting from clustering. This means both consistency and good correspondence with reality. Consistency is inversely proportional to the size of each matrix. Thus one has a tradeoff. The tree cluster of composite weights for eight criteria corresponding to level 3 in the case of PFO may suggest high confidence in judgement of the actors and also the reasonable final priority result derived from the judgement of each individual and an overall weighted priority (Figure 6).

Figure 4. Hierarchical decision-making for development planning.

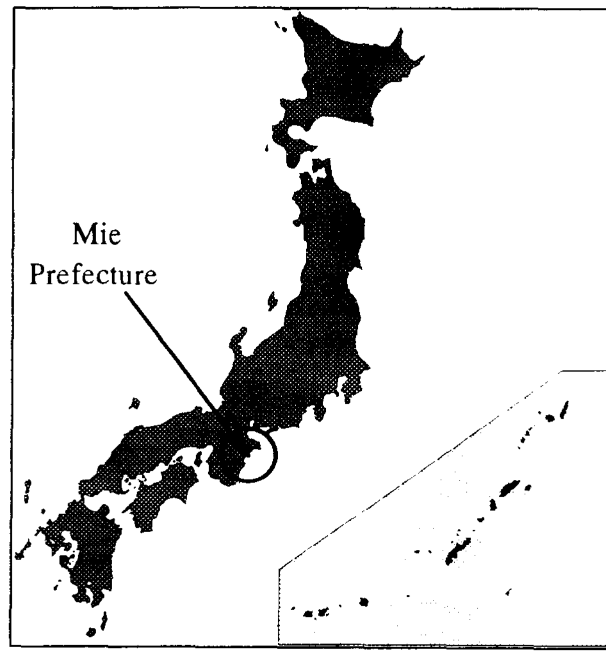

Figure 5. Location of study area.

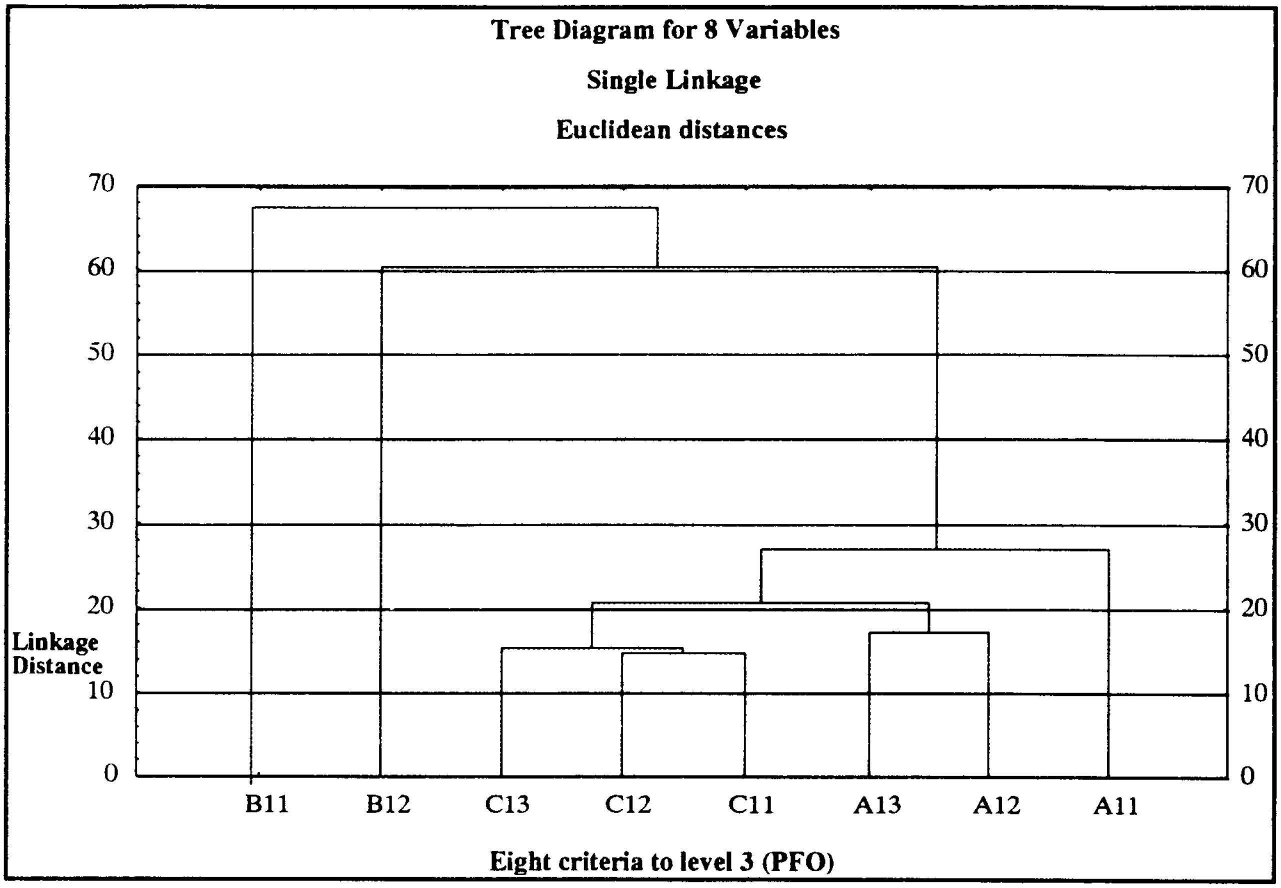

Figure 6. Tree cluster of composite weights for eight criteria to level 3 in case of indigenous private forest owners.

By pairwise comparison matrix with all the criteria of the proposed hierarchy, the final composite weights are calculated as shown in Figure 7.

A brief interpretation is that administrative staff, both prefectural and municipal, have almost equal priority with getting relatively balanced values. The indigenous private forest owner's objectives, on the other hand, are reasonably self-explanatory as indicated in Figure 8.

The difference between administrative officers and forest owners is that the former maintain road network development with moderate diversification while the latter de-emphasize road network development with aggressive diversification.

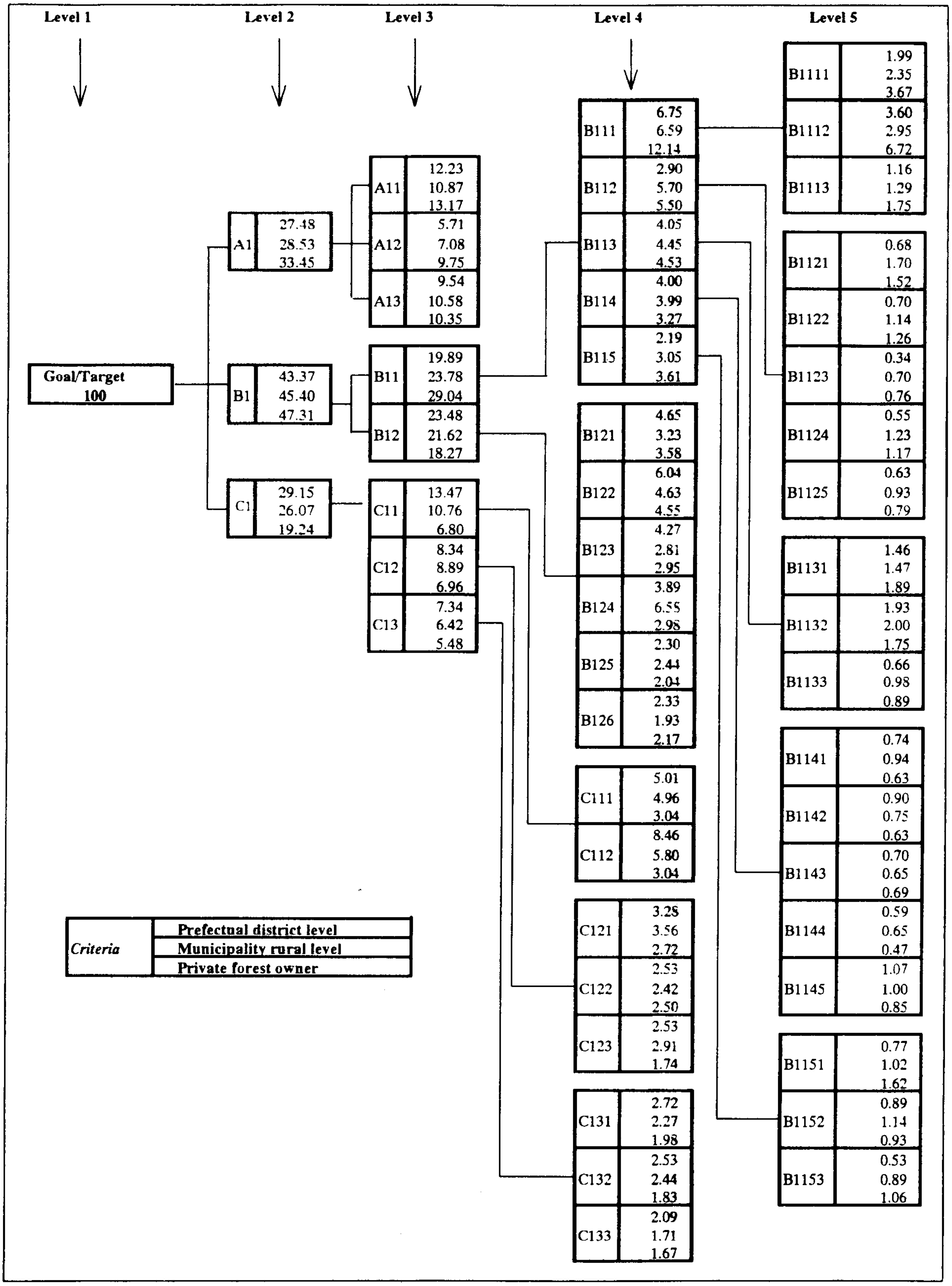

Figure 7. Estimated composite weights for all the criteria.

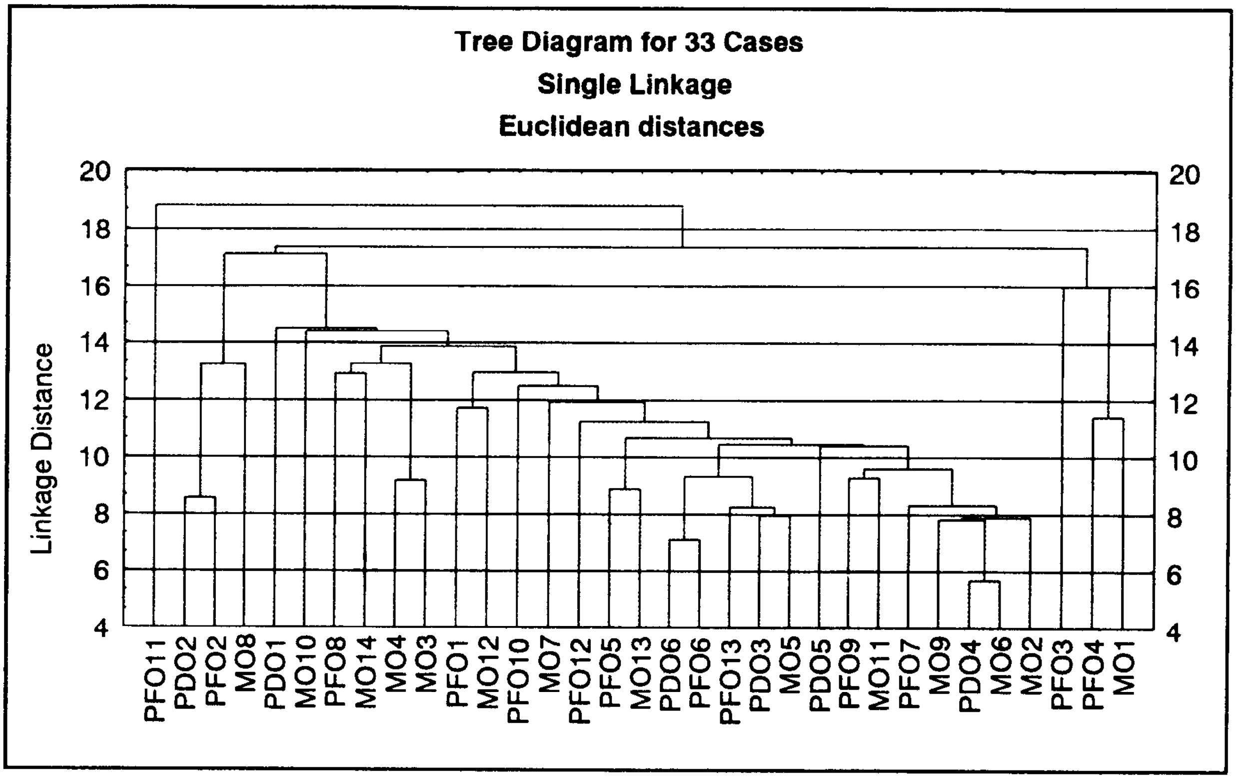

Figure 8. Dendrogram of hierarchy-single linkage for all the actors, PDO, MO and PFO.

CONCLUSIONS

This study is motivated to assist public administrative decision-making in local level extension to better conceptualize and formulate socioeconomic problems associated with mobility and accessibility infrastructure in mountainous areas so as to systematically and logically prepare evidence toward the selection of development strategies.

The Analytic Hierarchy Process (AHP) introduced here is a particularly useful vehicle for resolving political, economic, and environmental conflicts, as it can deal in a standard way with such intangibles as objects, feelings, power, social values, environmental impacts, and other common ideas in our society for which we have no other established means of assessment. The AHP-based approach should be repeated to identify the benefit structure of road network systems and to focus the development strategy in mountainous rural areas.

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REFERENCES

[1] Dietz, P., Knigge, W. and Loeffler, H. 1984. Walderschliessung. Verlag Paul Parely. Hamburg. 414 pp.

[2] Dykstra, D. P. 1984. Mathematical programming for natural resource management. McGraw-Hill Inc. NY. 308 pp.

[3] Fraser, G. A. 1983. Benefit-cost analysis of forestry investment. Information Report BC-X-275:1-20.

[4] Iverson, S. C. 1985. Quantitative methods for public administration in developing countries. John Wiley & Sons Ltd. NY. 162 pp.

[5] JFA. 1992. Forestry White Paper: Annual report on trends of forestry. Japan Forestry Agency. Tokyo. 38 pp.

[6] Keeney, R. L. and Raiffa, H. 1993. Decisions with Multiple Objectives. Cambridge Univ. Press. NY. 547 pp.

[7] Loeffler, H. and Timinger, J. 1977. Nutzen-Kosten Untersuchung ueber den forstlichen Wirtschastswegebau. Landwirtschaftverlag GmbH. Muenster-Hiltrup. 202 pp.

[8] Park, S. 1994. Quantitative methods for socio-economical impact evaluations in forest road network infrastructure development strategy: case study in Mie Prefecture. Graduation thesis. Mie. 250 pp.

[9] Saaty, T. L. 1980. The Analytic Hierarchy Process. McGraw-Hill Inc. NY. 269 pp.

[10] Shiba, M. 1993a. Optimierung der Waldwegenetzplanung und iher Bewertungsmethode mittels Variantenvergleichs (V). J. Jpn. Soc. 75(5): 431-439.

[11] Shiba, M., Masamura, S. and Ishikawa, I. 1993b. Systematisierung der Planung fuer die forstbetrieblichen Infrastrukturen mit Hilfe der Nutzwertanalyse (II). J. Jpn. Soc. 75(5): 424-430.

[12] Shiba, M. 1994. AHP-based multi-attribute benefit analysis of road network system in rural communities. Technical report of Shinkoukousaikai Foundation No. 3. (In press).