International Journal of Natural and Engineering Sciences 3 (3): 81-87, 2009
ISSN: 1307-1149, www.nobel.gen.tr

Efficiency Evaluation of Ground Skidding System and Determining the Optimum Forest Road Density in Caspian Forest (Northern Iran)

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Received: July 02, 2009
Accepted: August 10, 2009

ABSTRACT

Determining optimum forest road network density is one of the most important factors in sustainable forest management. Logging method is an important factor in determining optimum road network density. In this research in order to determine optimum road network density, skidding cost and road construction cost were calculated. The optimum road network density was concluded at the lowest total costs (skidding and road construction costs). The results showed that skidding costs was 6.27$/m3 and the road construction cost was 21878$/km and that the optimum road network density was between 7-10m/ha.

Key Words: Forestry Management, Optimization Modeling, Forest road density

INTRODUCTION

In the Caspian forests, most timber is extracted by different methods of ground skidding and the logging methods used is cut to length and tree length. Wheeled skidders appeared in the early 1970's and are now the most widely used. The major problem with wheeled skidders is their requirement of optimum road spacing.

There are many different reports on determining road construction and skidding costs of different logging method. Forest harvesting costs account for more than half of the cost of forest management unit and in Iran; it sometimes reaches 65 percent (Sarikhani, 1990). So it is very important to optimize the related harvesting costs in any forest management activities. At present forests administrators are concerned with these issues and try to find suitable approaches to reduce costs and increase efficiency.

The necessity of mechanization of harvesting systems to overcome the need of high wood production, leads to researches related to cost assessment and the efficiency of the systems being used. With regards to this, industrial development has been introduced as a forwarding motion, from a short wood system to a tree length and then a whole tree system. The main goal was to improve work allocation and to introduce appropriate approaches in order to reduce the expenses (MacDonald and Clow, 1999).

The evaluation of two mechanized logging systems (tree length and whole tree systems) in Shafarood forests, showed that the skidding cost per cubic meter in whole tree system and tree length system were 0.31$ /m^3 and 0.17$/$m^3$ respectively (Feghi, 1990).

Another study in this area using Clark 667 wheeled skidder showed that the skidding time depends upon the variables such as skidding distance, percentage of slope in skid trail, number of logs per turn and volume per turn (Sobhani and Ghasemzadeh, 1990).

In most studies carried out on the evaluation of systems efficiency and operation of harvesting machinery the time study techniques and statistical models were used for estimating time and cost of operation. One of the principles in this method is to divide the work into work elements which allows for a more precise study and also separates productive time and unproductive time (Bjorheden, 1991).

Favreau and Gingras, (1998) carried out a study on the amount of production and cost of productions at different stages of production (felling, bucking, loading and extraction) on full tree logging and cut to length logging methods. They concluded that the wood production cost per cubic meter in cut to length logging method at extraction stage was higher than full tree logging method. They found that length of logs, skidding distance, topographical conditions and skill of operators were important effective variables on production cost.

Today the development of mathematical equations of the skidding time is an effective method for estimating cost of production unit. Therefore the independent variables entered into the models must be flexible and represent real life situation of the systems (Goulet et al., 1979).

Ledoux and Huyler (2001) compared large cut to length and small cut to length system of harvesting in terms of production and operating costs with different machine utilization rates in broad leave forests of eastern USA. In their research they used time study method and examined the effective factors in extracting logs from feeling gaps to landings on the side of road. They concluded that the most important effective factors were load volume in each turn, skidding distance and number of logs in each turn.

The logging method is one of the important factors in determining type of roads and road network density (Lotfalian, 2001).Forest roads network are different in terms of technical specification with regards to topographical situation of the area, logging methods, type of machinery and length of logs. Therefore the roads construction and maintenance costs will be different. Construction and maintenance costs of roads are the main costs that directly affect road network density. On the other hand silvicultural system with regards to production output determines type of logging machinery and forest road network density (Naghdi, 2004).

Plamondon and Favreau (1994) stated that variables such as average production volume per hectare, road construction and maintenance costs and skidding costs are important factors in estimating optimum skidding distance. They evaluated four logging systems (cable skidder, clam bunk and grapple skidder and forwarder) in terms of efficiency and determined the optimal skidding or forwarding distance for them by using the combined road and skidding costs model. Their findings showed that cable skidder system with road construction cost of 12000$/km had lowest total construction and skidding costs. They showed that the stock per hectare of forest and wood yield per hectare are important effective factors on optimal skidding distance and optimal road network density. Therefore in order to examine the relation between stock per hectare and road network density, the road construction and skidding costs and also the combined costs per cubic meter of wood are calculated.

The results of researches carried out on the efficiency of ground skidding systems in northern forest of Iran showed that skidding distance has direct and linear relation with skidding costs (Feghi 1990, Naghdi and et al. 2005 and Eghtesadi, 1991).

With regards to results of the research by Heinrich (2001) construction of adequate density of forest roads are essential for development of close to nature forest management in mountainous forests. Since the major part of road construction costs consist of constructing roads in steep slopes, therefore the high costs of road construction in this area has negative effect on road density and decreases forest road network density.

Boghean and Pavel (2002) studied the relation between forest roads network and logging systems in Romania. They emphasized that considering the low road network density and long skidding distance in most forest management unit of Romania, it is necessary to consider combined ground skidding and cable skidding systems in forest logging.

In this study the cost of skidding in ground skidding system and road construction costs are determined for one cubic meter of wood. On this basis by estimating the total costs (skidding and road construction costs) the optimum forest roads network density is determined for the studied district.

MATERIAL AND METHODS

This study was carried out in compartment 926 of 9th district in Shafarood forest, with the altitude ranging between 1400 and 1600 meters and average annual precipitation of 1000 millimeters. The forest was uneven-aged and its type was fagetum (*Fagus orientalis Lipsky*) with the average growing stock of 330 cubic meters per hectare. The area of the compartment was 70 hectares and the existing road density of the studied district was 16.2m/ha. Maximum and absolute gradient of the compartment were 75% and 20% to 50%, respectively. Cutting regime and silvicultural method were single or group selective cutting. The total volume of primary transportation which was carried out by skidders in short and long logs was 1600m^3. The landings were prepared at the border of road in the lower part of the compartment, and therefore the direction of skidding was entirely downward. The type skidder used in this study was C450Timber Jack cable skidder, model 6BTA5.9 with 177hp and 10257kg weight.

Work study techniques were used to estimate production and unit costs of a volume of wood extracted. The cycle of skidding turn was broken down into different elements and was defined as follows:

- Travel empty
- Releasing: the time needed to release the winching cable
- Choker setting
- Winching
- Travel loaded
- Unhooking (choker releasing)
- Piling

In addition to these elements, there is a series of delay times in each turn. The delays were divided into three groups:

- Operational delay
- Technical delay
- Personal delay

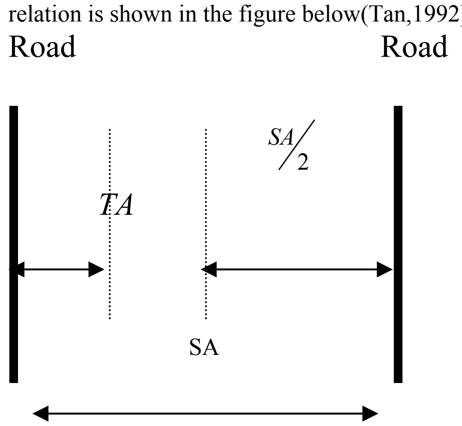
Time study data was collected in summer of 2004. In addition to the measurement of time for each work element, factors such as skidding distances, length and mean diameter of logs, gradient of skidding roads, winching distances, and number of logs in each skidding turn were also measured. In order to determine the number of required samples, first a preinventory was done to specify the time variance of skidding without considering delay time and then thirty cases of skidding were studied using time study method. With the use of following formula the required samples were 39 with 95% probability level of 10% accuracy.

$$n = \frac{t^2 \times s^2}{E^2} \qquad (1)$$

Where n is number of samples, t is t-student, s is standard deviation and E is standard error.

Scientific references and information concerning time studies of forest harvesting operations indicate that the best way to create mathematical models of task performance time for harvesting machinery is variance analysis and multi-variable regression models. Minitab software was used and a mathematical model for skidding turn was developed. For estimating machine rate, the FAO guideline (1980) was used. The skidding cost model was used to estimate the skidding cost for one cubic meter of wood extracted over different skidding distances.

Roads technical specification standard and method of wood extraction are two main factors that affect optimum road spacing of kidding operations. In other words these factors affect optimum forest road network density, which is determined by minimum total cost (skidding and road construction costs), (Rowan, 1976). Optimum road density is an important factor to help forest engineers optimize the harvesting costs using a suitable forest road network (Ghafarian et al. 2003) .There is a direct counter relation between skidding distance and road spacing, this relation is shown in the figure below(Tan,1992):



SA= Average road spacing

TA= Average skidding distance

SA= 4TA

Figure 1. Road spacing and skidding distance

In the above figure it is assumed that generally the roads are parallel and equal distance from each other. In fact these calculations are theoretical and are used as a general guide for explaining average skidding distance and skid trail borders. In practice forest road spacing can be determined with respect to different terrain conditions (Sedlak, 1981). Therefore the actual skidding distances were measured in the studied area. These distances are included in calculations and based on this optimum road network density is determined.

In this research in order to determine the optimum road network density, first skidding and road construction costs for unit volume wood were calculated . Then the optimum road network density was concluded at lowest total costs (skidding and road construction costs).

RESULTS AND DISCUSSIONS

Analysis of variance (ANOVA) is used to determine the relationship between dependent variable (total time) and independent variables in each work element and effective variables. In this analysis the first step is to make sure that the data are distributed normally and this is done by using normal plot and Anderson-Darling method. Then the relationship between time spent for work elements in each skidding turn and effective variables is specified with the use of scatter plot technique.

The relation between measured effective variables such as skidding distance, gradient, load volume and etc and their interaction with skidding time (skidding time without delay) are also determined and analyzed. The results show that the relation between variables and skidding time are mostly linear with different correlations. The stepwise regression is used to determine fixed coefficients. The model determined is as follows:

Mathematical equation of the skidding time as a function of effective factors

$$Y = -3.57 + 1.88X_1 + 0.02X_2 + 0.20X_3 + 3.09X_4 \qquad (2)$$

Where: Y= time needed for one turn (minutes), X_1= load volume in (m^3), X_2= skidding distance (m), X_3= load winching distance (m) and X_4 = number of logs in each turn

Table 1. Analysis variance of the model

Source	SS	df	MS	$F = \frac{MS_{Regression}}{MS_{Residual}}$	R^2
Regression	2206.6	4	551.64		85.9%
Residual	362.8	34	10.67	51.69	
Total	2569.4	38			P<0.001

Validity of the model

Previous to analyzing data, two series of time-study information are randomly taken out from the data to be used for determining the model validity. Confidence limits of skidding time estimated by the model are calculated and compared with real skidding time. To calculate confidence limits estimated by model (estimated time) following formula is used:

$$\hat{Y} \pm t_{\frac{a=\%5}{dfe}} \sqrt{(Mse)(1+\frac{1}{n}+\xi' sp^{-1}\xi)} \quad (3)$$

Where $\hat{Y}$ is estimated time by model for each turn of skidding without considering delay time, Mse is mean square error, n is number of skidding turns used in the model, ξ is numeric value obtained from time study of effective variables in the model to calculate time for each turn of skidding, Sp is sum of products and Sp^{-1} is inversion of sp.matrix. The results show that the model has acquired statistical validity (table.2).

Table 2. Validity of the model

Confidence limit	Measured time	Estimated time
13.17<Measured time<26.73	18.30	19.95
9.67<Measured time<23.23	15.10	16.45

Calculating production unit

$$\text{The production} = \frac{\text{Volume of wood skidded toward landing}}{\text{Time needed for skidding operation}}$$

The production without delay time =

$$\frac{\text{Total volume of wood skidded towards landing } (m^3)}{\text{Total used time (hour)}} = \frac{130.72}{9.77} = 13.38 m^3/\text{hour}$$

The production with delay time =

$$\frac{\text{Total volume of wood skidded towards landing } (m^3)}{\text{Total used time with considering delay time (hour)}} = \frac{130.72}{11.44} = 11.43 m^3/\text{hour}$$

Calculating production cost

The result of the study shows that the best model for skidding turns time is a function of independent variables: volume in each turn, skidding distance, winching distance and number of logs in each turn of skidding. Based on 99% confidence the model proved to be valid (table.1).

With the use of mean value of effective factors in these models, operational time and the cost of unit of production are estimated and based on this labor and machinery costs and finally the necessary budget for wood extraction can be estimated which is a positive step towards work management (these models can be used for similar regions with the same topography, gradient, infrastructure facilities and harvesting methods).

In order to calculate production cost over the location, FAO guideline manual is used (1980). So, using this manual the system costs consisting of machine costs simulation and labor costs are calculated and dividing this by the production over the location, production cost for one cubic meter are calculated. Scheduled daily work hours were 8 hours and useful work hours were 6 hours per day and productivity is calculated based on a 6 hour day. The number of work days was considered 150 days per year. The results show that skidding costs without delay time is 6.27 $/m^3$ and with delay time is 7.25 $/m^3$.

Skidding costs

In this research with the use of mathematical model of the skidding time prediction, the effect of variables changes on time is determined. Then by using skidding cost equation the skidding cost is determined for different skidding distances.

$$C = \frac{\frac{V \times [t \times Dt]}{v} \times Sc}{V} \quad (4)$$

C = Skidding cost ($/m^3$)

V = Total volume of skidded wood (m^3)

t = Time per skidding turn (hour)

Dt = Average delay time (hour)

Sc = System cost (machinery and labor costs) ($/hour)

v = Average volume of skidded wood in one turn (m^3)

Therefore the effect of skidding distance changes on skidding cost can be studied using the equation above. In this study in order to determine skidding cost for each different forest road network density, first skidding distances relevant to different road density are determined. Then with the use of skidding cost equation (4) and considering the relation between skidding distance and skidding costs, the skidding costs for different skidding distances and for different road density is calculated (table.3).

Skidding trail construction cost

$$\text{Length of skidding trails per hectare} = \frac{\text{Total length of skidding trails (m)}}{\text{Compartment area (hectare)}} = \frac{2911}{58} = 50 m/ha$$

Annual forest growth is 6m ^{3}/ha and for 10 years period (in single selection method), annual forest growth is 60 m^3/ha.The skid trails construction cost is 1000$/km, this is the cost for excavation, earth filling and preparing the skid trails (Shafarood Forest Cooperation, 2004). Therefore for 50m is 50$.This is the cost for 60m^3 of wood, therefore for skidding one cubic meter is 50/60=0.83$/m^3.Consequently the skid trails construction cost (0.83$/m^3) is added to skidding cost to obtain final skidding cost (table 3).

Table 3.Relationship between road network density, average skidding distance and skidding cost

Forest road network density(meter per hectare)	Actual Average skidding distance in operation(meter)	Skidding cost ($/m^3)	Final skidding cost ($/m^3)
5	943	11.26	12.09
6	786	10.29	11.12
7	673	9.60	10.43
8	589	9.08	9.91
9	524	8.68	9.51
10	471	8.36	9.19
11	429	8.10	8.93
12	393	7.88	8.71
13	363	7.69	8.52
14	337	7.53	8.36
15	314	7.39	8.22
16	295	7.28	8.08
17	277	7.17	8.00
18	262	7.07	7.9
19	248	6.99	7.82
20	236	6.91	7.74

Relationship between road network density and road construction costs

Road construction costs

The existing roads in the studied area adhere to the standards related to main access forest road. The road construction costs include excavation and filling (construction of trails by bulldozer), pavement and finishing and retaining wall and drainage construction costs. The planning costs of forest road project are taken as 10% of these costs (table 4), (Shafarood forest cooperation. (2004).

Table 4. Road construction and planning costs in the studied area

Type of cost	Cost($/km)
Excavation and filling	5667
Pavement and finishing	8111
Retaining wall and drainage construction	6111
Planning	1989
Total	21878

Road cost

Annual forest road cost of one kilometer is determined by total cost of capital interest, depreciation and repair and maintenance costs (table.5).

Capital interest

I =A×i

i =16.5%

A = Average capital value $

Annual capital interest = I =21878/2=10939×0.165=1805$/km

Depreciation

Annual Depreciation cost =

$$D = \frac{\text{Cost (\$/Km)}}{\text{Useful life(year)}} = \frac{21878}{50} = 438\$/km$$

Repair and maintenance cost

Repair and maintenance cost of road is 5% of road construction cost.

Annual repair and maintenance cost = 19889×0.05=994$/km

Restoration cost

Road restoration cost for 20 years is 30% of capital cost. Therefore annual restoration cost is 1.5% of capital cost.

Annual restoration cost = 19889×0.015=298$/km

Table 5. Annual road construction cost ($/km)

Type of cost	Cost ($/km)
Capital interest	1805
Depreciation	438
Repair and maintenance	994
Restoration	298
Total	3535

Annual road construction cost for different forest road network density is calculated in $/m^3 (table 6).For example annual road construction cost is 3535$/km, therefore for forest road network density of 5 m/ha and forest growth of 6m^3/ha (in single selection method) the road construction cost is 2.95$ /m^3.Consequently the road construction cost is added to final skidding cost (skidding cost and skid trail construction cost) to obtain total cost.

Table 6. Relationship between road network density and road construction costs

Forest road network density (meter per hectare)	Road construction costs ($/m^3)	Total cost ($/m^3)
5	2.95	15.04
6	3.54	14.66
7	4.12	14.56
8	4.71	14.63
9	5.30	14.82
10	5.89	15.08
11	6.48	15.42
12	7.07	15.78
13	7.66	16.19
14	8.25	16.62
15	8.84	17.07
16	9.43	17.54
17	10.02	18.02
18	10.61	18.51
19	11.20	19.02
20	11.78	19.53

As shown in fig.2 with the help of total costs curve which is composed of road and skidding costs, the optimum road network density limit can be determined. This limit is at the lowest level of the curve of total costs. The graph shows that suitable forest road network density in the studied area with regards to road and skidding costs, is in the range of 7-10 m/ha. The results of this research show that the high costs of road construction in the studied area is a motive to reduce road network density and increase length of skid trails and that's the reason for low skidding costs per cubic meter.

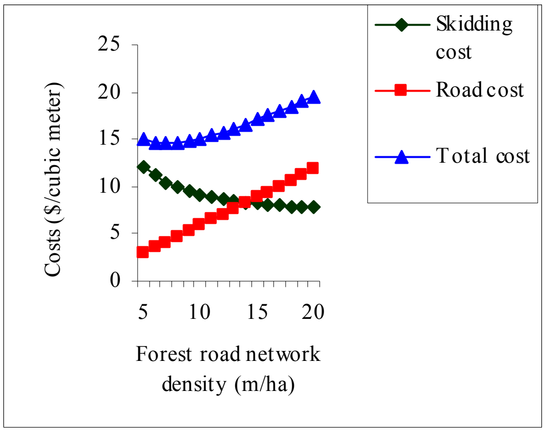


Fig.2. Relationship between costs and forest road network density

CONCLUSIONS

The aim of this research was to calculate skidding and road construction costs, in order to determine optimum forest road network density. The mathematical model for predicting skidding time was determined and with the use of this model, time and cost of skidding for different skidding distances were calculated.

Skidding distances were determined for different road density. The skidding cost/m^3 of wood for different skidding distances is calculated using cost equation 4.Then annual road construction cost is determined for unit volume of wood extracted from forest roads.

The sum of road construction and skidding costs for different road density are determined. Based on minimizing these two costs, the optimum forest road network density was estimated to be 7-10m/ha.The road skid trail density was 50m/ha. With these densities of road network and skid trails, all the parcels are available for extracting wood.

This shows that by constructing roads and skid trails with suitable density in selective silvicultural method which is used in mountainous forest of northern Iran, the costs can be reduced.

In this research the existing road density was 16 m/ha (for shelter wood system and intensive logging which was used up to 1991) and recent years selective system is used and therefore road density for these systems must be determined.

With the use of mean value of effective factors in these models, operational time and the cost of unit of production are estimated and based on this labor and machinery costs and finally the necessary budget for wood extraction can be estimated which is a positive step towards work management (these models can be used for similar regions with the same topography, gradient, infrastructure facilities and harvesting methods).

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