Preliminary note

Estimating Time Consumption and Productivity of Roundwood Skidding in Group Shelterwood System – a Case Study in a Broadleaved Mixed Stand Located in Reduced Accessibility Conditions

Stelian Alexandru Borz, Gheorghe Ignea, Bogdan Popa, Gheorghe Spârchez, Eugen Iordache

Abstract

In Romanian forestry, skidders represent the most used equipment for wood extraction, while the group shelterwood system is one of the most used silvicultural forest management strategies. Production rates are important indicators when trying to assess the efficiency of a process, since they can be used in different practical applications, starting with operational planning and ending with energetic analyses or LCA studies. The reduced accessibility of forest stands is one of the main problems of Romanian forestry, and therefore a lot of time and energy is usually spent in harvesting operations. In the present days, it has become very important to know the effects of these operational conditions. In order to evaluate the effects of very long skidding distances on the time inputs and productivity, a time study was conducted for a Romanian skidder that operated in a mixed hardwood stand located in Central Romania, where group shelterwood cuttings were applied. We found out that the time input of a winching work cycle was most affected by winching distance and the number of logs, and developed time consumption models for the main groups of operations. For the mean conditions (winching distance of 8.7 m, mean skidding distance of 1706.3 m, a load volume of 4.89 m^3 and 6.48 logs per turn) the net and gross production rates were of 4.41 m^3/h and 3.12 m^3/h, respectively. The results of this study may be helpful in operational costing or harvesting planning when dealing with reduced accesibility conditions.

Keywords: skidding, reduced accessibility, group shelterwood system, time consumption, production rates

1. Introduction

In Romania, forests cover almost 27% of the national territory, and about 37% of them are located in the hills zone. Such forests are usually composed of mixed broadleaved stands with an important participation of oaks. Also, high forest regime is mostly used for managing such forests, which are generally harvested at the age of 100–120 years. Therefore, the use of chainsaws seems to be the only option in harvesting such forests, especially when associated with large trees (Jourgholami et al. 2013). On the other hand, it is quite commonly accepted that the increment of mechanization level in harvesting operations will result in a greater economic efficiency (Oprea 2008). It depends in a great measure on a series of factors such as forest and intervention type, particular terrain conditions, level of social acceptance, and legislative aspects. Harvesting systems, such as those associated with chainsaws and skidders, are quite common in Europe when dealing with extractions that yield important wood quantities, e.g. selective (Sabo and Poršinsky 2005, Ghaffaryian et al. 2013, Vusić et al. 2013) and conversion cuttings (Picchio et al. 2009), where the owning and operating costs are better amortized (Oprea 2008). It is also possible to use such equipment in thinning operations (Zečić 2005, Gallis and Spyroglou 2012, Vusić et al. 2013), or in other particular conditions such as salvage logging (Borz et al. 2013) or on sensitive sites when they may be used along with animal traction (Magagnotti and Spinelli 2011). On the other hand, in the Romanian forestry conditions, animal traction is used intensively in thinning operations (Borz and Ciobanu 2013), especially in the first ones, while skidders or farm tractors are more frequently used when dealing with main cuttings. Also, in Romania, the harvesting system associated with chainsaws and skidders is the most frequently used (Sbera 2007) especially when dealing with increased volumes of logs, even if other modern equipment has been introduced and used on small scale in harvesting operations (Borz et al. 2011). Furthermore, knowing the efficiency of the equipment used in harvesting operations may help in a better production organization, while the assessment of their environmental impact is very helpful in formulating strategies and policies (Magagnotti and Spinelli 2012a). The efficiency assessment of a production system in harvesting operations is carried out by using work measurement techniques, which are applied in order to develop models or to compare between two or more alternative treatments (Magagnotti and Spinelli 2012a). Modeling studies are usually done in order to obtain empirical models either in case of testing new equipment or in case of equipment working in new, unstudied conditions (Visser and Spinelli 2011).

In timber harvesting operations, an adequate development of the forest transportation infrastructure may offer the premises for an increased productivity (Oprea 2008) and a reduced impact, by shortening the time of equipment deployment in the forest and reducing the energy expenditure in harvesting operations. In fact, the whole strategy related to forest road network development at optimal parameters is related to the efficiency of upstream processes such as timber harvesting (Bereziuc et al. 2006) and in particular to timber extraction operations (Ghaffaryian and Shobani 2008, Naghdi and Limaei 2009). Unfortunately, one of the main particularities of harvesting operations in Romania is that they are frequently developed in reduced accessibility conditions due to an insufficient development of the forest transportation network (Oprea 2008), which is characterized by a density index of only 6.5 m/ha (Olteanu 2008), and which could be one of the limiting factors when considering the use of new short or medium distance harvesting equipment such as processor tower yarders (Borz et al. 2011). Furthermore, if compared with forests located in mountainous areas, Romanian hill forests are characterized by quite different work conditions due to preponderant presence of hardwoods such as oaks, beech and hornbeam as well as other mixed hardwood forests (Şofletea and Curtu 2008) located on clayey-loamy soils and managed by applying, mainly, group shelterwood silvicultural systems.

Since the harvesting strategy plays a key role in forestry, a lot of attention has been given to efficiency assessment of different harvesting equipments. In case of skidding operations, the studies done so far revealed that the time consumption per turn may be explained by certain independent variables. Furthermore, skidding distance has been found to be one of the most relevant independent variables when explaining the time consumption (Borz et al. 2013, Borz et al. 2014a, Gallis and Spyroglou 2012, Ghaffaryian et al. 2013, Özturk 2010a, Özturk 2010b, Sabo and Poršinsky 2005, Vusić et al. 2013). However, most of the studies have been conducted for short extraction distances, usually up to 400 m (Gallis and Spyroglou 2012, Ghaffaryian et al. 2013, Özturk 2010a, Özturk 2010b, Sabo and Poršinsky 2005, Vusić et al. 2013) reporting different productivities depending on other factors such as load volume, while the effect of very long extraction distances on time consumption and productivity has never been thoroughly studied.

In this context, the aim of this paper was to estimate the time consumption and skidding productivity for a felling area located in reduced accessibility conditions, where group shelterwood cuttings were applied. In order to fulfill the aim of the study, the objectives were set to: (i) modeling of time consumption for skidding, (ii) estimating the productivity of the entire system and (iii) provide an overview of general time structure in such operational conditions.

2. Material and methods

The study was carried out in compartment 77C located in Laslea-Floreşti forest administrated by the State Forest District of Sighişoara. This forest is located in the central part of Romania, right at the border between Mureş and Sibiu counties (Fig. 1), and is characterized by altitudes ranging from 400 to 500 m, presence of natural forests containing native deciduous species such as beech, sessile oak and hornbeam. Felling area was located on a plateau having the general slope between 0 and 10% and it was opened up by two

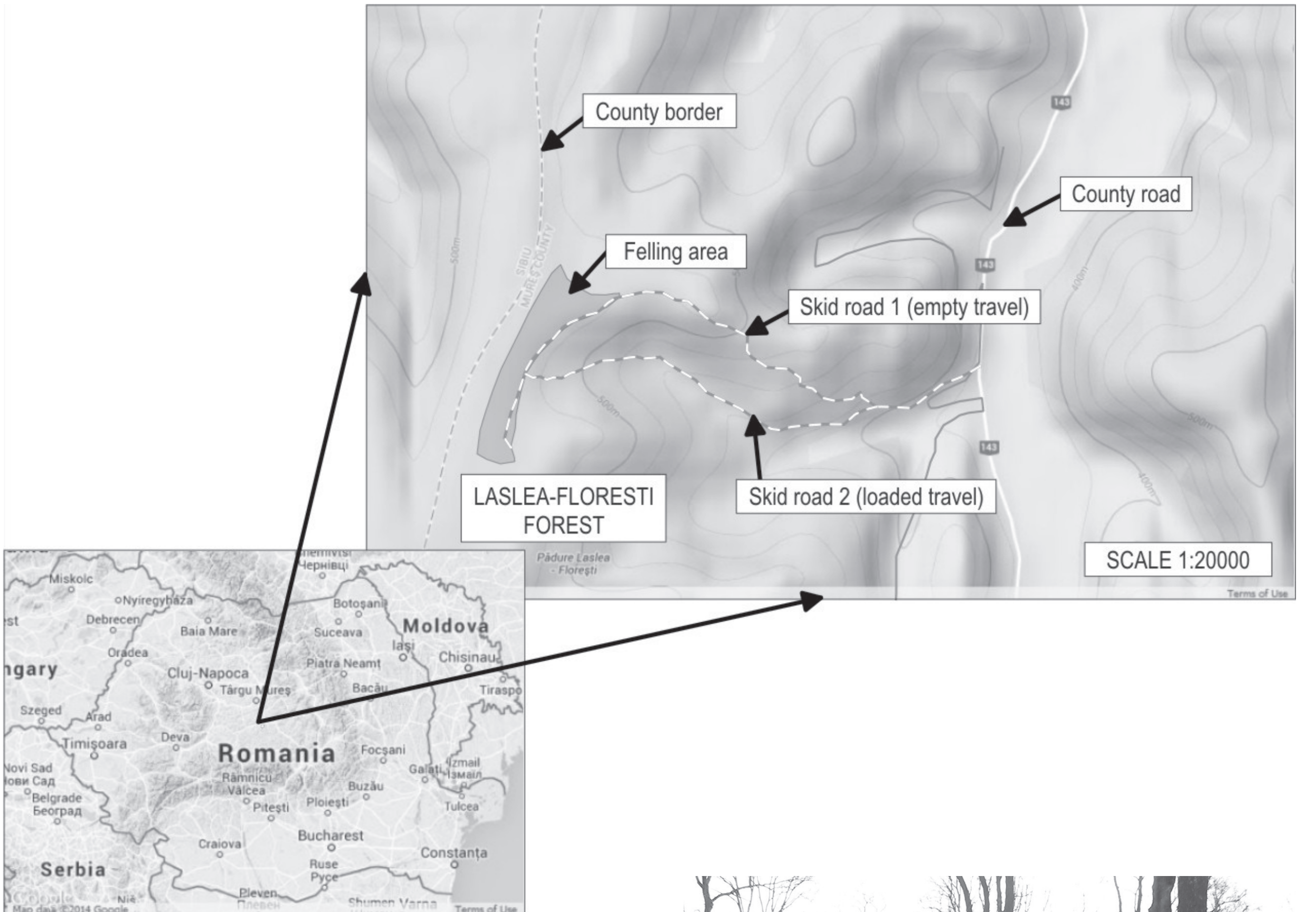

Fig. 1 Study location

skid roads developed near a peak and a stream, respectively (Fig. 1). In such conditions the Romanian forest management is done by applying the high forest regime and group shelterwood silvicultural system. Following the tree inventory in the felling area, a volume of 605 m^3 was proposed for extraction (beech – 119 m^3, sessile oak – 234 m^3 and hornbeam – 252 m^3). The forest was 120 years old. As usual in Romania (Oprea 2008), harvesting operations were performed by a team composed of three workers, of which one was responsible for tree felling and processing, while the other two dealt with skidding operations. Also, following tree felling and processing, in such operations the resulting logs having lengths up to 20 m (usually imposed by forest administrator) are extracted by cable skidders to the roadside landings, where supplementary operations are required in order to obtain final assortments and stack them into piles (Oprea 2008). Skidding operations were performed by a TAF 690 OP wheeled winch skidder (Fig. 2), equipped with a double–drum TA-2AM Romanian made winch, mechanically powered and steered electro-pneumatically,

Fig. 2 TAF 690 OP winch skidder in the studied area

having a nominal pulling force of up to 11 tons. This skidder is equipped with a Perkins 1104C-44T made engine with the nominal power of 67 kW. One of the supplementary equipment is the hydraulically powered adjustable front blade, which is used for landing operations (stacking) and for skid roads cleaning.

A team composed of 4 operators collected data during the field study. Time and quantity inputs/outputs,

Table 1 Description of work (time) elements and process variables

Factor	Description	Measurement/calculation
Winching		
Maneuvring and parking, *Tmp*	(Optional) Begins when the skidder has just ended its empty travel (arrived at winching area) and ends when all the positioning maneuvers end	Camera + office processing of media files
Cable releasing, *Tcr*	Begins when the worker has just grabbed the cable and ends when the worker arrives at the log to be winched	Camera + office processing of media files
Log hooking, *Tlh*	Begins when the worker performs the first action in order to hook the log and ends when it signals the skidder operator that the log can be winched	Camera + office processing of media files
Mechanical winching, *Tmw*	Begins when the winch starts pulling and ends when the log arrived in the rear part of the skidder	Camera + office processing of media files
Log unhooking, *Tlu*	(Optional) Begins when the worker initiates the first action in order to detach the log and ends when the cable is free again	Camera + office processing of media files
Species, *S*	–	Visually assessed
Winching distance, *WD*	Slope distance measured between the rear part of the skidder and the end at which the log was attached	Tape
Diameter at the small end, D_{thin}	–	Caliper
Diameter at the large end, D_{thick}	–	Caliper
Log length, *LL*	Distance between log ends, measured on the log	Tape
Log volume, *LV*	Volume of the log calculated in function of D_{thin}, D_{thick} and LL using classical relations	MS Excel database + calculus relations
Number of logs, *NL*	Number of logs winched in order to make a load for on–road skidding	Visually assessed
On-road skidding		
Empty travel, *Tet*	Begins when the skidder has ended its actions on landing (or first start of a day) – initiates movement, and ends when the skidder arrives at the winching area	Stopwatch
Load attachment, *Tla*	Begins when worker starts to hook all the logs in the rear part of the skidder and ends when the load is suspended in the rear part of the skidder	Stopwatch
Loaded travel, *Tlt*	Begins when the skidder initiates its movement from winching area and ends when the skidder stops on the landing for detachment	Stopwatch
Load detachment, *Tld*	Begins with the first action of landing the load and ends when both cables are released	Stopwatch
Empty travel distance, *ETD*	Slope distance between the point in which the load was attached and the point in which the load was detached on landing	GPS receiver + Digital Terrain Model + GIS software
Loaded travel distance, *LTD*	Slope distance between the point in which the load was detached on landing and the point in which the skidder stopped for winching or maneuvering and parking	GPS receiver + Digital Terrain Model + GIS software
Load volume, *V*	Sum of volumes of logs within a load	MS Excel calculation
Landing operations		
Maneuvering and stacking, *Tlo*	Begins when first movement maneuver is initiated and ends when all maneuvering and stacking tasks are accomplished. Maneuvers up to 25 m in distance.	Stopwatch

as well as process variables, were measured differently according to the studied group of operations, by adapting a time study to the general concepts described by Björheden et al. (1995), respectively Magagnotti and Spinelli (2012a). In case of winching operations, time was recorded using a video camera while distance was measured using a measuring tape. In case of on-road skidding, time was measured using a professional stopwatch, while distance was measured using a GPS receiver. All the operational variables were recorded in a field book, and, depending by the data acquisition method, some of them were further processed during the office phase of the study (Table 1) in order to obtain the needed data. For each winched log, we measured the diameters at the ends (D_{thin} and $D_{thick,}$ respectively), length (*LL*) as well as the winching distance (*WD*). The volume of each log (*LV*), as quantitative input/output, was computed based on its diameters and length. Log volumes were used for determining the volume of each load (*V*). Species (*S*) of each log, as well as the number of winched logs (*NL*) within a winching work cycle, were visually assessed/counted and recorded in the field book. A particularity of on–road skidding operations was that the skidder operator used one skid road for the empty travel and the other for loaded travel, while loaded travel was performed downhill (Fig. 1). A description of work and time elements, as well as of recorded process variables, is presented in Table 1. Skidding operations were studied in a period of one week. A total number of 285 logs were winched and a total number of 44 work cycles were studied for winching, on–road skidding and landing operations. During the field study, we collected separately the whole operational duration, as well as the duration of mechanical (*MD*), operational (*OD*) and personal delays (*PD*). Empirical models concerning the time consumption were developed using Statistica 8.0 software package. These models were developed in order to estimate the time consumed in a winching work cycle (*WCT*), empty travel (*ETT*) and loaded travel (*LTT*). The net production rates for winching and on–trail skidding operations were calculated as the ratio between the realized production and the delay–free time consumption. Overall net and gross production rates (including landing operations) were calculated the same way, by using the total time (including delays) in case of gross production rate.

3. Results and discussion

During the field study, a number of 285 logs were skidded, having a total volume of 215 m^3 (Table 2), which represented about 36% of the volume to be harvested within the felling area. This meant that, on average, a number of 6.48 logs were skidded per turn, in the conditions of a mean volume of 4.89 m^3 per load. In the above described conditions and for a mean winching distance of about 9 m, the time consumption for a delay-free winching work cycle was about 12 minutes (Table 2). Also, by excluding the winching time, in the same conditions regarding the volume and the number of logs per load, and for a mean skidding distance of about 1 706 m, the time consumption for a delay-free on-road skidding cycle time was about 50 minutes (Table 2). This means that it took about 61.4 minutes for a full skidding turn, excluding landing operations, which is comparable to the results obtained when using a farm tractors equipped for skidding in case of winching distances of 17 m and skidding distances up to 500 m (Spinelli and Magagnotti 2012). Given the reduced slope and the character of felling specific to the local conditions, which eased the cable releasing, within a winching work cycle the most time consuming category (Fig. 3) was that referring to mechanical winching. However, this would be characteristic to the local, studied conditions since other studies revealed that slope may affect the time consumption in winching operations as well as the distribution of time consumed by certain work elements within a work cycle (Borz et al. 2014b, Magagnotti and Spinelli 2012b). Skidder maneuvering and parking took less time than other elements as a result of the same local easy work conditions, while log hooking and unhooking accounted for almost the same share (Table 2, Fig. 3). While the empty travel took, on average, about 18 minutes in conditions of a mean distance of about 1764 m, in case of loaded travel about 23 minutes were necessary in conditions of a mean distance of about 1649 m (Table 2), because the loaded travel imposed a different driving behavior when compared with the empty travel. Furthermore, the field conditions (wet clayey soil) posed, frequently, adherence problems. Therefore, as shown by field results, the driving speed was 5.73 km/h in case of empty travel and 4.31 km/h in case of loaded travel, and these results are comparable with those reported by Spinelli et al. (2012) in case of a 40 kW Hittner Ecotrac V55 mini–skidder made in Croatia, and somehow in the range of those reported by Spinelli and Magagnotti (2012) in case of a number of farm tractors equipped for skidding operations. Also, Sabo and Poršinsky (2005) reported similar figures (5.33 and 3.99 km/h, respectively in case of unloaded and loaded travels), when analyzing the time consumption of a Timberjack 240C skidder used for extracting wood in selective harvests. Furthermore, they found out that travelling speed was also different when traveling on strip roads and landings, respectively. Within an on-road work cycle (including load attachment and detachent), loaded travel work element accounted for almost half of the consumed time (Table 2, Fig. 4). Also, an important amount of time was required by load attachment. This was related with several attachments/detachments performed on groups of logs until the load was finally attached and suspended in the rear part of the skidder. When introducing significantly simpler procedures, load detachment was the work element that required the smallest amount of time. It took about five minutes, on average, to perform landing operations that consisted of log manipulation and stacking (Table 2).

Table 2 Statistics of inputs/outputs and operational variables of skidding operations in the field study

Factor	Sum	Mean	Minimum	Maximum	Standard Deviation
Number of logs per load – *NL*	285	6.48	2	13	2.95
Volume per load – *V*, m^3	214.97*	4.89	3.04	6.63	0.71
Time consumption					
Maneuvering and parking – *Tmp*, s	1873.11	42.57	0.00	134.65	33.45
Cable releasing – *Tcr*, s	5005.48	113.76	24.39	334.71	69.12
Log hooking – *Tlh*, s	7737.03	175.84	48.12	442.27	97.70
Mechanical winching – *Tmw*, s	10,724.59	243.74	44.31	641.16	139.55
Log unhooking – *Tlu*, s	5239.01	119.07	20.19	340.88	76.18
Empty travel – *Tet*, s	48,803.00	1109.16	852.00	1756.00	165.77
Load attachment – *Tla*, s	17,233.32	391.67	72.79	967.29	235.32
Loaded travel – *Tlt*, s	60,580.00	1376.82	1088.00	1711.00	143.75
Load detachment – *Tld*, s	4829.00	109.75	45.00	228.00	42.16
Landing operations – *Tlo*, s	13,534.00	307.59	62.00	1068.00	182.40
Winching cycle time – *WCT*, s	30,579.22	694.98	204.04	1519.49	338.27
On-road skidding cycle time – *RSCT*, s	131,445.32	2987.39	2425.00	3578.11	337.61
Overall skidding cycle time – *OSCT*, s	175,558.54	3989.97	2920.83	5228.78	625.12
Process variables					
Winching distance – *WD*, m	–	8.66	2.6	16.5	3.94
Empty travel distance – *ETD*, m	–	1764.07	1604.00	1971.00	109.50
Loaded travel distance – *LTD*, m	–	1648.55	1448.00	1879.00	96.60
Skidding distance – *SD*, m	–	1706.31	1597.00	1897.00	71.65
*Total skidded volume					

Although not effectively measured in the field, a characteristic of landing operations was that the maneuvers were deployed on distances up to 25 m, while stacking included only a few log movements using the front blade of the skidder. Within an entire skidding work cycle, the loaded travel work element also accounted for the greatest share (Fig. 5). Surprisingly, it took more time to attach the load than to perform landing operations, even if the latter involved several maneuvers and movements. This was related with a relatively large number of logs within a load, as well as with the procedure of attaching the load. Most of the delays occurred due to operational and personal reasons – including meals taking about an hour each day (Fig. 6) – and represented about 29.3% of the total studied time. This fact reflects an improved operational time management, if compared with studies done for the same kind of skidding equipment (Borz et al. 2013, Borz et al. 2014a). The regression analysis conducted for a winching cycle time has revealed that

Table 3 General statistics for the empirical model developed for winching operations

Model	R^2	*F*	Sig.	Independent variable	*p*
WCT, s = 18.02 × WD + 94.78 × NL – 75.02	0.84	107.00	p<0.000	WD	0.003
				NL	<0.000

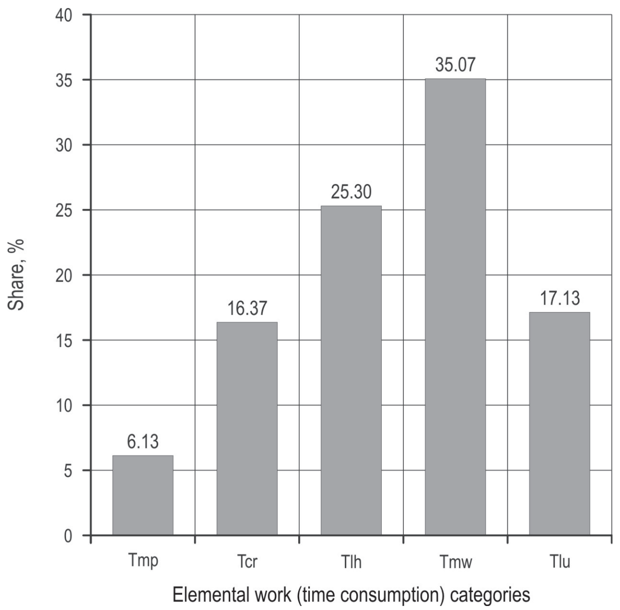

Fig. 3 Structure of elemental time consumptions (%) within a delay-free winching work cycle (*Tamp*: Time consumption for manoeuvering and parking, *Tcr*: Time consumption for cable releasing, *Tlh*: Time consumption for log hooking, *Tmw*: Time consumption for mechanical winching, *Tlu*: Time consumption for log unhooking)

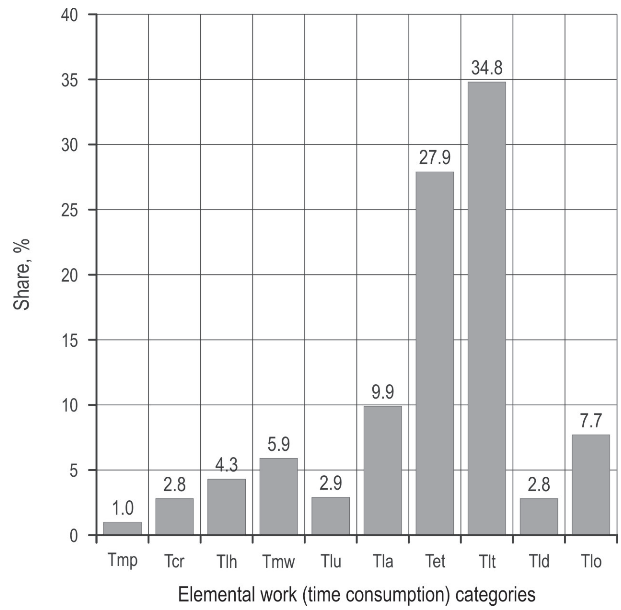

Fig. 5 Structure of elemental time consumptions (%) within a delay-free on-road skidding work cycle (*Tamp*: Time consumption for maneuvering and parking, *Tcr*: Time consumption for cable releasing, *Tlh*: Time consumption for log hooking, *Tmw*: Time consumption for mechanical winching, *Tlu*: Time consumption for log unhooking, *Tla*: Time consumption for load attachment, *Tet*: Time consumption for empty travel, *Tlt*: Time consumption for loaded travel, *Tld*: Time consumption for load detachment, *Tlo*: Time consumption for landing operations)

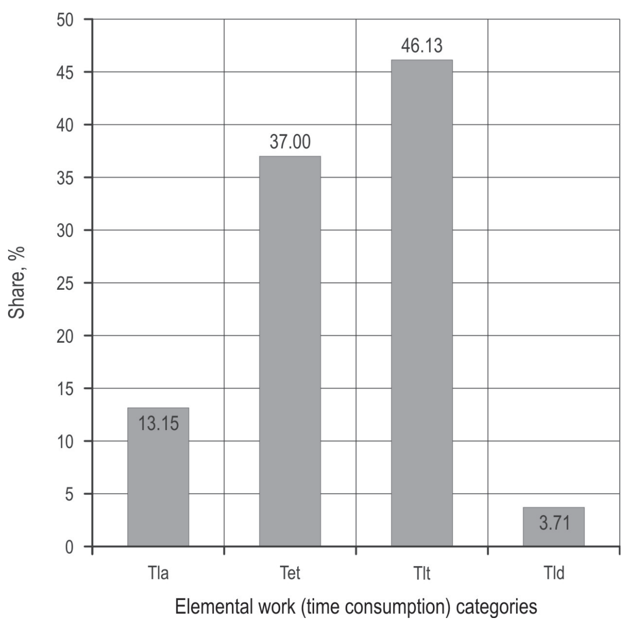

Fig. 4 Structure of elemental time consumptions (%) within a delay-free on-road skidding work cycle (*Tla*: Time consumption for load attachment, *Tet*: Time consumption for empty travel, *Tlt*: Time consumption for loaded travel, *Tld*: Time consumption for load detachment)

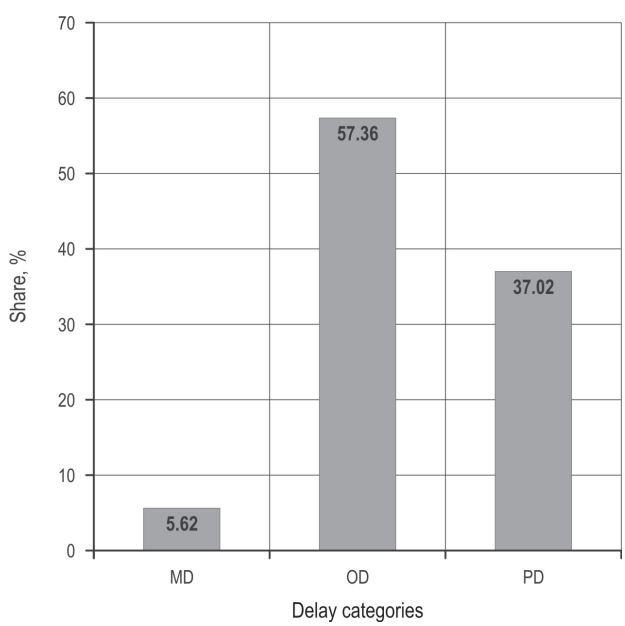

Fig. 6 Delay time distribution by categories (*MD*: Mechanical delays, *OD*: Operational delays, *PD*: Personal delays)

Table 4 Calculation of net and gross production rates for skidding operations

Operation / Group of operations	Delay free time, s	Total time, s	Production, m^3	Net production rate, m^3/h	Gross production rate*, m^3/h
Winching	30,579.22		214.97	25.31	
On-road skidding	131,445.32		214.97	5.89	
Winching + Skidding (excluding landing operations)	162,024.54		214.97	4.78	
Overall	175,558.74	248,202.14	214.97	4.41	3.12

*Includes all the delays

the winching distance as well as the number of winched logs significantly affected the time consumption. These independent variables were significant at the chosen confidence level $p < 0.05$ as shown in Table 3.

Given the particularities of the study (empty and loaded travels on different skid roads), as well as the fact that, for these work elements, only the distance was recorded in the field, we have developed time consumption models for each element by considering only this independent variable. The resulted models are presented in Equations 1 and 2.

$$T_{\mathrm{et}}, \mathrm{s} = 0.428 \cdot ETD, \mathrm{m} + 354.04 \quad (1)$$

$$T_{\mathrm{lt}}, \mathrm{s} = 0.314 \cdot ETD, \mathrm{m} + 858.64 \quad (2)$$

In case of winching operations, the study yielded a net production rate of 25.31 m^3/h, which seems to be fairly acceptable for the operational conditions presented in Table 2, if compared with other results reported for such equipment (Borz et al. 2013, Borz et al. 2014a). However, the net production rates for on-road skidding of only 5.89 m^3/h (Table 4), as well as the net production rate of only 4.71 m^3/h for winching and skidding (excluding landing operations) were strongly affected by the increased skidding distances. Of course, this is also correlated with a more reduced load per turn, if compared with results reported in different conditions for the same equipment (Borz et al. 2013, Borz et al. 2014a). Furthermore, in the case of gross production rate, the situation was even worse, since our study yielded only 3.12 m^3/h. If compared with the results by other studies, our results regarding the net production rate are similar with those reported by Spinelli et al. (2012) when using the Hittner Ecotrack mini-skidder made in Croatian in conditions of a mean skidding distance of only 130 m. This fact also emphasizes the effect of long skidding distance in our study. Also, even if the mean skidding distance was a little bit unclear, Ghaffaryian and Shobani (2008) reported production rates in the range of 5.93 to 8.33 m^3/h, when analyzing a predecessor of the TAF skidder, which was considered in our study. On the other hand, Spinelli and Magagnotti (2012) obtained similar results when studying a 96 kW farm tractor in conditions of a mean skidding distance of 1119 m. In their study, the mean load size was smaller if compared with the load presented in this study, but they found out that empty and loaded travel speeds were of 8.1 and 7.3 km/h, respectively, which were significantly higher than those determined in this study.

The results presented above have several implications. Although our intention was not to calculate the harvesting operation costs, it is quite obvious that the reduced accessibility conditions have negative repercussions over both, the harvesting company and the workers' paychecks, since the latter are paid based on the realized production. On the other hand, in Romania the stands located up to 2 km from a permanent transportation infrastructure are considered accessible. However, when using skidders, and, especially in steep terrain, bladed roads are frequently required (Oprea 2008). When taking into consideration that the external skid roads are required for harvesting a 5 hectare felling area (this study case), it is obvious that due to erosion processes the environmental impact will also be greater. This is of great importance in hilly forests of Romania, usually located on clayey soils, and otherwise very sensitive to the combined action of skidding and moisture (Oprea 2008). Also, the time consumption models developed in this study may have their limits and should be used carefully by considering only the conditions similar to those observed in this study (Table 2).

4. Conclusion

Thinking globally, timber skidding is a highly variable operation, with many process variables affecting the relations between inputs and outputs. The aim of this paper was not to identify new predictors or to model new unknown relations, but to emphasize and quantify how and to what extent, the reduced accessibility conditions (in terms of extraction distance) may affect the time consumption and operational productivity in skidding operations. As shown by the results, our study yielded very low production rates, which can be particulary related to the increased skidding distance. Also, the conditions imposed by a cleaner extraction (such as limiting the log lengths during skidding) affects the loading capacity of the skidder, which in combination with very long extraction distances leads to reduced productivities, increased number of turns in order to extract the same quantity of wood and increased energy expenditure per unit of product.

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5. References

Bereziuc, R., Alexandru, V., Ciobanu, V., Ignea, G., Abrudan, I., Derczeni, R., 2006: Ghid pentru proiectarea, construirea şi întreținerea drumurilor forestiere (Handbook on designing, building and maintaining forest roads). Editura Universității Transilvania din Braşov. 296 p.

Björheden, R., Apel, K., Shiba, H., Thompson, M. A. 1995: IUFRO Forest work study nomenclature, Swedish University of Agricultural Science, Dept. of Operational Efficiency, Grapenberg, 16 p.

Borz, S.A., Ignea G., Popa, B., 2014a: Assessing timber skidding efficiency in a group shelterwood system applied to a fir-beech stand. African Journal of Agricultural Research 9(1): 160–167.

Borz, S.A., Ignea, G., Popa, B., 2014b: Modeling and comparing timber winching performance in windthrow and uniform selective cuttings for two Romanian skidders. Journal of Forest Research 19(6): 473–482.

Borz, S.A., Ignea G., Popa, B., Dinulică, F., 2013: Time consumption and productivity of skidding Silver fir (*Abies alba* Mill.) round wood in reduced accessibility conditions: a case study in windthrow salvage logging from Romanian Carpathians. Annals of Forest Research 56(2): 363–375.

Borz, S.A., Ciobanu, V. D., 2013: Efficiency of motor–manual and horse logging in small scale firewood production. African Journal of Agricultural Research 8(24): 3126–3135.

Borz, S.A., Bîrda, M., Ignea, G., Oprea, I., 2011: Technological aspects regarding timber exploitation using Mounty 4100 cable yarder. Bulletin of the Transilvania University of Braşov 4(53): 1–6.

Gallis, C., Spyroglou, G., 2012: Productivity linear regression models of tree–length harvesting system in natural coastal Aleppo Pine (*Pinus halepensis* L.) forests in the Chalkidiki area of Greece. Croatian Journal of Forest Engineering 33(1): 115–123.

Ghaffariyan, M.R., Naghdi, R., Ghajar, I., Nikooy, M., 2013: Time Prediction Models and Cost Evaluation of Cut-To-Length (CTL) Harvesting Method in a Mountainous Forest. Small Scale Forestry 12(2): 181–192.

Ghaffariyan, M.R., Shobani, H., 2008: Optimum road spacing of ground based skidding operations in Nowshahr, Iran. Caspian Journal of Environmental Sciences 6(2): 105–112.

Jourgholami, M., Majnouinan, B., Zargham, N., 2013: Performance, capability and costs of motor–manual tree felling in Hyrcanian hardwood forest. Croatian Journal of Forest Engineering 34(2): 283–293.

Magagnotti, N., Spinelli, R., Spinelli, R. (Eds.), 2012a: Good Practice Guideline for Biomass Production Studies – COST Action FP0902. CNR IVALSA, Florence, Italy. ISBN978-88-901660-4-4. 41 p. Available at: www.forestenergy.org.

Magagnotti, N., Spinelli, R., 2012b: Replacing Steel Cable with Synthetic Rope to Reduce Operator Workload During Log Winching Operations. Small Scale Forestry 11(2): 223–236.

Magagnotti, N., Spinelli, R., 2011: Integrating animal and mechanical operations in protected areas. Croatian Journal of Forest Engineering 32(2): 489–499.

Naghdi, R., Limaei, S.M., 2009: Optimal forest road density based on skidding and road construction costs in Iranian Caspian forests. Caspian Journal of Environmental Sciences 7(2): 79–86.

Olteanu, N., 2008: Drumuri forestiere. Volumul I: Proiectarea drumurilor foresteire. Rețele de drumuri forestiere (Forest roads. Volume I: Designing forest roads. Forest roads networks) Editura Universității Transilvania din Braşov. 339 p.

Oprea, I., 2008: Tehnologia exploatării lemnului (Timber harvesting technology). Transilvania University Press Braşov. 273 p.

Özturk, T., 2010a: Productivity of New Holland farm tractor at beech stands on mountainous areas in Black Sea region. Forestry Ideas 16(1): 52–57.

Özturk, T., 2010b: Productivity of MB Track 900 tractor at beech stands on mountainous areas in Black Sea region. African Journal of Agricultural Research 5(1): 28–33.

Picchio, R., Maesano, M., Savelli, S., Marchi, E., 2009: Productivity and energy balance in conversion of a *Quercus cer-*

ris L. coppice stand into high forest in Central Italy. Croatian Journal of Forest Engineering 30(1): 15–26.

Sabo, A., Poršinsky, T., 2005: Skidding of fir roundwood by Timberjack 240C from selective forests of Gorski Kotar. Croatian Journal of Forest Engineering 26(1): 13–27.

Sbera, I., 2007: Resursele de lemn şi potenţialul pieţei din România (Wood resources and market potential in Romania). Meridiane Forestiere 2: 3–7.

Şofletea, N., Curtu, L., 2008: Dendrologie (Dendrology). Editura Pentru Viaţă. Braşov. 418 p.

Spinelli, R., Magagnotti, N., Relaño, R.L., 2012: An alternative skidding technology to the current used crawler tractors in Alpine logging operations. Journal of Cleaner Production 31: 73–79.

Spinelli, R., Magagnotti, N., 2012: Wood Extraction with Farm Tractor and Sulky: Estimating Productivity, Cost and Energy Consumption. Small Scale Forestry 11(1): 73–85.

Visser, R., Spinelli, R., 2012: Determining the shape of the productivity function for mechanized felling and felling–processing. Journal of Forest Research 17(5): 397–402.

Vusić, D., Šušnjar, M., Marchi, E., Spina, R., Zečić, Z., Picchio, R., 2013: Skidding operations in thinning and shelterwood cut of mixed stands – work productivity, energy inputs and emissions. Ecological Engineering 61: 216–223.

Zečić, Z., Krpan, A.P.B., Vukušić, S., 2005: Productivity of C Holder 870F tractor with double drum winch Ingland 4002 in thinning beech stands. Croatian Journal of Forest Engineering 26(2): 49–57.

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Authors' address:

Assist. Prof. Stelian Alexandru Borz, PhD.*
e-mail: stelian.borz@unitbv.ro
Prof. Gheorghe Ignea, PhD.
e-mail: igneagh@unitbv.ro
Assist. Prof. Bogdan Popa, PhD.
e-mail: popa03@gmail.com
Assist. Prof. Eugen Iordache, PhD.
e-mail: i.eugen@unitbv.ro
Transilvania University of Braşov
Faculty of Forestry
Department of Forest Engineering
Şirul Beethoven No. 1
500 123 Braşov
ROMANIA

Prof. Gheorghe Spârchez, PhD.
e-mail: sparchez@unitbv.ro
Transilvania University of Braşov
Faculty of Forestry
Department of Silviculture
Şirul Beethoven No. 1
500 123 Braşov
ROMANIA

* Corresponding author