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Evaluation of Tree Length and Assortment Logging Methods with Respect to Timber Production in Caspian Forest in the Northern Iran

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Abstract: In order to find an efficient way of selective logging methods, two logging methods, in ground skidding systems, were compared with respect to productivity. In this study, for estimating production and cost of a unit volume of wood in two logging methods the work study technique was used. The total productions in tree length and assortment logging methods, without delays were 18.60 and 13.38 m^3 h^{-1}, respectively and with delays were 14.60 and 11.43 m^3 h^{-1}, respectively. The results of this study show that timber production in the tree length method with the use of trailers for transporting timber to factory yards was higher than the assortment method which used truck for transporting timber. The production costs without delay times in tree length and assortment logging method were 4.30 and 6.27 \$ m^{-3}, respectively and with delay time in the tree length method was 5.43 and 7.25 \$ m^{-3} for the assortment logging method.

Key words: Ground skidding system, logging method, work study technique, productivity, Iran

INTRODUCTION

The Caspian forest located in the north of Iran covers the north facing slopes of the Alborz mountain ranges and classified as mountain forest. The majority of these forests are managed as uneven aged forest and about 60% of the forest is used for timber production. For this reason forest harvesting is one of the important factors for Caspian forest management. In the Caspian forests, most timber is harvested by some form of ground skidding. Wheeled skidders appeared in the early 1970' s and are now the most widely used. The major problem with wheeled skidders is their requirement for a dense network of roads.

Another problem is that the skidding cost without having the machine rate (\$ h^{-1}) can not be calculated. Forest managers are trying hard to find the timber production cost per cubic meter and also trying to find the best way of optimizing productivity with respect to the potential and condition of the forest.

At present forest management is preoccupied with these problems and tries to find suitable approaches to solve them. On the other hand, forest harvesting costs account for more than half of the cost of forest management unit and in Iran it sometimes reaches 65% (Sarikhani, 1990). So it is very important to optimize the related harvesting costs in any forest management activities. Industrial development has been introduced as a forwarding motion from a short wood system to a tree length and then a full 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 methods (tree length and full tree methods) at Shafarood forests in Iran, showed that the skidding cost per cubic meter of timber in full tree system and tree length system were 0.32 and 0.17 \$ m^{-3}, respectively (Feghi, 1987). 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 (Sobhany and Ghasemzadeh, 1990). In different kinds of skidders, the difference in machinery efficiency is due to the size and type of machinery, operator's skill and terrain (Abeli, 1996).

In east Alberta forest three methods (cut-to-length, tree length and full tree) were compared with respect to stand damages and productivity. The result showed that factors like felling equipments, skidders and forwarders for transferring the wood from stump to landing, position and area of landing, road density and spacing, skidding

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distance and work organization have an effect on the production efficiency which can be used for evaluating logging systems (Pulkki, 2000).

The amount of production is dependent on the condition of harvesting i.e., factors and variables that affect efficiency and cost of production. These variables are mean volume of logs, stand density per hectare, skidding distance and topography and micro topography (Stenzel *et al.*, 1985). Paying attention to the skill and efficiency of work force and motivating them increased production efficiency (Dykstra and Heinrich, 1996). Therefore by training the work force the goals of efficiency and safety in production operation which complement each other can be achieved (Gaskin and Parker, 1993).

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 small work elements which allows for a more precise study and also separates productive work (productive time) from unproductive work (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 assortment logging methods. They concluded that the wood production cost per cubic meter in assortment 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.

Almost in all of these studies, statistical and simulation models have been used to estimate the skidding time and cost. Today the development of mathematical equations of the skidding time is an effective method for estimating cost of unit of production. Therefore the independent variables entered into the models must be flexible and represent real life situation of the systems (Goulet *et al.*, 1979).

The objective of this study was to evaluate productivity and production cost in tree length and assortment logging methods which are the only mechanized methods used for forest harvesting in Iran.

MATERIALS AND METHODS

The research was carried out in two compartments of ninth district in Shefarood forest, with the altitude ranging between 1400 and 1600 m and average annual precipitation of 1000 mm. The forest was disturbed, uneven-aged and its type was fagetum (*Fagus orientalis Lipsky*) with the average growing stock of 330 m^3 h^{-1}. 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 or long logs and tree length were 2800 m^3. The landings were prepared at the border of road in the lower part of the compartment and therefore the directions of skidding were entirely downward. The type skidder used in this study was 450C Timber Jack cable skidder, model 6BTA5.9 with 177 hp and 10257 kg weight.

In this study, the production and cost were compared in tree length and assortment logging methods in Shefarood region (West of Caspian forest), during June and July 2004. Single selection method was used and felling operation was carried out by chain saws. In order to estimate production and cost of a unit volume of wood, the work study techniques was used. Work-study included method-study and elemental time-study techniques. 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 June/July 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 and number of logs in each turn of skidding and winching distances were also measured. Huber formula was used to calculate volume of logs (Zobiery, 1999). In order to determine the number of required samples, first a pre inventory 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 chosen, 41 and 39 samples for tree length and assortment logging methods, respectively, with 95% probability level of 10% accuracy.

$$n = \frac{t^2 \times s^2}{E^2}$$

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 model was used (FAO, 1996).

RESULTS AND DISCUSSION

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 models determined are as follows:

Mathematical equation of the skidding time as a function of effective factors in tree length method

$$Y = -14 + 4.39X_1 + 0.15X_2 + 0.03X_3 + 0.60X_4$$

Where Y is time needed for one turn in minute, X_1 is number of logs in each turn, X_2 is load volume in m^3, X_3 is skidding distance in m and X_4 is longitude gradient of skidding route in %.

Source	SS	df	MS	$F = \frac{MS_{Regression}}{MS_{Residual}}$	R^2
Regression	1305.4	4	326.36		75.1%
Residual	373.8	34	10.99	29.68	
Total	1679.3	38			p<0.001

Mathematical equation of the skidding time as a function of effective factors in assortment method

$$Y = -3.57 + 1.88X_1 + 0.02X_2 + 0.20X_3 + 3.09X_4$$

Where Y is time needed for one turn in minute, X_1 is load volume in m^3, X_2 is skidding distance in m, X_3 is load winching distance in m and X_4 is number of logs in each turn.

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 models: 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:

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

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.

Table 1 and 2 show the model validity for tree length and assortment methods, respectively. The results show that the two models have acquired statistical validity.

Calculating the production unit

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

Table 1: Validity of model in tree length method

Confidence limit	Measured time	Estimated time
18.91<Measured time<32.89	28.25	25.90
5.92<Measured time<18.70	17.50	12.32

Table 2: Validity of model in assortment method

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

The production in tree length logging method

$$\text{The production without delay time} = \frac{\text{Total volume of wood skidded towards landing (m}^3\text{)}}{\text{Total used time (hour)}} = \frac{160.33}{8.62} = 18.60\ \text{m}^3\ \text{h}^{-1}$$

$$\text{The production with delay time} = \frac{\text{Total volume of wood skidded towards landing (m}^3\text{)}}{\text{Total used time with considering delay time (hour)}} = \frac{160.33}{11.01} = 14.60\ \text{m}^3\ \text{h}^{-1}$$

The production in assortment logging method

$$\text{The production without delay time} = \frac{\text{Total volume of wood skidded towards landing (m}^3\text{)}}{\text{Total used time (hour)}} = \frac{130.72}{9.77} = 13.38\ \text{m}^3\ \text{h}^{-1}$$

$$\text{The production with delay time} = \frac{\text{Total volume of wood skidded towards landing (m}^3\text{)}}{\text{Total used time with considering delay time (hour)}} = \frac{130.72}{11.44} = 11.43\ \text{m}^3\ \text{h}^{-1}$$

Calculating production cost: In order to calculate production cost over the location, FAO manual is used (FAO, 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. These calculations are in accordance with machinery and instruments price list for the year 2003 (Anonymous, 2003). Scheduled daily work hours were 8 h and useful work hours were 6 h per day and productivity is calculated based on a 6 h day. The number of work days was considered 150 days per year. The results show that skidding costs (stump to landing extraction costs) in tree length and assortment logging methods are 4.30 and 6.27 \$ m^{-3}, respectively, these figures do not include delay time cost. The production cost with delay time cost included is 5.47 and 7.25 \$ m^{-3} for tree length and assortment logging method, respectively.

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 and by assigning these effective factors to the operational time, mathematical models of skidding time were developed for tree length and assortment methods. 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). The best and most suitable situation for effective factors can be provided by considering them in the models.

The analysis of work elements show that in both logging methods the load winching time after empty travel time and loaded travel time is the third most important part of each turn time. The load winching time for assortment logging method is higher than tree length logging method (mean load winching time of 3.6 and 2.7 min for assortment and tree length logging methods, respectively). This is due to the higher number of long and short logs being transported from logging site to the landing site (mean turn time of 2.2 and 1.6 min for assortment and tree length logging methods, respectively). The operational delays are another important part of time elements (mean operational time of 3.1 and 2.2 min for assortment and tree length logging methods, respectively). Dykstra and *et al.* (1996) in their studies mentioned that by training the work force the efficiency and safety can be increased and therefore delays can be prevented. Feghi (1987) also said that by good management these kinds of delays can be decreased which increases production efficiency.

Therefore with good management these kinds of delays could be decreased in order to decrease skidding cost. For example, preparing logs to the felling position for skidding before the arrival of the skidder and preventing skidder being delayed can decrease operational delays.

After calculating the model credence, it became clear that the model has statistical credence. In assortment logging method the gradient variable is not entered in to the model, because gradient range differences are not extensive. The total productions without delays are 18.60 and 13.38 $m^3\ h^{-1}$ for tree length and assortment logging methods, respectively and with delays is 14.60 and 11.43 $m^3\ h^{-1}$, respectively.

The production costs without delay times in tree length and assortment logging methods are 4.30 and 6.27 $ m^{-3}, respectively and with delay time in the tree length method is 5.43 and 7.25 $ m^{-3} for the assortment logging method.

CONCLUSIONS

Forest harvesting cost is the most expensive cost involved in forest operations, therefore paying attention to increasing productivity at this stage is fundamental and very important. The study showed that output efficiency in tree length logging method is much higher than assortment logging method. This is very important especially in the areas where infrastructural facilities such as road network, road geometric characteristics, harvesting and transporting machinery and equipments provide the necessary requirements for tree length logging method and these conditions were available in the area where the study was carried out.

This study also showed that load winching time is an important part of work elements, therefore with regard to high power of 450C Timber Jack skidder few chokers can be used to winch many logs in each stage of load winching so that in addition to reducing time the traffic is also reduced which in turn decrease soil compaction in skidding routes. Delay time has significant effect on increasing skidding costs and this study showed that operational delays are more important than other delays (personal and technical), therefore with proper management operational delays can be reduced in order to decrease skidding cost.

The findings of this study can be very useful for forest harvesting manager to find out the machine efficiency in different ground skidding systems (assortment and tree length logging method). With the results obtained in this study labor force and the required machinery can also be estimated more precisely and therefore the planning process can be faster and easier.

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