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Assessing timber skidding efficiency in a group shelterwood system applied to a fir-beech stand

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Skidders are one of the most used machines in harvesting operations, especially when dealing with large timber. Their use is still widespread around the world, a fact reflected by numerous efficiency studies. Since 95% of logging operations in Romania are done by means of skidders and farm tractors, this study aimed to assess timber skidding efficiency in a mixed fir-beech stand undergoing group shelterwood cuttings. Following a time study performed on 100 winching replications which corresponded to 31 on-trail skidding replications, it was found that a winching replication was most affected by winching distance and log volume whereas an on-trail skidding replication was affected by skidding distance. However, in case of all skidding operations, winching distance, skidding distance and number of logs forming a load were the most significant independent variables for the time consumption estimation. Delays (technical, operational and personal) accounted for 28% of the total skidding time, whereas in a delay-free skidding work cycle, winching and on-trail skidding accounted for 30 and 70% respectively of skidding time. If mean conditions are considered (winching distance of 23.02 m, on-trail skidding distance of 1037.32 m, volume of load of 7.12 m^3 and 3 logs per load), the net production rate was of 12.65 m^3h^{-1}. The results of this study may be useful for an improved organization of harvesting operations in similar conditions.

Key words: Skidding, efficiency, group shelterwood system, time prediction, production rates.

INTRODUCTION

When harvesting large timber, mechanized logging means are required in order to match tractive power with the logs dimensions. Excepting some cases when final thinning operations are applied and animal logging could be used, timber hauling is done mostly by the use of skidders, forwarders or cable yarders. Skidders are specialized for logs winching (dragging) and loads skidding (semi-dragging), this latter type of machines being classified as winch skidders (Oprea, 2008). Of course, other skidder types are used around the world in forest harvest operations such as grapple skidders and clam bunk skidders.

In post-socialist Romania, skidders represent one of the most used machines in timber harvesting operations (Sbera, 2007) a fact which relates to their mobility and productivity (Oprea, 2008), despite the fact that most of the Romanian forests are located in steep terrain (Report on Forest State, 2010) where cable yarders would be a better choice. Another reason which promoted the use of skidders in Romania for the last two decades is the poor developed forest transport infrastructure (Bereziuc et al., 2011) which generates impossible harvesting conditions

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due to reduced accessibility and the lack of trained personnel. For instance, in Romania, most (>95%) of the timber logging operations are done using skidders and farm tractors (Sbera, 2007), while the use of modern cable yarders is just beginning to achieve prominence (Borz et al., 2011). After market-release of the first specialized Romanian-produced skidder, several improved or almost completely re-engineered models were developed: TAF 657, TAF 690-OP, and the most recent TAF 2012. Unfortunately, work studies and efficiency analyses have not kept up with technological advancements in timber skidding machines from Romania, a fact which is reflected in the last realized time and production rates developed for TAF 650 being in 1989. However, this has not been the case of other countries which have tried and succeeded to develop efficiency studies for several skidding machines (Kluender et al., 1997; Kluender et al., 1998; Wang et al., 2004; Sabo and Poršinsky, 2005; Zečić et al., 2005; Horvat et al., 2007; Behjou et al., 2008; Naghdi and Mohammadi, 2009; Behjou, 2010; Özturk, 2010a, b; Spinelli and Magagnotti, 2012; Ghaffarian et al., 2013; Mousavi, 2012).

Work measurement is employed in forest operations in order to produce empirical models which can be used for different purposes including planning and cost calculations (Spinelli et al., 2002). Also, this kind of studies may help in understanding the behavior of harvesting equipment in various terrain and stand conditions (Visser and Stampfer, 1998; Viser and Spinelli, 2012). When carried out on new equipment or on the same equipment used in new conditions (Visser and Spinelli, 2012), this kind of studies may help in assessing the equipment's optimum use. In skidding operations, timber extraction costs depend in a great measure by the mean extraction distance, as well as by the mean extracted volume per turn (Oprea and Borz, 2007), factors which are regarded as process variables (Acuna et al., 2012). Their variation leads to completely different shapes of both, time consumption and productivity models (Oprea and Borz, 2007). The studies done so far reported mean loads per a skidding turn ranging from 1.053 (Spinelli and Magagnotti, 2012) to 5.34 m^3 (Horvat et al., 2007), and mean skidding distances usually under 400 m (Behjou, 2010; Ghaffarian, 2013).

The TAF 690-OP winch skidder is one of the most used machines in timber harvesting operations in Romania. Also, resinous species are most often located in mountainous areas, generally having reduced accessibility (Report on Forest State, 2010), while group shelterwood cuttings represents one of the most applied silvicultural systems (Report on Forest State, 2010). In this context, this study aimed to assess timber skidding efficiency in a fir dominated stand when applying the group shelterwood cuttings, and focused on developing time prediction models and production rates for timber skidding in conditions of increased loads per turn and long skidding distances. Consequently, the objectives of the study were to: (i) develop time prediction models for winching, on-trail timber skidding and overall skidding operations and (ii) estimate the production rates in timber skidding for the studied conditions. Results of the study may be helpful for production planning, as well as for calculating the skidding operations costs.

MATERIAL AND METHODS

Study location

The research was carried out in the summer of 2012 in a 25.5 ha stand within forest compartment No.42 of Mişina Management Unit, located at 45º 48' 32'' N to 26º 39' 12'' E near Soveja village, Vrancea County Romania. This forest is administrated by the Soveja Forest District. The average altitude was 1100 m and the average slope was 30%. The study stand was even-aged and consisted of mixed fir and beech. The average volume per tree was 2.50 m^3 and the total volume to be harvested was 3060 m^3. The applied silvicultural system consisted of group shelterwood cuttings whereas the applied harvesting method was a combination of tree-length and cut-to-length. Tree felling and processing was done by means of a Husqvarna 365XP chainsaw, while skidding was done by the means of a TAF 690-OP winch skidder (Figure 1). Two crews worked during the harvesting operations: one in tree felling and processing which was done before starting the skidding operations, and a second crew consisting of a skidder operator and a worker responsible for non-mechanized elements such as cable release, logs hooking and logs unhooking. A total number of 100 logs were skidded during the field study, representing a volume of approximately 221 m^3 (7% from the volume to be harvested).

Data collection

A three person team collected data during the field study. Two of whom were responsible for collecting data during winching operations, while the third collected data for on-trail skidding. One hundred replications were collected for winching operations and 31 for on-trail skidding. In both cases the continuous time study method was used. Each skidding cycle was divided in two main groups of operations (Figure 2): winching and on-trail skidding. The winching operation was that applied at the felling site and divided in the following work and time elements: skidder establishment time (T_e), cable releasing (T_{cr}), log hooking (T_h), mechanical winching (T_{mw}) and, when necessary, log unhooking in the rear part of the skidder (T_{uh}). On-trail skidding operations were also divided in the following elements: empty travel (T_{et}), load attachment (T_{la}), loaded travel (T_{lt}) and load detachment at the roadside (T_{ld}). Load attachment was optional and it occurred only when more than 2 logs were skidded at the time. Delay free winching time (*DFWT*) was obtained for each replication as a sum of time consumptions. The same procedure was applied in order to obtain the delay free on-trail skidding time (*DFotST*). Total delay-free skidding time (*DFST*) was obtained by considering the delay-free time consumptions for realizing each skidding load (for two or more logs) as well as the time consumptions for skidding each load. Delays were collected for all the studied operations. For the timber winching operation, the following variables were determined: winching distance (*Wdistance*), slope on the winching direction (*Wslope*) and winching direction (*Wdirection*). Winching direction was visually assessed: uphill and downhill for each winched log. For on-trail skidding, measurements were made for the following variables: skidding distance (*Sdistance*) and weighted slope on the

Figure 1. TAF 690-OP winch skidder.

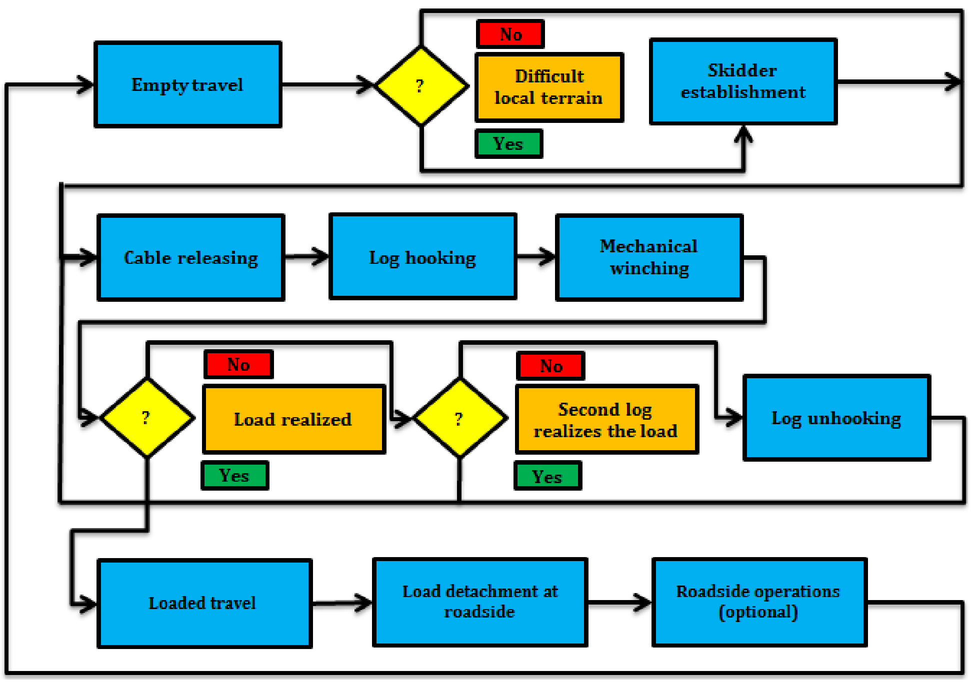

Figure 2. Organization of a timber skidding cycle within the studied area.

skidding trail for each load (*Sslope*). Volume per log (*Vlog*) and per load (*Vload*) were calculated using diameters at the ends (*Dthick* respectively *Dthin*) and lengths of each log (*Length*). For the overall skidding operation, the number of logs per load (*Nlog*) was computed based on the field data.

Data analysis

All the data was analysed using Statistica 8 (StatSoft, 2008) software. Data analysis consisted of a check for outliers (Acuna et at., 2012) and normality using the Shapiro-Wilk statistic test (Zar, 1974; Acuna et al., 2012). Time consumption estimation models were developed by means of a stepwise backward regression technique (Zar, 1974) in which the significance was considered to be at p<0.01, following a co-linearity test to eliminate redundant independent variables (Acuna et al., 2012). This test was performed using a correlation matrix and the variables which were strongly correlated were removed from subsequent tests and analyses. The removal criterion was that offered by Roemer-Orphal's scale for strong correlations (*R*>0.5). Not all the predictors were considered for each time consumption model. For instance, eventual relations between log volume (*Vlog*), log length (*Length*) and manual cable releasing, as well as between empty travel and number of logs (*Nlog*) respectively load volume (*Vload*) were excluded right at the beginning. Some of the initial independent variables were removed from analysis following the redundancy test. This referred to the two diameters recorded for log ends (*Dthick* and *Dthin*). However, log length (*Length*) was kept for further analysis for two reasons: it failed to meet the previous requirements regarding the minimum value of the correlation coefficient (*R*>0.5) and, at the beginning of the study it was assumed that relations may exist between the time consumption and log length with regard to mechanical winching work element.

Table 1. Testing of normality.

Variable	Shapiro-Wilk test and diagnose		
	W	***p***	**Normal distribution**
Diameter at the thick end of the log - *Dthick* (cm)	0.845	0.000	No
Diameter at the thin end of the log - *Dthin* (cm)	0.982	0.254	Yes
Log length – *Length* (m)	0.966	0.022	Yes
Volume of the log – *Vlog* (m^3)	0.975	0.054	Yes
Volume of the load – *Vload* (m^3)	0.942	0.092	Yes
Number of logs within load – *Nlog*	0.874	0.002	No
Winching distance – *Wdistance* (m)	0.972	0.028	Yes
On-trail skidding distance – *Sdistance* (m)	0.954	0.297	Yes
Winching slope – *Wslope* (%)	0.945	0.003	No
Skidding slope – *Wslope* (%)	0.782	0.000	No
Winching direction – *Wdirection*	0.629	0.000	No
Skidder establishment time – *Te* (s)	0.957	0.025	Yes
Cable releasing time – *Tcr* (s)	0.955	0.002	No
Log hooking time – *Th* (s)	0.782	0.000	No
Mechanical winching time – *Tmw* (s)	0.922	0.000	No
Log unhooking time – *Tuh* (s)	0.774	0.000	No
Empty travel time – *Tet* (s)	0.975	0.672	Yes
Load attachment time – *Tla* (s)	0.872	0.002	No
Loaded travel time – *Tlt* (s)	0.958	0.282	Yes
Load detachment time – *Tld* (s)	0.656	0.000	No
Delay free winching time – *DFWT* (s)	0.982	0.205	Yes
Delay free on-trail skidding time – *DfotST* (s)	0.956	0.229	Yes
Overall delay free skidding time – *DFST* (s)	0.983	0.879	Yes

Following the described procedures, time prediction models were developed for work elements such as cable releasing, mechanical winching, overall winching, empty travel, loaded travel, overall on-trail skidding and overall skidding operation (winching and on-trail skidding). The time consumption distribution of various work elements was computed using percentages calculated from the time sums corresponding to each work element and total work time. The net production rate for timber skidding operations was calculated based on time study data (delay-free time) and the realized production.

RESULTS

Time consumption models

No outliers were identified in the first step of statistical analysis. Therefore, a testing for normality was performed for all the variables taken into study. More than half of the measured or calculated variables for winching operations were normally distributed as shown by Table 1. This was also the case with on-trail skidding variables were 5 of the 9 variables were normally distributed. Data which were normally distributed were characterised using mean values; the rest were characterised using the median values (Table 2).

Total delay-free skidding time represented 72% of the total work time (Figure 3). Delays were recorded mostly during winching operations and they occurred because of the applied silvicultural system. Thus, many operational delays were recorded because the residual trees had to be avoided and supplementary manual corrections of winching direction had to be realized. As expected, long on-trail skidding distances generated an important share in the total delay free time (Figure 4) and a delay free winching time accounted for only 30%. However, this corresponds to the majority of skidding efficiency studies which have been conducted, while the main difference could concern the productivity. If all the work elements are considered (Figure 5), loaded travel and empty travel consumed most of the time.

Time prediction models were computed for almost all of the work elements (Table 3). An attempt was made to elaborate time prediction models for manual phases of skidding operation but no suitable models could be applied because of the different work procedures from log to log and load to load. Time consumption variation of the manual cable releasing work element was most affected by the winching distance variation (Table 3, Figure 6), a fact which could be explained by the reduced mean slope on the winching direction (Table 2) which had less effect on the worker movement. However, a mean volume per log of 2.21 m^3 (Table 2), which in other studies represented the equivalent of an entire load, was found to

Table 2. Descriptive statistics of the studied independent and dependent variables.

Variable	Descriptive statistics				
	Min.	Max	Range	Median ± Standard deviation	Mean ± Standard deviation
Diameter at the thick end of the log - *Dthick* (cm)	5	52	47	18.00±6.94	-
Diameter at the thin end of the log - *Dthin* (cm)	15	76	61	-	46.67±12.84
Log length – *Length* (m)	7.0	29.0	22.0	-	20.12±4.46
Volume of the log – *Vlog* (m^3)	0.26	5.58	5.32	-	2.21±1.18
Volume of the load – *Vload* (m^3)	1.50	12.43	10.93	-	7.12±2.46
Number of logs within load – *Nlog*	2	5	3	3.00±0.96	-
Winching distance – *Wdistance* (m)	2.0	47.0	45.0	-	23.02±11.00
On-trail skidding distance – *Sdistance* (m)	696	1250	554	-	1037.32±148.77
Winching slope – *Wslope* (%)	2	28	26	10.00±5.54	-
Skidding slope – *Wslope* (%)	6	10	4	8.00±8.19	-
Winching direction – *Wdirection*	-	-	-	-	-
Skidder establishment time – *Te* (s)	3.40	67.00	63.60	-	29.35±16.42
Cable releasing time – *Tcr* (s)	5.00	149.00	144.00	49.50±31.92	-
Log hooking time – *Th* (s)	3.00	115.00	112.00	18.50±20.82	-
Mechanical winching time – *Tmw* (s)	5.00	223.00	218.00	55.50±47.20	-
Log unhooking time – *Tuh* (s)	0.00	78.00	78.00	5.00±15.84	-
Empty travel time – *Tet* (s)	332.00	776.00	444.00	-	580.19±106.16
Load attachment time – *Tla* (s)	0.00	141.00	141.00	60.00±51.84	-
Loaded travel time – *Tlt* (s)	431.00	1000.00	569.00	-	730.65±156.20
Load detachment time – *Tld* (s)	18.00	171.00	153.00	34.00±33.87	-
Delay free winching time – *DFWT* (s)	32.67	427.50	394.83	-	189.22±83.29
Delay free on-trail skidding time – *DfotST* (s)	1051.0	1860.0	809.0	-	1418.77±237.59
Overall delay free skidding time – *DFST* (s)	1283.0	2757.0	1474.0	-	2029.16±362.84

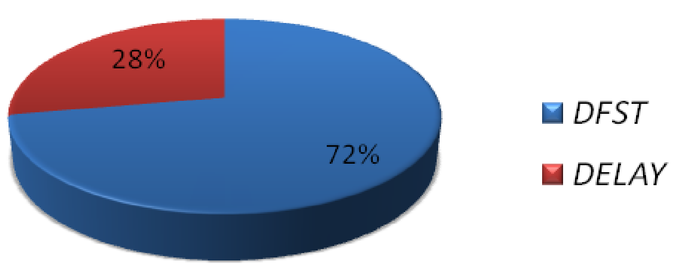

Figure 3. Time consumption distribution on categories. Delays versus productive time.

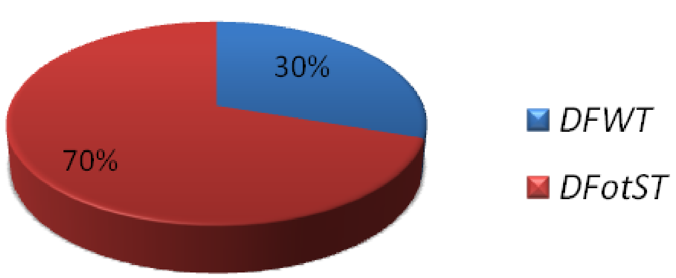

Figure 4. Time consumption distribution on categories. Delay-free winching time versus delay-free on-trail skidding time.

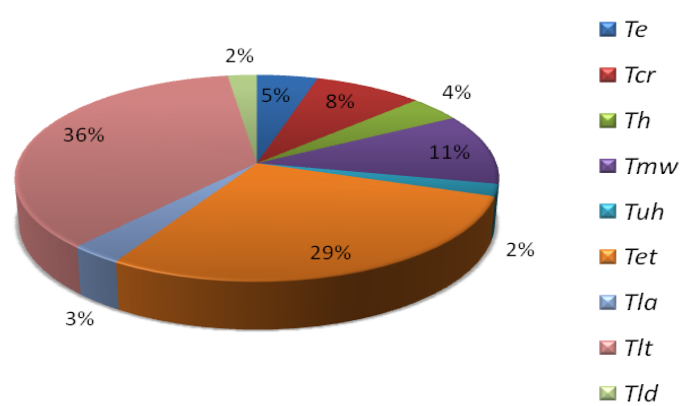

Figure 5. Time consumption distribution on categories. Delay free time consumptions shares for each work element.

be a significant variable when expressing the time consumption variation of the mechanical winching work element. Therefore, the time consumption model for this work element considered both, the winching distance and the log volume as independent variables. This was also the case of a winching repetition, where both variables were significant. When dealing with on-trail skidding

Table 3. Time prediction models for skidding operations.

Time prediction model [seconds]	Descriptive statistic			
	Sig. F	**R^2**	**Predictor**	**p**
Winching operation				
Tcr=4.87 + 2.07 × *Wdistance*	<0.000	0.51	*Wdistance*	<0.000
Tmw = -9.23 + 11.04 × Vlog + 2.39 × Wdistance	<0.000	0.41	*Vlog* *Wdistance*	0.001 <0.000
DFWT = 30.95 + 19.48 × Vlog + 5.01 × Wdistance	<0.000	0.54	*Vlog* *Wdistance*	<0.000 <0.000
On-trail skidding operation				
Tet= - 64.90 + 0.62 × Sdistance	<0.000	0.76	*Sdistance*	<0.000
Tlt= - 135.56 + 0.84 × Sdistance	<0.000	0.64	*Sdistance*	<0.000
DFotST = - 60.67 + 1.43 × Sdistance	<0.000	0.80	*Sdistance*	<0.000
Overall skidding operation				
DFST = - 787.81 + 141.14 × Nlog + 17.79 × Wdistance + 1.88 × Sdistance	<0.000	0.80	*Nlog* *Wdistance* *Sdistance*	<0.000 <0.000 <0.000

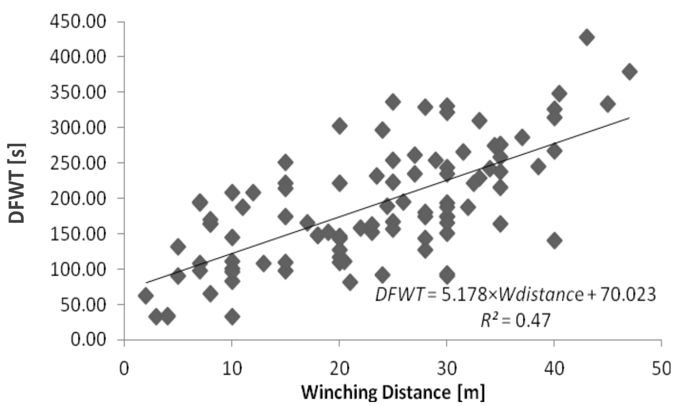

Figure 6. Relation between time consumption during winching and the winching distance.

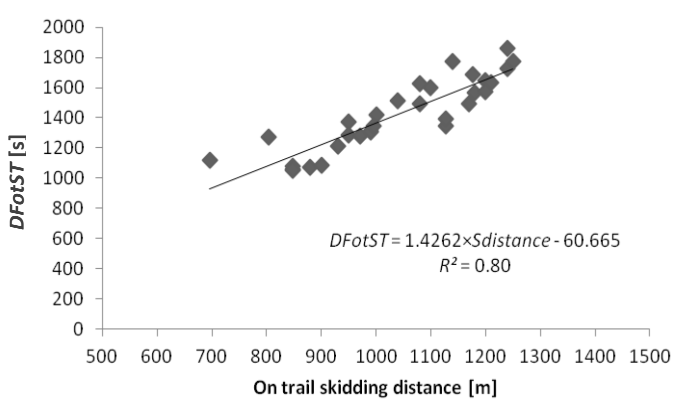

Figure 7. Relation between time consumption during on-trail skidding and the skidding distance.

operation (Table 3, Figure 7), it was found that for all the work elements, only the skidding distance was a significant independent variable. In the overall skidding operation, the time consumption for logs hooking and unhooking had an important effect. Therefore, the volume of the log lost its significance and the number of logs per load along with winching and skidding distances, became significant independent variables.

Skidding productivity

A net production rate for skidding operations of 12.65 m^3h^{-1} was obtained for a mean skidding distance of 1037.32 m, and a mean winching distance of 23.02 m, in conditions of a mean volume per log of 2.21 m^3, a mean volume per load of 7.12 m^3 and a mean number of logs per load of 3. By comparison, gross production rate was significantly affected by delays. Consequently, a gross rate of only 9.13 m^3h^{-1} was obtained, representing a 28% reduction in production.

DISCUSSION

Increased skidding distances within the studied area affected the distribution of delay-free time consumption for the two studied operations (winching and on-trail skidding). Since winching time distribution within a delay-free work time is strongly affected by on-trail skidding distance and most of the studies realized until now reported that the share of winching time in the total delay-free skidding time was greater than 25% (Sabo and

Poršinsky, 2005; Behjou et al., 2008; Behjou, 2010; Özturk 2010a, b; Spinelli and Magagnotti, 2012; Caliskan, 2012; Ghaffarian et al., 2012; Mousavi, 2012), we would expected to find significant differences in time distribution of the two groups of work elements due to the increased skidding distance in this study. However, it seems that increased volumes of the logs and the corresponding time consumption on winching work elements compensated somehow this distribution. If an individual time-analysis is considered, non-mechanized work elements were responsible for the smallest shares of total delay-free skidding time. Log hooking time was considerably greater by comparison with log unhooking time. Generally, this distribution may be explained by the greater difficulty in attaching the log to the cable as the cable must be passed under the logs each time. This became quite difficult when diameters at the thicker end were increased. By comparison, log unhooking was facilitated by the position of attachment hooks, which in the majority of cases was above the logs. The same applies to load attachment and load detachment time shares because load attachment was more difficult. However, log position and the fact that this work element was not always required, led to a smaller share within the total delay-free time. Surprisingly, mechanical winching took more time than manual cable releasing. This was related to several non-avoidable interventions of the manual worker, which were required to unblock logs. This happened especially in the case of very large logs. By comparison, cable releasing was more facile because nothing restricted it. All the on-trail skidding was done downhill. However, to avoid the residual trees located near skidding trails, the skidder operator drove more carefully when loaded. Therefore, the reduced speed (in average 5.11 km×h^{-1}) by comparison with empty travel (in average 6.48 km×h^{-1}) led to an increased time during this work element.

In this study, winching and on-trail skidding distances represented the most relevant predictors when dealing with time prediction models in skidding operations. Despite the fact that the maximal model contained winching distance, winching slope and winching direction, after refining, only winching distance became a relevant predictor for the manual cable releasing work element. This may be explained by the fact that more than half of the winching replications were done uphill, therefore the worker had to pull the cable downhill. Also, winching operations were done in conditions of a gentle slope, fact which could represent another reason of the slope on winching direction not imposing itself as a relevant independent variable. By comparison, the mechanical winching time was affected also by the log volume which became a relevant independent variable due to the supplementary time consumed when large logs were obstructed by different obstacles and the manual worker had to intervene for solving these problems. This was also the case of a delay-free winching cycle, case in which the determination coefficient was improved, because supplementary time for logs hooking-unhooking was added. Therefore, the significance of *Vlog* predictor was also improved.

In case of on-trail skidding, only the skidding distance was relevant at the chosen confidence threshold for all the developed time prediction models. Also, when adding all the work elements, the determination coefficient was significantly improved (R^2=0.80). However, load volume was not relevant, fact deduced also from relatively constant travelling speed when loaded no matter the load size.

Starting from all the possible to include independent variables, as well as by adding the number of logs per load (*Nlog*) which reflected in fact the number of required winching replications to make a skidding load, the best time prediction model in terms of independent variables relevance was that containing the number of logs respectively winching and on-trail skidding distances. On-trail skidding slope became highly irrelevant as well as the winching direction, slope and load volume. This was related with generally reduced slopes as well as with the driving pattern when loaded.

Net and gross production rates were strongly correlated with the general work conditions. Thus, increased loads per turn (7.12 m^3) did not compensate the increased skidding distances (1037.32 m) and generated more reduced net production rates by comparison with results reported by other studies (Behjou et al., 2008; Behjou, 2010; Ghaffarian et al., 2012) according to which both, the skidding distance and load volumes per turn were smaller. However, other work conditions may affect productivity even in case of smaller skidding distances, reason for which smaller productivities were obtained in case of very small distance by comparison with this study (Sabo and Poršinsky, 2005; Özturk 2010a; Özturk, 2010b; Mousavi, 2012). In what concerns the skidding distance, by comparison with quite similar studies (Spinelli and Magagnotti, 2012) skidding productivity was almost twice higher. This may be the consequence of differences between specialised skidders (present study) and farm tractors adapted for forest operations which cannot undertake very large loads. In what concerns the gross production rate, it may be concluded that it was strongly related to the time management of operations. In this study, delays which accounted 28% of the total work time affected significantly the gross production rate.

Conclusion

Following the results of this study, it can be concluded that in case of skidding high volume logs and loads, the time consumption estimation may be explained using the winching and skidding distances, as well as the number of logs forming a load. However, the productivity of skidding operations was still affected by the increased skidding distances even if the volume of loads was increased.

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