Analytical hierarchy process to choose the best earthwork machine in northern forests of Iran

A. Parsakhoo[1], S.A. Hosseini[2]

[1] *Department of Forestry, Faculty of Forest Sciences, Gorgan Agricultural Sciences and Natural Resources University, Gorgan, Iran*

[2] *Department of Forestry, Faculty of Natural Resources, Sari Agricultural Sciences and Natural Resources University, Sari, Iran*

ABSTRACT: This study attempts to use the analytical hierarchy process to choose the most appropriate earthwork machine for slope classes of 30–50% and 50–70%. Required data were collected by pairwise comparison as questionnaires filled by experts of forest engineering. Results showed that cross-sections and grade line (Technical criteria), soil excavation and displacement (Environmental criteria), production rate and multi-application (Operational criteria), production cost (Economic criteria) with the respective weights of 0.345, 0.345, 0.136, 0.058, 0.058 and 0.058 were the most important criteria for choosing the earthwork machines in the slope class of 30–50%. These coefficients for the slope class of 50–70% were 0.329, 0.329, 0.174, 0.056, 0.056 and 0.056, respectively. Overall priority of bulldozer in slope classes of 30–50% and 50–70% was 0.51 and 0.48, respectively. Therefore, in slope class of 30–50% bulldozer and in slope class of 50–70% hydraulic excavator must be selected for earthwork operation.

Keywords: best selection; earthwork machine; environmental criteria; analytical hierarchy process; northern forests

In optimal selection of earthwork machines that are used in forest road construction projects it is required to determine the effective factors influencing the machine performance and its environmental consequences. In recent years on earthy and steep slopes of Hyrcanian forests a contention about the selection of the best earthwork machine was observed between the operators of road construction and experts of natural resources and environment (Parsakhoo et al. 2008a). Thus, economic aims conflicted with environmental issues. One of the management methods to increase efficiency and improve the process at the stage of road construction is optimal selection and evaluation of earthwork machines (Akay et al. 2008). Analytical hierarchy process is an appropriate tool for scheduling and decision making in special projects such as road construction in forest areas (Coulter et al. 2006).

The effective factors in choosing the best alternative among different types of earthwork machines are divided into technical parameters such as standard cross-section and grade line, operational parameters such as production rate and multi-application, economic parameters such as production cost and environmental parameters such as soil excavation and displacement (Abeli 1993). Determination and analysis of these parameters are especially important in countries having limited sources and facilities (Gorton 1985). Listing method, relative benefit method, cost and benefit, economic surplus, mathematical scheduling and simulation models are the most common methods for determining the priority of criteria and alternatives. In spite of the abundant usage of these methods, there are some problems such as high cost and lack of theoretical framework. Saaty (1980) suggested the Analytical Hierarchy Process (AHP) as a suitable tool for pairwise comparison and alternative priority.

Nowadays, this method is widely used in management ambiguous decision making such as selecting appropriate models to develop information technology, priority of the projects of energy and environment, priority of the projects of power ministry, priority of the agricultural research plans,

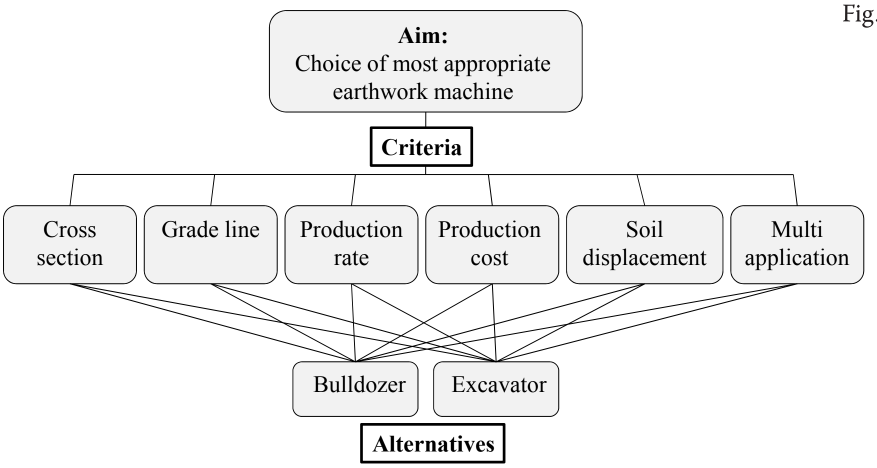

Fig. 1. AHP decision support hierarchy

selection of suitable machines for excavation and digging, routing for road construction projects, scheduling of forest road maintenance and determining the susceptible area to landslide and mass wasting (Stentz et al. 2009). Bulldozers and hydraulic excavators are the most important excavation machines which are used in road building projects. Reports on operational and economic properties of these two machines showed that in normal work conditions the efficiency of bulldozer is higher than that of hydraulic excavator (Tunay, Melemez 2004). Moreover, it was reported that the environmental damage to the natural ecosystem was lower during the work of hydraulic excavator (Parsakhoo et al. 2008b).

In recent years, the use of hydraulic excavators in earthworking projects has increased in Hyrcanian forests due to their environmental aspects and precision in operation. Furthermore, the crawler bulldozer is another machine which is used in earthworking operations. Approximately 80% of forest roads are constructed by bulldozer. One of the major factors preventing the more frequent use of excavators is their low productivity. There is a contention between experts and scientists about applying bulldozer and/or hydraulic excavator on slopes from 30% to 70% where an environmental issue is important. The main aim of this research was to use analytical hierarchy process to choose the most appropriate earthwork machine in each slope classes of 30–50% and 50–70%.

MATERIAL AND METHODS

In this study it was attempted to choose the best earthwork machine in slope classes of 3–50% and 50–70%. Some criteria are very important in these classes. Among them are standard cross-section and grade line of roads which were constructed by bulldozer and hydraulic excavator. Another factor is production rate which is defined as the soil volume which can be excavated by machine per unit time. This shows the velocity of the machine in road construction. Production cost is the indicator showing the economic advantage of each machine. It is obtained through calculating fixed and variable costs. In steep slopes, displaced soil covers the regeneration and soils are exposed to erosive agents. So, the area of displaced soil is an environmental factor which was considered in this research. Beside the earthwork operation an excavation machine can do other operations such as digging, grubbing, pipe installation, logging and etc. Indeed, multi-application is important to reduce company's costs (Fig. 1).

AHP is a method that enables to reach a decision by using quantitative and qualitative data. As the problem is stated in the hierarchical tree structure in this method, the problem becomes easy to understand (Acaroglu et al. 2006). AHP is based on determining the relative priorities (weighting) of the criteria by pairwise comparison (Aykul et al. 2007). For controlling the consistency of comparison, the consistency ratio is determined. If the ratio is below 0.1, this shows the comparison is consistent. In pairwise comparison, the question is asked 'how many times is a criterion more impor-

Table 1. Scale for pairwise comparison

Definition	Degree of importance
Equal	1
Moderate	3
Strong	5
Very strong	7
Extreme	9

2, 4, 6 and 8 can also be used

Table 2. Technical parameters of earthworking machines used in northern forests of Iran

Machine	Weight (t)	Bucket capacity (m^3)	Engine power (hp)
Komatsu bulldozer D60	17	5	220
Caterpillar bulldozer D6	16.5	5	140
Hydraulic excavator Libherr R912	17.7	1	146.3
Hydraulic excavator PC220	24	1	180

tant than another one?' and it is answered according to the scale in Table 1. Expert choice software was used for data analysis.

Expert choice (EC) software is used for the analysis of multi-criteria issues and decision making using the analytical hierarchy process. In this method the sensitivity of the matrix can be evaluated using performance, dynamic, gradient, 2D plot and different commands. The criteria to evaluate the machine performance were the ability to build standard cross-sections and grade line, soil excavation and displacement, production rate and multi-application, production cost and the alternatives were bulldozer and hydraulic excavator (Table 2). General conditions of the study site are shown in Table 3. Required data were gathered through pairwise comparison questionnaires filled by forest engineers (Table 4).

RESULTS AND DISCUSSION

Expert choice represents a significant contribution to the decision making process. It assists a decision maker in solving complex problems involving many criteria and several courses of action (Kagayo 1997). An expert choice solution to a problem reflects the expertise of the decision maker, not of the computer. The decision making was done in expert choice software in a model with hierarchy framework with levels of purpose, criteria and alternatives.

Tables 5 and 6 show the pairwise comparison matrix of alternatives for the different slope classes. Expert choice is based on the AHP, a methodology for decision making. It provides users with the tools to make decision frameworks from both quantitative and qualitative data and ways to include value judgments in these decision frameworks. This framework is a hierarchy used to choose the best factors to solve a problem in a systematic way. This hierarchy begins from the goal to the criteria and subcriteria and then ter-

Table 3. General conditions of earthy slopes in northern forests of Iran

Soil texture	Bedrock	Slope direction	Altitude (m)	Other characteristics
Lime (micro aggregate)	marl, lime marl, lime, sandstone, limestone	northern	100–800	moderate rooting, depth of roots 65–70 cm, soil porosity 40–47%, moisture 10–22%, litter thickness 2–3 cm and soil without rock fragments

Table 4. Technical and environmental parameters of bulldozer and hydraulic excavator

Machine	Slope (%)	Cross-section (%)	Grade line (%)	Production ($m^3 \cdot h^{-1}$)	Cost ($USD \cdot m^{-3}$)	Displaced soil (m^2/20 m)*	Multi-application
Bulldozer	30–50	84.11	92.73	150.4	0.1	242.6	excavation, rolling, displacing boulders by ripper
	50–70	85.49	92.73	169.8	0.1	298.6	
Hydraulic excavator	30–50	88.81	83.67	66.6	0.2	216.2	excavation, building, rooting trunk, boulder blasting by hammer
	50–70	91.11	83.67	68.8	0.2	236.4	

*area (m^2) of soil displacement by bulldozer and/or excavator when they construct each 20 m of road length

Table 5. Pairwise comparison matrix for alternatives in the slope class of 30–50%

Cross-section	Bulldozer	Grade line	Bulldozer	Production rate	Bulldozer
Excavator	0.3	excavator	0.5	excavator	0.9
Production cost	bulldozer	soil displacement	bulldozer	multi-application	bulldozer
Excavator	0.9	excavator	0.3	excavator	0.3

The values in Table 5 and 6 were obtained from the arithmetic average of assigned scales by experts based on Table 1

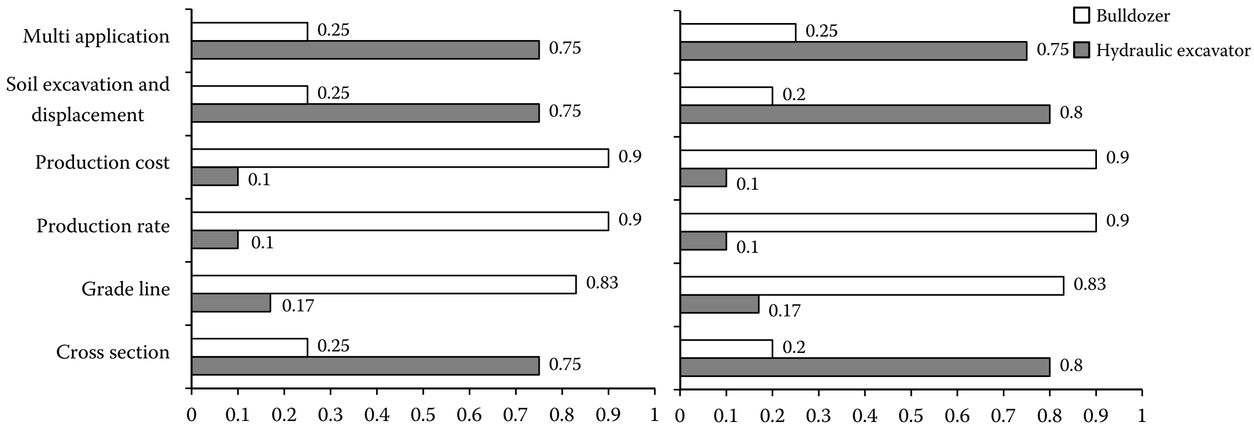

Fig. 2. Priorities of alternatives with respect to criteria in different slope classes

minates to alternatives of a decision (Dey, Ramcharan 2008).

Fig. 2 shows the relative weight of alternatives including bulldozer and hydraulic excavator with respect to different criteria. The pairwise comparison matrix of criteria is shown in Table 7. The inconsistency ratio for all pairwise comparisons was less than 0.1. So the matrixes were acceptable.

Results showed that cross-sections and grade line (Technical criteria), soil excavation and displacement (Environmental criteria), production rate and multi-application (Operational criteria), production cost (Economic criteria) with the respective weights 0.345, 0.345, 0.136, 0.058, 0.058 and 0.058 were the most important criteria for choosing the earthwork machines in the slope class of 30–50%. These coefficients for the slope class of 50–70% were 0.329, 0.329, 0.174, 0.056, 0.056 and 0.056, respectively (Fig. 3). Productivity is defined as the rate of product output per unit time (meter or cubic meter of excavated road) for a given production system, the production rates of a system can easily be estimated if time studies are combined with measurements of the output of production and it has been completed per effective machine in a working time.

Overall priority of each alternative was calculated after integrating relative weights of alternatives and criteria in ideal status. The priorities of the various earthwork machines for slope classes 30–50% and 50–70% were bulldozer and hydraulic excavator, respectively (Fig. 4). Therefore, in slope class of 30–50% bulldozer and in slope class of 50–70% hydraulic excavator must be selected for earthwork operation. Excavator machines have multimodal applications in forestry operations which include road excavating, loading, wood harvesting, timber extracting, grubbing, culvert installations, blasting of rocks and big boulders (Budny et al. 2003). Thus, from the operational

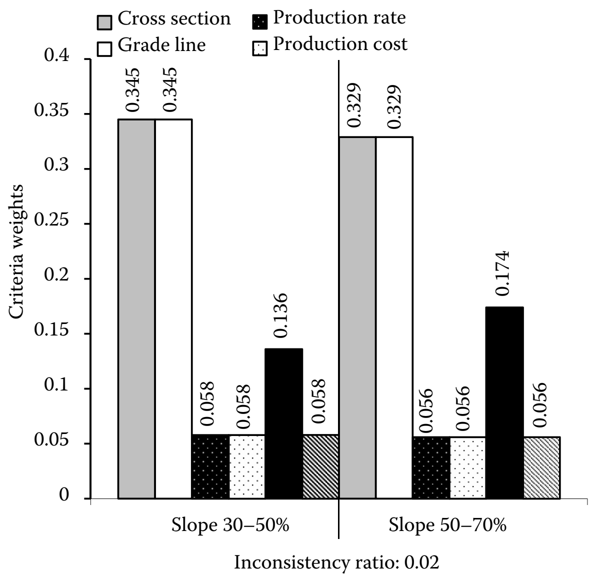

Fig. 3. Priorities of criteria with respect to the goal in different slope classes

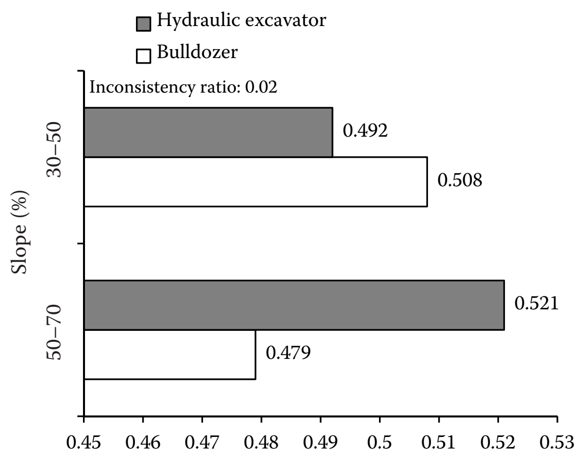

Fig. 4. Overall priority of alternatives using the ideal status for different slope classes

Table 6. Pairwise comparison matrix for alternatives in the slope class of 50–70%

Cross-section	Bulldozer	Grade line	Bulldozer	Production rate	Bulldozer
Excavator	0.4	rxcavator	0.5↑	excavator	0.9↑
Production cost	bulldozer	soil displacement	bulldozer	multi-application	bulldozer
Excavator	0.9↑	rxcavator	0.4	excavator	0.3

↑ priority direction, in other cases are ← direction

Table 7. Pairwise comparison matrix of the criteria

Criteria	Grade line	Production rate	Production cost	Soil excavation and displacement	Multi-application
Slope of 30–50%					
Cross section	1	5	5	4	5
Grade line		5	5	4	5
Production rate			1	3↑	1
Production cost				3↑	1
Soil excavation and displacement					3
Slope of 50–70%					
Cross section	1	5	5	3	5
Grade line		5	5	3	5
Production rate			1	4↑	1
Production cost				4↑	1
Soil excavation and displacement					4

↑ priority direction, in other cases are ← direction

point of view larger excavators with different attachments such as blades, hydraulic hammer, brush cutter, harvester head, bucket, grapple and winch could be recommended for improving excavator productivity in forest road construction projects (Filipsson, Eriksson 1989). Furthermore, qualified workers are necessary to work with the best machines such as hydraulic excavators, using methods to construct forest roads and performing forest harvesting so as environmental damage would be minimized (Johansson 1995).

CONCLUSIONS

The optimal selection process determines which of the earthwork machines has minimum environmental impacts and maximum economic and technical performance. In other words, we should determine which machine can be suitable for earthworking in forest areas. This study reveals that hydraulic excavator was the most appropriate earthwork machine for the slope class of 50–70%. When no hydraulic excavator is available, bulldozers of small size such as D6 types are used for earthwork operations.

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Corresponding author:

Aidin Parsakhoo, Gorgan Agricultural Sciences and Natural Resources University, Faculty of Forest Sciences, Department of Forestry, Gorgan city, Golestan province, P. O. Box 386, Iran
e-mail: Aidinparsakhoo@yahoo.com