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# PRODUCTIVITY AND COSTS OF EXTRACTION OF SMALL SIZED TIMBER BY MULES – A CASE STUDY: PLANTATIONS IN N.W. IRAN, TYROMROOD BASIN, TONEKABON CITY

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**Abstract**

To assess productivity and costs of extraction, a time study was made. A model of performance was developed with extraction distance and log sizes as influencing factors. Average experimental data were: log diameter 12 cm, extraction distance 42 m, delay-free productivity 1.88 $m^3$ per hour, productivity with delay 2.017 $m^3$ per hour, average speed 2.73 km per hour when loaded and 3.198 km per hour unloaded, extraction costs 1.77 USD/$m^3$.

**Key words:** wood extraction, mules, thinning, time study, plantation stand

## INTRODUCTION AND PURPOSE

Maple and alder plantations in the area of the present study are established because of local scarcity of wood and also for ecological reasons (Marvi Mohajer, 2005; Sarikhani, 2000). They are thinned for silvicultural reasons – the qualitative and quantitative improvement of the stands (Firuzan et al., 2006; Gorji Bahri, 1989), but the removed wood is nevertheless used in the particleboard industry. Doing early silvicultural operations in forest is costly, but our previous studies confirmed in general the profitability of supplying these products to the market (Hamedi Qazi, 2015). In regard to this, the costs had to be studied more thoroughly, since timber extraction is the most expensive part of exploitation, also in the conditions of Iran (Nikooy, 2003; Naghdi, 2004). In order to study the costs, a time study was made. Time studies give flexible results (models), easy to adapt to objects, which do not share all average characteristics of the studied stands (Mousavi, 2009).

In the region of the study, wood and small timber is extracted by mules. The traditional technology that uses human and animal power has dominated for ages (Saarilahti, Isaho, 1992; Jourgholami et al., 2008). Although it is in decline in industrial societies, it has not lost its importance. Research demonstrates that traditional logging (horses, mules, etc.) causes less damage to the remaining soil and trees in comparison with mechanized logging (Shrestha et al., 2008; Ghaffarian, 2002; Wang, 1997; 1999; McCabe, Tiner, 1992; Rodriguez, Fellow, 1986). Nowadays, the Natural Forests Program prohibits any exploitation of standing trees, the construction of skidding routes and the use of heavy skidders and thus it promotes the use of animals for the scattered removals available. Evaluating timber transportation using animals in China, Wang stated, too, that reduced harvest volume per ha and environmental pressure have caused using animals for skidding to be common in mountainous forests of Heilongjiang (Wang, 1999).

A great deal of studies on the use of animals for extraction of logs and short wood has been carried out. It is known that it is economic up to the distance of 500 m (Lotfaliyan, 2011). It is also known that reducing skidding distance and increasing tree size decrease significantly the exploitation costs, s. for instance (Pan et al., 2008). That is why most authors direct their attention to the last cutting stage. Early thinnings have not been well studied yet and there are no studies on them in the plantations in Iran. Therefore the present study tries to fill this gap.

## MATERIALS AND METHODS

### The investigated area

The stand where the study was carried out is located in the northern side of Alborz mountain range in the number 32 basin of Tyromrood. Alborz condenses the moisture of Caspian Sea over its Northern slope which, in turn, leads to appropriate rainfall in the area and a climate appropriate for forests and forestry. The soil is generally brownish (Cambisols, CM). Tyromrood is a monitoring unit subordinate to the Natural Resources Office of Tonekabon and Kashku. It is located between 36º 53' 44'' and 36º 50' 00'' latitudes and between 50º 42' 22'' and 50º 30' 46'' altitudes. It stretches from the low mountains to middle mountains belt. The elevations above sea level range from 70 m in the compartment 626 to 1300 m in the compartment 601.

### The experiment

The dominant tree species planted in the investigated area are maple (*Acer velutinum* Boiss.) and caucasian alder (*Alnus subcordata* C.A.Mey). The marked trees were felled and cut into products which could be carried by mules. In each extraction cycle, depending on the weight, 2 or 3 items were loaded on the animal and extracted from the forest. The wood was extracted by groups of two or four men depending on the size of logs and topographic conditions. While extracting, one or two people were busy in loading and one or two in unloading. In the average, one man operated 2 mules.

### Research method

Sample number. A number of 40 extraction cycles were measured. The number of 40 was chosen to be sufficient to obtain a reliable mean value of productivity. It was calculated using the usual formula for non-stratified samples (Zobeiry, 1994),

$$n = \left( t \frac{CV}{error\ percent} \right)^2, \quad (1)$$

wherein $CV$ is the coefficient of variation (about 30%).

**Statistical calculations.** The mathematical model of predicting the time of extracting was prepared using SPSS software version 21. Normal distribution of the time study data was ensured using the Kolmogorov-Smirnov test. In order to identify the influential factors on the rate of production, a multivariate linear regression model was used.

Time study details. A digital camera was used for timing. The main effective factors registered were the extraction distance (from cutting area in the forest to depot), slope (percent), volume and number of logs and their mean diameter. Each cycle of extraction was divided into four elements:

| | |
|---|---|
| Travel unloaded | Begins when the mule leaves the depot and ends when it arrives at the cutting area. |
| Loading | Begins when the mule stops at the cutting area and ends when the rope fastens the timber on the mule. |
| Travel loaded | Begins when the mule departs towards depot and ends with arriving at the depot. |
| Unloading | Begins when the rope ties are unfastened and ends by piling the logs. |

The operative time $t_0$ (a.k.a. net time or pure time) was figured out as the sum of the times spent for travel unloaded $t_1$, loading $t_2$, travel loaded $t_3$ and unloading $t_4$, thus

$$t_0 = t_1 + t_2 + t_3 + t_4 \quad (2)$$

In addition to operative time, delay time $t_5$ was measured which included necessary operative, technical and personal delays. The gross time $t$ is the sum $t_0 + t_5$ of operative time and necessary delays, thus

$$t = t_1 + t_2 + t_3 + t_4 + t_5 \quad (3)$$

Unnecessary delays (errors and so on which were rare) have not been measured. Thus $t$ used to be simply the total time of an extraction cycle.

The productivity (performance, rate of production, hourly production) was estimated by dividing extracted wood volume $v$ by time spent. The net productivity was calculated as

$$p_o = \frac{v}{t_o}, \quad (4)$$

and the gross productivity (or simply the productivity) was calculated as

$$p = \frac{v}{t}, \quad (5)$$

wherein $v$ was the load volume the mule brought.

The time consumption (a.k.a. time per unit or standard time) is the reciprocal of productivity which can be calculated with delays ($TC = 1/p$, gross t.c.) or without them ($TC_0 = 1/p_0$, net t.c.).

The speed was calculated as the ratio of extraction distance $L$ to spent time, separately for 'travel unloaded' ($L/t_1$) and 'travel loaded' ($L/t_3$).

**Equation of total production and timing**

The time consumption of timber extraction is known to be directly proportional to skidding distance and inversely proportional to timber sizes. This means, that time consumption is a linear function written with the formula

$$TC = \frac{a_1 + a_2 L}{x} + b_1 + b_2 L \qquad (6)$$

wherein $L$ is skidding distance, $x$ is some measure of log size and $a_1$, $a_2$, $b_1$, $b_2$ are regression coefficients. As a measure of log sizes, the mean log volume $\bar{v}$ or the square $d^2$ of the mean timber diameter are commonly used. Instead of log size, the load volume $v$ can be also used. However, this is only methodically correct, when the load is bundled by somebody else and not by the extraction workers.

In the present study, due to the flatness of the study area (less than 5 percent slope), the effect of slope on extraction was not taken into account.

Cost calculations. The system costs include the costs of buying fixed assets (machines, also animals), the costs for materials and the labor costs (Akay, 2005). The basis for estimating expenses is the year 2015. The summary of extraction expenses is presented in Table 1. The yearly costs calculation method is shown in Table 2 (Naghdi 2005).

**Table 1.** Expenses of wood extraction by mule in the investigated area

| | Price (USD) |
|---|---|
| Yearly cost of a mule (fixed cost) ($P$=1000, $S$=200, $N$=5, $i$=0.21=21%, see Table 2) | 324 Yearly |
| Packsaddle for mules (variable cost) | 46.78 Yearly |
| Halter and Rope (variable cost) | 15.62 Monthly |
| Shoe the mule (variable cost) | 26.56 At any time |
| Daily feeding costs (variable cost) | 3.12 |
| Support costs (variable cost) inc. dietary supplements, pharmaceuticals, veterinary services, cleaning and guards | 50 |
| Labor costs (variable cost) | the half of 13.12 Daily |

The hourly costs were calculated by dividing yearly, monthly and daily costs by the appropriate number of work hours: 5 h a day, 20 days per month and 6 months per year were assumed corresponding to local weather conditions.

Per unit costs (costs per cubic meter) $c$ were calculated as the product of hourly costs $HC$ and time consumption including delays (no real work without delays!), thus

$$c = \frac{\mathrm{HC}}{p} = \mathrm{HC} \cdot \mathrm{TC} \qquad (7)$$

Per unit costs calculated without delays

$$c_o = \frac{\mathrm{HC}}{p_o} = \mathrm{HC} \cdot \mathrm{TC_o} \qquad (8)$$

**Table 2.** Yearly cost calculation method for an asset

| | |
|---|---|
| $A = \frac{(P-S)(N+1)}{2N} + S$ | $A$ = annual investment, USD;<br>$P$ = purchase price, USD;<br>$S$ = salvage value, USD;<br>$N$ = economic life, years, |
| $I = A \times i$ | $I$ = interest, USD; $i$= interest rate = 21% |
| $D = \frac{(P-S)}{N}$ | $D$ = depreciation, USD; |
| $T = (D + I) \times 10\%$ | $T$ = insurance |
| $TFC = D + I + T = 1.1\ (D + I)$ | TFC = total fixed cost; USD/year |

were also taken into consideration, as they constitute the minimum cost achievable, $C_0 \leq C$.

## RESULTS

### Distribution of consumed time

The mean total spent times are presented in Table 3 and their percentages are shown in Fig. 1. As indicated in it, the maximum time share (43%) is attributed to loading. The preparatory operations (unloading, travelling unloaded, loading) consume 69% of the total working time, while the real work (the carrying of the loads) consumes only 22%. The delays consume the rest of the total working time – 9%.

**Table 3.** Mean time of extraction phases

| Average spent times, seconds | Phases of extraction |
|---|---|
| 46.37 | Travel unloaded |
| 105.05 | Loading |
| 54. 00 | Load carrying |
| 17.27 | Unloading |
| 21.00 | Delays |

According to the flatness of the research area with a slope less than 5 percent and rather short distance between cutting area and depot, the times needed for travel unloaded and travel loaded were close (19 and 22 percent).

The timing results of the 40 extraction cycles are presented in Table 4.

Table 5, an SPSS output, shows the coefficients of the regression model and their statistical evaluation. All coefficients are significant and have rather high determination coefficient. The model is defined by formula (6). In Table 5 it comprises only two coefficients, because the other ones proved to be of little influence or insignificant. Thus, the model of productivity was reduced to

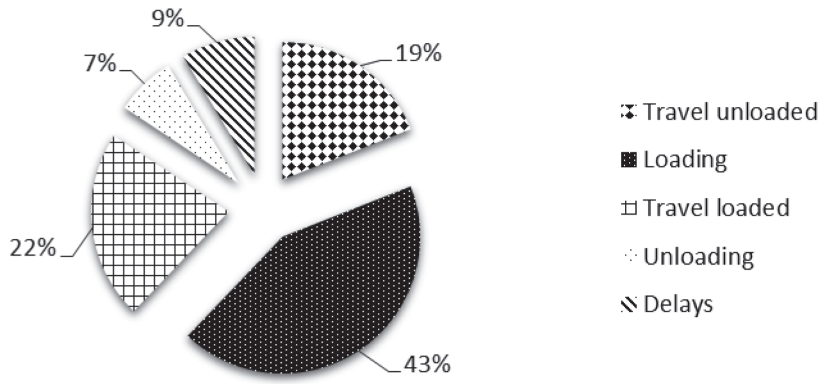


**Fig. 1.** Time distribution of the cycle elements

**Table 4.** Extraction experiment characteristics

| | **Mean** | **Min** | **Max** | **Std. dev** |
|---|---|---|---|---|
| Volume ($m^3$) | 0.120 | 0.062 | 0.200 | 0.040 |
| Extraction distance (m) | 41.42 | 13.30 | 66.50 | 16.57 |
| Diameter (cm) | 12.10 | 8.74 | 15.71 | 1.87 |
| Travel unloaded (s) | 46.37 | 14 | 77 | 16.97 |
| Loading (s) | 105.05 | 79 | 155 | 15.78 |
| Travel loaded (s) | 54.00 | 22 | 80 | 16.83 |
| Unloading (s) | 17.27 | 9 | 24 | 3.95 |
| Delays (s) | 21.00 | 0 | 122 | 43.58 |
| Speed unloaded (km/h) | 3.20 | 2.10 | 3.78 | 0.80 |
| Speed loaded (km/h) | 2.73 | 1.28 | 4.05 | 0.80 |
| Pure time (s) | 222.70 | 157 | 284 | 39.60 |
| Gross time (s) | 243.70 | 165 | 397 | 43.78 |
| Net Productivity ($m^3$/h) | 2.02 | 1.03 | 3.94 | 0.84 |
| Gross Productivity ($m^3$/h) | 1.88 | 0.72 | 3.75 | 0.84 |

$$TC_o = \frac{46.514}{d^2} + 0.006L \qquad (9)$$

wherein $TC_0$ is net time consumption of extraction ($h/m^3$), $d$ is average log diameter (cm) and $L$ is extraction distance (m).

**Table 5.** Model summary

| R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|
| 0.995 | 0.990 | 0.989 | 0.06212 |

| factors | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|
| | B | Std. Error | Beta | | |
| *L* | 0.006 | 0.001 | 0.405 | 8.676 | 0.000 |
| $d^{-2}$ | 46.514 | 3.582 | 0.606 | 12.984 | 0.000 |

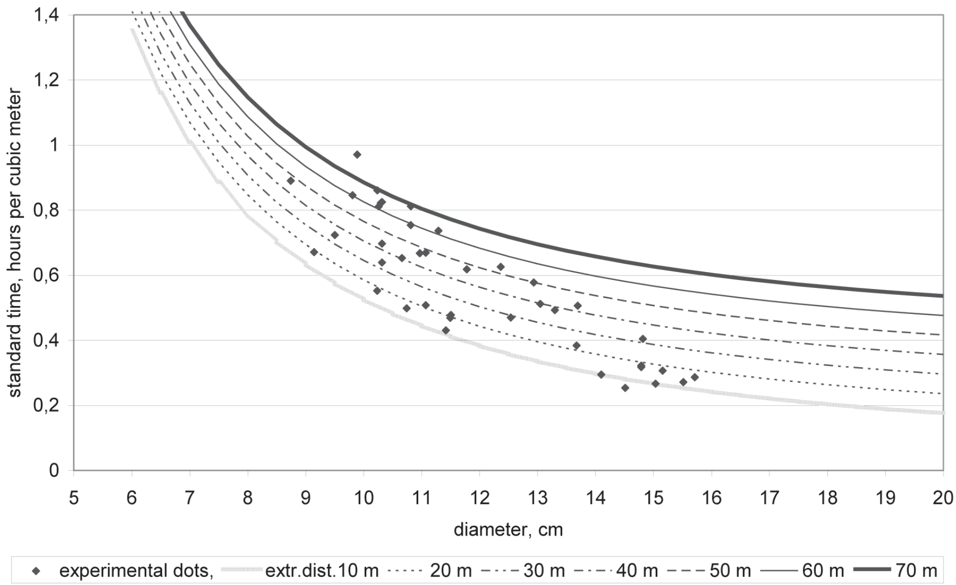


**Fig. 2.** Standard time (time consumption) model, based on mean log diameter

The model predicts the pure time of extraction, i.e. the time without delays. If the intensity of delays is equal to the observed one (which should be the common case), the predicted time should be augmented with 10% to obtain the full (or gross) time, i.e.

$$TC = 1.10\ TC_0 \qquad (10)$$

In the following figures the model curves are displayed together with the scatter plots of the measured data. All plotted performances resp. standard times have been calculated without delays.

Fig. 2 indicates the combined effect of log sizes and extraction distance on the pure time. As it is observed in the picture, extraction time increases with increasing the distance and decreasing the diameter. The effect of an additional distance apparently does not depend on the diameter.

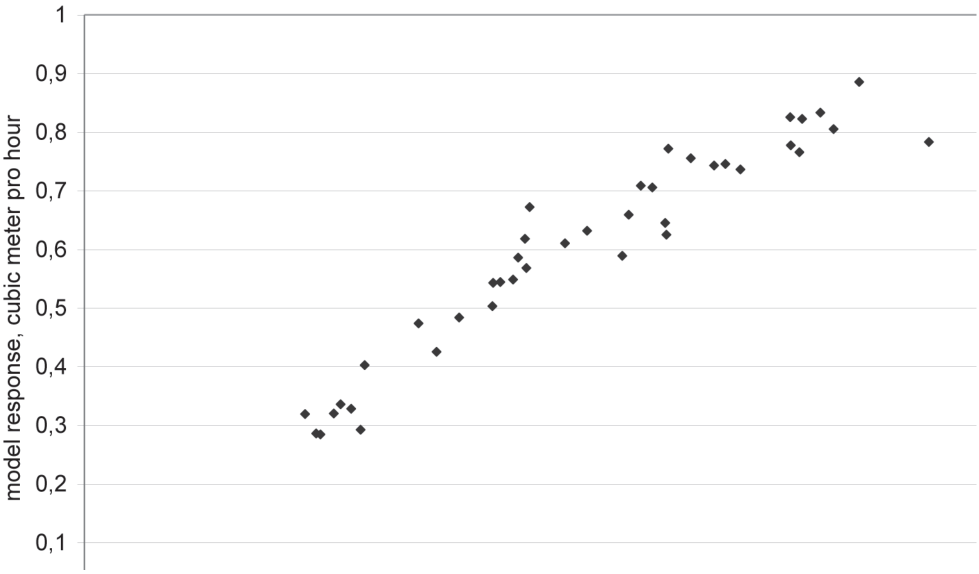


**Fig. 3.** Comparison result to data

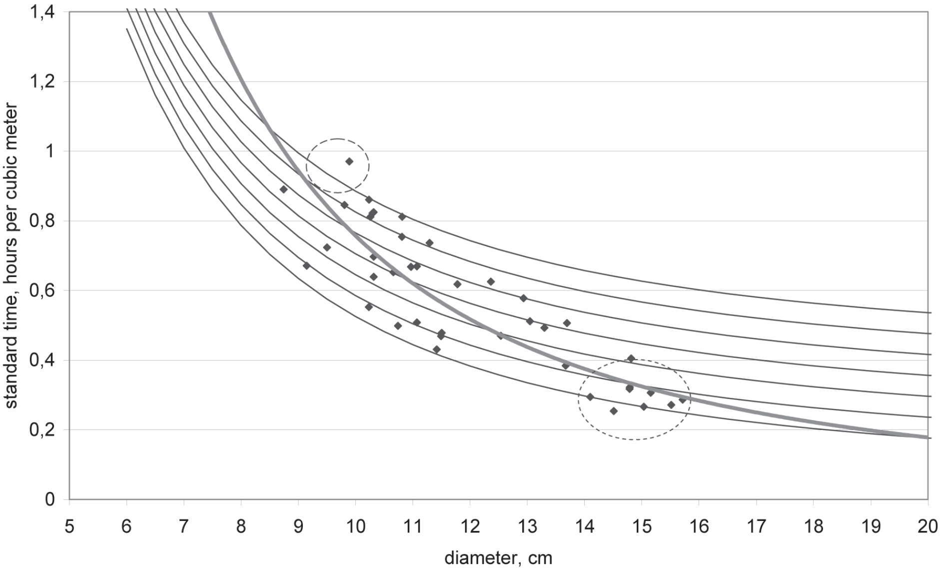


**Fig. 4.** Time consumption model – bias

Fig. 3 compares the model results to the measured data. The relation is tight and does not indicate apparent heteroskedasticity.

Fig. 4 is a second plot of the same relationship as in Fig. 3 made in order to indicate that, in the measured sample, the largest tree sizes are presented only on the shortest distances and, vice versa, the longest distances are undertaken with very small logs only (see the dot clusters indicated with circles). Thus an attempt to fit a curve based

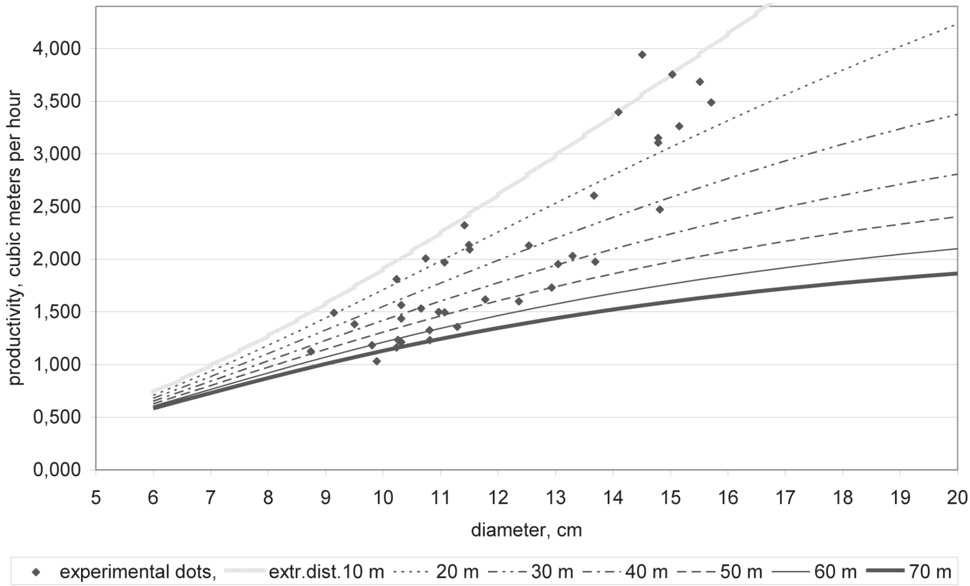


**Fig. 5.** Performance model

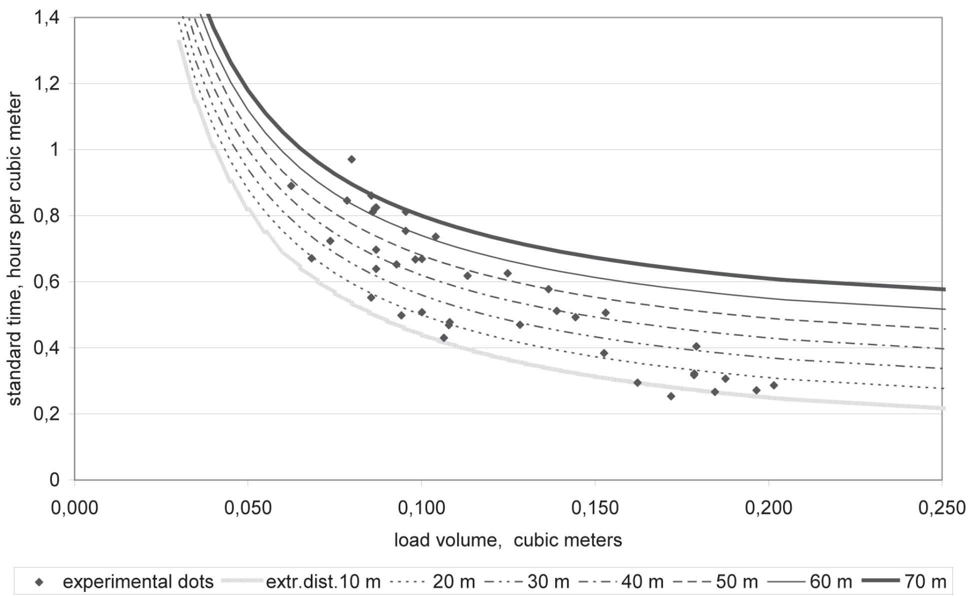


**Fig. 6.** Standard time model, based on load volume

only on diameter would give a misleading result (e.g. the power function on Fig. 4 that crosses the model lines).

In Fig. 5, the productivity is plotted instead of standard time. Fig. 6. shows the result of fitting a model based on load volume instead of log volume or diameter. The result looks almost also good, although methodically less correct.

## ESTIMATING COSTS

The estimated basic hour costs are presented in Table 6.

**Table 6.** Hourly expenses

| | USD/h |
|---|---|
| Mule (Fixed cost) | 0.54 |
| Packsaddle Mule (Variable cost) | 0.08 |
| Halter and Rope (Variable cost) | 0.16 |
| Shoe the mule (Variable cost) | 0.53 |
| Daily feeding costs (Variable cost) | 0.62 |
| Support costs (Variable cost) (dietary supplements, pharmaceuticals, veterinary services, cleaning and guards) | 0.08 |
| Labor costs (Variable cost) | 1.31 |
| Total hourly system cost (the costs of a mule) | 3.32 |

The labor costs in Table 6 equal the half of the hourly costs of a worker because of the usual relation mules:men = 2:1.

From the total hourly cost in Table 6 and the average productivity estimates of Table 4, the mean costs per cubic meter for the investigation area have been obtained (Table 7).

**Table 7.** Extraction expenses

| | Mean (USD/m$^3$) |
|---|---|
| calculated without delays | 1.65 |
| calculated with 10% of delays | 1.77 |

Fig. 7 presents the dependence of costs per m$^3$ (calculated without delays) on timber size and extraction distance. From it is apparent that costs decrease with increasing diameter. The least cost per cubic meter belongs to the case when extraction distance was minimal and timber size was relative high.

## DISCUSSION

Researching productivity and costs of wood extraction by mules greatly benefits the managers in planning of early thinnings (Ghafariyan et al., 2009). To the best of our knowledge, the present productivity study is the first dedicated to extraction by mules in the plantations of NW Iran. Its main result is a productivity model which can be used in similar stands and which will be helpful to assess profitability of early thinnings later on.

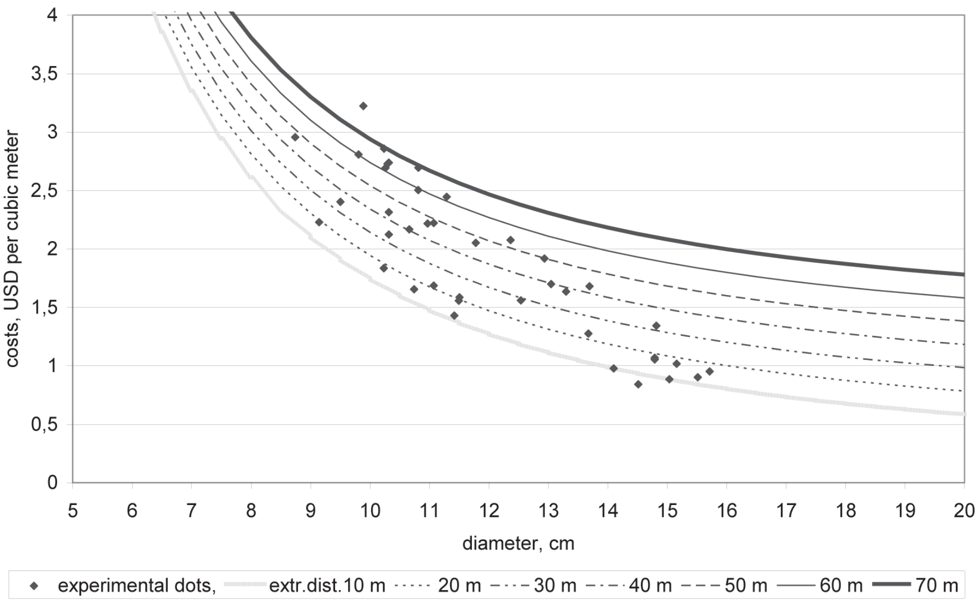


**Fig. 7.** Costs per cubic meter

According to the data it was produced of, the model is valid for dense broadleaved stands with small sized timber (log diameter from up to 20 cm) and short extraction distances (up to 70 m). Besides, the model can be easily extrapolated with plausible results (it has a good extrapolation behaviour), but beyond the cited limits it has not yet been tested with real data.

In general, the time consumption of extraction by mules is known to depend mainly on skidding distance, load volume and slope of the skidding path (Rasti, 2008; Jourgholami et al., 2008; Ghaffariyan et al., 2009; Gilanipor, 2010). Rasti (2008) stated that distance is the main influential factor. That is true even with short extraction distances as in our experiment.

The model proposed uses as main predictors the extraction distance and the log diameter as a measure of log size. Instead of load volume we used log diameter which is easy to use in planning and the model based on it fits well to measured data.

We could not investigate the influence of slope, because all our data were measured on flat terrain. Slope is the weakest of the major influence factors – its influence is measured in percents – but it is still a major factor. To take account of it, Jourgholami et al. (2008) included in their model the product of slope and volume and Gilanipor (2010) included the product of slope and distance. However, the influence of slope is not linear. It is common knowledge that gentle slope (up to 15%) is even favourable when the animals carry the load downwards and only steep slope becomes cumbersome. On the other hand, even a gentle slope is difficult when the animals must carry the load upwards. These relations deserve further investigation, but a preliminary practical solution would be to reduce productivity with about 10% for upwards extraction and extraction down a steep slope.

A partial verification of the plausibility of the present study is delivered by the comparison of some parameters with the results of other studies.

The studies of Ghaffariyan et al. (2009) and Shrestha et al. (2005) have estimations of productivity in comparable conditions which are consistent with our findings. In the present study was observed a net productivity of 2.017 $m^3/h$ with a very small mean diameter – 12 cm, and a quite short mean extraction distance – 42 m. Gaffariyan et al. (2009) observed a productivity of extraction of firewood by mules of 2.135 $m^3/h$ with the average extraction distance of 64.34 m. Shrestha et al. (2005) observed in Alabama a productivity of extraction by mules of 2.23 cubic m per hour when the mules worked in the combination with a forwarder which also implies a short extraction distance for the mules.

In the average, it was found that the maximum consumed time was related to loading and unloading – 50 percent of total time. This conclusion is in harmony with the studies by Jourgholami et al. (2008), Rasti (2008) and Gilanipor (2010) who stated in addition that increasing extraction distance reduced the share of loading and unloading.

It is known that the speed of a mule in the forest depends on slope, distance, load volume, forest density, animal's physical condition and the number of extraction cycles. In our study, the average speed was estimated to be 3.198 and 2.73 km/h for travel unloaded and travel loaded, respectively. These findings are consistent with the findings of Kantola, Harstela (1988) who measured the average speed of 3 km/h.

## CONCLUSIONS

In dense broadleaved stands with small sized timber (log diameter up to 20 cm) and with short extraction distances (up to 70 m), the net time consumption of extraction by mules can be assessed using the formula

$$TC_o = \frac{46.514}{d^2} + 0.006L$$

wherein $TC_0$ is the necessary hours per cubic meter, $d$ is the average log diameter (cm) and $L$ is the extraction distance (m).

To plan a realistic working time, the net time consumption $TC_0$ must be augmented with the percent of delay time, at least 10%,

$TC = TC_0 + TC_0 \times 10\%$.

To plan the costs, the time consumption $TC$ must be multiplied by the hourly costs 3.32 USD/h, actualized by inflation rate, starting from 2015.

## REFERENCES

Akay, A.E. 2005. Determining cost and productivity of using animals in forest harvesting operations. J. of Applied Sciences Research, 1(2), 190-195.

Firouzan, A., Bonyad, A., Falahchi, A. 2006. The investigation of thinning on the quantitative and qualitative variables on loblolly pine (*Pinus taeda*). J. of Agricultural Sciences, 12, 3, 513-524.
Ghaffarian, M. R. 2002. Investigation of production and stand damage of mule logging in Kheyroudkenar forest. MSc Thesis. Natural Resources Faculty. University of Tehran, 140.
Ghaffariyan, M. R. Durston, T. Sobhani, H. Marvi Mohadjer, M.R. 2009. Mule logging in Northern Forests of Iran: a study of productivity, cost and damage to soil and seedlings. Croat. J. For. Eng., 30(1), 67-75.
Gilanipor, N. 2010. Investigation of productivity and cost of ground base operations and animal skiding for determining the best composition. MSc Thesis. Natural Resources Faculty. University of Tarbiat Modares, 71.
Jourgholami, M., Majnounian, B., Zobeiri, M., Feghhi, J. 2008. Evaluation of production and costs of mule logging in down and up slopes (Case study: Kheyrud Forest). Iran J. Nat. Res., 61(3), 625-636.
Gorji Bahri, Y. 1989. Results of Ioblolly pine (*Pinus teada*). Forest Research Station, 45, 513-524.
Hamedi Qazi, P. 2015. Study on production rate and cost of thinning operation in the forest plantation in the northern Iran. MSc Thesis. University of Urmia, 90.
Kantola, A., Harstela, P. 1988. Handbook on appropriate technology for forestry operations in developing countries, Part 2. National Board of Vocational Education of the Government of Finland. 192.
Lotfaliyan, M. 2011. Transportation. Ayizh Press. 360.
Marvie Mohajer, M.R. 2006. Silviculture. University of Tehran Press, 119-204.
McCabe, P., Tiner, H., 1992. Mule logging: dying art? Treasures Forest, 14-15.
Mousavi, R. 2009. Comparison of productivity, cost and environmental impacts of two harvesting methods in Northern Iran: short-log vs. long-log. PhD Thesis. University of Joensuu. Joensuu, Finland, 93.
Naghdi, R. 2004. Study on productivity and cost of Timber jack 405-c skidder in Shafaroud Forests, Iranian Natural resources J., 4(57), 675-686.
Naghdi, R. 2005. Investigation and comparison of two harvesting systems: tree length and cut-to-length method in order to optimize road network planning in Neka, Iran. PhD Thesis, Tarbiat Modares University Tehran, 177.
Nikooy, M. 2003. Study on productivity, cost, and environmental impacts of traditional and well planned stand in Guilan Forest. PhD Thesis. University of Tehran, 67.
Pan, F., Han, H., S. Johnson, R.L. Elliot, J.W. 2008. Production and cost of harvesting, processing, and transporting small-diameter (≤ 5 inches) trees for energy. Forest Prod. J., 58(5), 47-53.
Rasti, R. 2008. Comparaison wood production and cost during planned and unplanned mule logging in Kheiroudkenar forest. MSc Theses. Natural Resources Faculty. University of Tehran, 98.
Saarilahti, M. Isoaho, P. 1992. Handbook for Ox skidding researches. The Finnish Forest Research Institute, 442.
Sarikhani, N. 2000. Forest utilization. Tehran university press. 2099. Second edition, 776.
Shrestha, S. P., Lanford, B.L. 2005. Utilization and cost of log production from animal logging operations. International J. of Forest Engineering, 16(2), 167-180.
Shrestha, S.P., Lanford, B., Rummer, R.M. 2008. Soil disturbances from horse/mule logging operation coupled with Machines in the southern United States. International J. of Forest Engineering, 19(1), 17-23.
Wang, L. 1997. Assessment of animal skidding and ground machine skiding under mountain conditions, International J. of Forest Engineering, 8(2), 57-64.
Wang, L., 1999. Environnementaly sound timber extraction techniques for small tree harvesting, Presentation at the 1999 ASAE Annual International Meeting Sponsored by ASAE, Toronto, Canada, 7.
Zobeiry, M. 1994. Forest Inventory. University of Tehran Press. 401.

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