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Time consumption and productivity of skidding Silver fir (*Abies alba* Mill.) round wood in reduced accessibility conditions: a case study in windthrow salvage logging form Romanian Carpathians

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Abstract. Natural calamities (especially windthrows) may generate difficult work conditions in timber harvesting operations. When associated with the reduced accessibility conditions, the work conditions become even harder. This study investigates the time consumptions on specific work elements in timber skidding, develops time prediction models for timber skidding work elements and assesses the production rates for timber skidding in reduced accessibility stands where windthrow salvage cuttings were applied. Following a time study done for two skidders (TAF 690 OP and TAF 657) operating simultaneously in the same felling area, it has been found that, in average, in a delay free skidding cycle time, lateral winching accounted for a share of 26-33%, on-trail skidding accounted for a share of 64-71% and landing operations accounted for a share of 3%. Total delays accounted for 51% and 43% of the total work time in the case of TAF 690 OP skidder and TAF 657 skidder, respectively. Regression models for lateral winching (both skidders) revealed that the winching distance and the number of logs were the relevant predictors for the time consumption estimation (p <0.01), whereas in the case of on-trail skidding only the skidding distance was relevant (p <0.01). For the overall skidding operation (excluding landing operations) winching and skidding distances were found as relevant predictors (p <0.01) for 690 OP, whereas the number of logs became an additional relevant predictor for 657. In conditions of an average winching distance of 19.90 m and an average on-trail skidding distance of 980.32 m, the time study yielded a net production rate of 7.70 $m^3 h^{-1}$ and a gross production rate of 3.75 $m^3 h^{-1}$ in the case of TAF 690 OP skidder. By comparison, in the case of TAF 657 skidder, for an average winching distance of 22.86 m and an average on-trail skidding distance of 871.00 m, the net and gross production rates were of 5.61 $m^3 h^{-1}$ and 3.20 $m^3 h^{-1}$ respectively.
Keywords time consumption, productivity, skidder, reduced accessibility, windthrow salvage cuttings.

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Introduction

Skidders represent ones of the most frequently used forest ground-based logging means, probably due to their increased mobility and productivity, reason for which several efficiency studies have been done so far around the world for this kind of forest equipment (Behjou et al. 2008, Naghdi & Mohammadi 2009, Behjou 2010, Spinelli & Magagnotti 2012, Ghaffarian et al. 2013). Despite the fact that most of the Romanian forests are located in mountainous regions where cableway setups would be a more appropriate choice if the environmental concerns are in question, at present, most of the timber logging operations (more than 95%) are done using skidders and farm tractors (Sbera 2007).

Generally, the skidding costs depend on the skidding distance (Oprea & Borz 2007), as the excessive long distances, specific to the stands located in reduced accessibility conditions, generate lower productivities (Oprea 2008, Oprea & Sbera 2004) and increased operation costs. The majority of the recent studies regarding the timber skidding efficiency took into consideration skidding distances which were generally short, with averages between 25 (Zečić et al. 2005) and 1119 m (Spinelli & Magagnotti 2012). In these cases, most frequently, the timber skidding efficiency was assessed in selective cuttings (Kluender et al. 1997, Kluender et al. 1998, Sabo & Poršinsky 2005, Behjou et al. 2008, Naghdi & Mohammadi 2009, Mousavi 2012), thinning (Kluender et al. 1997, Kluender et al. 1998, Zečić et al. 2005, Spinelli & Magagnotti 2012) and clear cuttings (Kluender et al. 1997, Kluender et al. 1998, Zečić et al. 2005, Spinelli & Magagnotti 2012).

Due to some difficult work conditions, salvage logging specific to windthrows, especially when dealing with scattered windthrown timber, generates special problems by comparison with regular cuttings (Oprea & Sbera 2004, Magagnotti et al. 2013), both as timber felling and logging operations. First, especially in the case of resinous species, the prompt intervention with the needed harvesting technology is imperative, in order to avoid wood decaying and mass infestations (Oprea 2008). Second, these kinds of interventions require quite expensive forest equipment when dealing with large scale wind damages, being commonly regarded as industrial scale harvests when they concentrate an increased amount of timber to be harvested (Magagnotti et al. 2013). By comparison, reduced quantities of affected timber, dispersed on large areas may be a problem when trying to use highly mechanized systems (Oprea 2008). Other special problems related to salvage logging of windthrown timber are those related to work safety (Sullman & Kirk 2001), which is quite reduced by comparison with regular interventions, as well as to the impossibility to use of some types of cable yarders in certain situations due to the inexistence of suitable trees to support the main line. When associated with reduced accessibility conditions, windthrow salvage logging becomes even more difficult due to the increased production costs (related to smaller productivities) and depreciation of the harvested timber (Nieuwenhuis & Fitzpatrick 2002). These may represent sufficient reasons for trying to find cost-effective low-investment alternatives for harvesting winthrown timber as demonstrated by Magagnotti et al. (2013). However, the available knowledge when dealing with winthrow salvage logging is still limited in time consumption and productivity for different harvesting setups and equipments, including the association between chainsaws and skidders, as specific situations may occur due to different work conditions from one workplace to another. This becomes even more relevant since, in forest operations, the productivity studies try to understand the behavior of both, the new equipment or equipment used in new conditions (Visser & Spinelli 2012). Thus, developing time prediction models and estimating the production rates for these conditions may help in organizing the production in harvesting operations.

Efficiency assessment in timber harvesting operations for different forest equipments is done by using time study techniques (Björheden et al. 1995, Acuna et al. 2012) realized in order to express the time consumption and (or) realized production related to relevant influence factors. The obtained regression models for time consumption estimation may depend on the amount of field collected data (Zar 1974), and, depending on the specific work conditions, the studies done so far in case of skidders used between 30 (Özturk 2010a,b) and 300 (Spinelli & Magagnotti 2012) work cycles, being conditioned in some specific cases by the amount of timber to be harvested in a certain location. The mentioned studies focused either on one skidder (most of the studies) or several tests realized for different equipments (Spinelli & Magagnotti 2012).

TAF 690 OP and its predecessor TAF 657 are relatively new produced forest equipments widespread in Romanian forest operations. The last available data concerning the productivity for Romanian skidders is available in a dedicated normative for old concept machinery, but no separations are provided between specific silvicultural interventions (Ministry of Timber Industrialization and Materials, 1989). Also, studies regarding the efficiency of mentioned skidders, especially in scattered windthrow salvage logging were not done until now.

Consequently, the goals of this study were to: (i) develop a critical survey regarding the time consumptions for timber skidding in reduced accessibility conditions in the case of windthrow salvage cuttings, (ii) develop time consumption models for the main work elements in the case of timber skidding for the mentioned conditions and (iii) assess the production rates in the case of timber skidding for the mentioned conditions and skidders.

Material and methods

Study location and work organization

The field study was carried out in a forest stand located at 45º 37’ 44’’ N 26º 09’ 50’’ E, in proximity of Zăbrătau village belonging to Covasna County, Romania. The mentioned forest stand is administrated by Buzăul Ardelean Forest District, and is located in Management Unit I Țăranu, on the southern part of Bota Mare watershed area. In the studied location, the windthrown timber was rather a scattered than a mass phenomenon as provided by timber selling documentation realized for the forest stand in question. Timber skidding operations were done in the spring of 2012, by the means of two Romanian produced skidders: TAF 657 and TAF 690 OP which worked simultaneously until all the affected timber was extracted. Each skidder was served by a work team composed of two men who had improved experience in harvesting operations. Harvesting operations were organized in several steps (Figure 1), including chainsaw tree felling (when necessary), partial processing, cable winching, on-trail skidding and landing operations. The main characteristics of the studied felling area are presented in Table 1.

Field data sampling

For the of estimation time consumption and the of assessment productivity a time for the two mentioned skidders study (Björheden et al. 1995, Acuna et al., 2012) was conducted. Practically, 41 work cycles for TAF 690 OP skidder and 46 work cycles for TAF 657 skidder were studied in the field. The continuous time study method was applied to collect the needed data for time consumption prediction models. A complete skidding work cycle was divided in three groups of work elements: winching, on-trail skidding and landing operations (Fig. 1). For each winching work element, distance, slope on winching direction and dendrometric data (diameters and lengths of the winched logs) were measured. Based on the dendrometric data the volume of each log was computed in the office using the classical mathematical relations. Winching cycle time (*WCT*) was divided in the following elements: assuring the skidder's stability (T_{ss}), winch preparing (T_{wp}), cable releasing (T_{cr}), logs' hooking (T_{lh}), mechanical winching (T_{mw}) and logs' unhooking (T_{lu}). For each on-trail skidding element, number of logs per load, distance and slope of the trail were measured. On-trail skidding cycle time (*OTSCT*) was divided in the following time elements: travel empty (T_{te}), load attaching (T_{la}), load rising (T_{lr}), travel loaded (T_{tl}) and load detachment (T_{ld}). The maximum movement distance in the case of landing operations was less than 50 meters. Time spent

Table 1 Main characteristics of the harvested stand

Parameter	Value
Area (hectares)	50.10
Average terrain slope (%)	47
Altitude (m)	950
Species composition	75 Fir 21 Spruce 5 Beech
Average volume per tree (m^3)	1.4
Harvesting method	Combination between CTL and TL
Silvicultural system	Salvage cuttings (windthrow)

Note. CTL – cut to length, TL – tree length

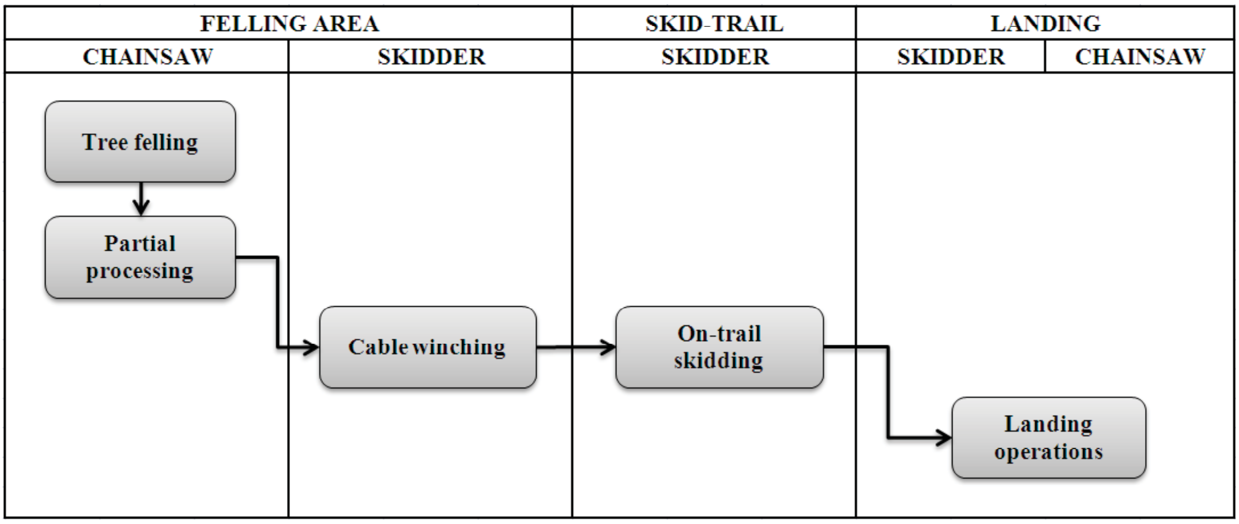

Figure 1 Work organization in the studied felling area

for landing operations (T_{lo}) was not divided in subsequent time elements. Each skidder was served by a team consisting of two men (skidder's driver and a load attachment-detachment worker). The personal (T_{pd}), operational (T_{od}) and technical delays (T_{td}) were recorded separately during the time study.

Data analysis

For data analysis, it was assumed that the time spent in a winching cycle is a function of winching distance (*WD*), winching slope (*WS*), and the number of winched logs (*NWL*). Also, it was assumed that the time spent in an on-trail skidding cycle is a function of skidding distance (*SD*), on-trail skidding slope (*SS*) and skidding load volume (*SLV*). Consequently, for the overall skidding cycle, it was assumed that most of the measured variables may influence the time consumption. The statistical significance of these relationships was tested through regression analysis by considering several iterations for each group of work elements (winching, on-trail skidding and overall skidding excluding landing operations). Before starting the regression analysis, a normality test was performed for all variables taken into study ($\alpha = 0.01$), by the means of Shapiro-Wilk test (*W*), followed by a multicollinearity test performed only for the independent variables considered for each initial (maximal) model. This last step was performed using a correlation matrix, developed for all the considered independent variables. A value of $\geq \pm$ 0.50 was used as exclusion threshold for the correlation coefficient (variables strongly correlated according to Roemer–Orphal's scale). The remaining independent variables for each initial (maximal) model were used in the regression analysis. For this purpose, the stepwise backward regression technique (Zar 1974) was applied. This meant including all the possible independent variables (maximal model), significance analysis for the overall obtained model (p <0.001) as well as for each independent variable (p <0.01) at each iteration level, followed by the exclusion of those independent variables presenting no significance at the chosen confidence threshold. AIC (Akaike Information Criterion)(Akaike 1974) was computed for each obtained model to provide the basis for the choosing model. Models for winching, on-trail skidding and overall skidding operations time consumption estimation were elaborated for the both studies skidders. Net production rate was calculated for each skidder, by considering the delay-free time consumption, whereas the calculation of gross production rates for each skidder involved the use of all the time consumption (including delays).

All the statistical analysis was performed Statistica 8.0 with (StatSoft 2008).

Results

Characteristics of working conditions and time consumptions

Generally, the mean or median values of winching slope (*WS*) winching distance and number of logs (*NWL*) (Table 2) were greater in the case of data pools analyzed for TAF 657, while mean (median) values of skidding distance (*SD*) and load volume (*LV*) were smaller by comparison with those generated by analyzing the data pool for TAF 690 OP. These facts led to specific responses when analyzing the shares of time consumption within a delay-free skidding work cycle (Tables 2-3). Consequently, the delay-free time consumption for skidding operations (excluding landing operations) was, on average, greater for TAF 657 than TAF 690 OP (Table 2). Delay-free shares of time consumptions for winching and on-trail skidding work elements were computed and they are presented in Table 3, while time shares on main operations (group of work elements) and time distribution on main time consumption categories are presented in

Table 2 Characteristics of working conditions for TAF 690 OP and TAF 657 skidders

Parameter	TAF 690 OP			TAF 657		
	Mean	Min.	Max.	Mean	Min.	Max.
Winching slope WS (%)	21.96 (19.60)	6.00	57.00	22.83 (22.00)	7.50	61.00
Skidding slope SS (%)	20.51 (21.00)	6.00	23.00	18.57 (21.00)	6.00	23.00
Winching distance WD (m)	19.90 (20.00)	3.10	44.40	22.86 (20.31)	9.80	56.50
Skidding distance SD (m)	980.32 (1080.00)	128.00	1338.00	871.00 (886.00)	107.00	1526.00
Load volume SLV (m^3)	6.52 (6.36)	4.17	10.03	5.38 (5.30)	1.97	8.33
Number of logs per load NWL	5.10 (5.00)	2.00	11.00	6.17 (6.00)	2.00	12.00
Delay-free cycle time, including landing operations (s)	3053.02 (3093.00)	1625.00	4031.00	3449.59 (3310.50)	574.00	4175.00

Note. In paranthesis are the median values.

Tables 4-5. As shown, mechanical winching and cable releasing were responsible for most of the time consumed for winching, whereas the empty travel and loaded travel accounted for the greatest shares in on-trail skidding (Table 3). Nevertheless, the time consumption distribution on individual work elements was quite the same in case of the two studied skidders (Table 3). Within a delay-free skidding work cycle, on-trail skidding accounted for the greatest shares of time consumption due to the increased skidding distances, followed by winching and landing operations (Table 4). An important part of the total work place time (almost half) was consumed due to delays caused by different reasons (43 respectively 51%): personal, operational and mechanical (Table 5).

Time consumption models

Following the Shapiro-Wilk test, half of the variables taken into study proved to be normally distributed ($\alpha = 0.01$). In the case of datasets which were analyzed for TAF 690 OP, load volume (*SLV*), winching distance (*WD*), delay-free winching time (T_{lw}) and total delay-free skidding time (excluding landing operations) were found the normally distributed. Also, in case of data analyzed for TAF 657, number of logs per load (*NWL*), load volume (*SLV*), skidding distance (*SD*), delay-free on-trail skidding time (T_{ots}) and total delay-free skidding time (excluding landing operations) the data supparted the normality. Therefore, when a variable in question failed to pass the normality test, data presented in Tables 2-3 was adapted by inclusion of median as additional descriptive statistic. By considering the models developed for winching, on-trail skidding and overall skidding operations (excluding landing operations), the correlation matrixes imposed the exclusion of certain independent variables from very beginning. In the case of winching operations, only the winching slope (*WS*) was excluded for datasets analyzed for TAF 690 OP. Skidding slope (*SS*) was also excluded in the case of TAF 690 OP dataset, while both, winching slope (*WS*) and skidding slope (*SS*) were excluded in case of the overall skidding operations and TAF 690 OP dataset. When choosing, preference was awarded to operating distances instead of slopes since in most of the studies, operating distances proved to be significant predictors in time consumption estimation.

Table 3 Effective time consumption on work elements for TAF 690 OP and TAF 657 winch skidders

Operation/Work element	Share in total delay-free time consumption							
	TAF 690 OP				TAF 657			
	%	Min. (s)	Max. (s)	Mean (s)	%	Min. (s)	Max. (s)	Mean (s)
Lateral winching	100	282.00	1753.00	787.80 (728.00)	100	437.00	2719.00	1028.20 (1065.00)
Time consumption for assuring the skidder's stability (Tss)	1	0.00	15.00	7.17 (7.00)	1	0.00	37.00	11.02 (10.00)
Time consumption for winch preparing (Twp)	10	0.00	296.00	76.80 (62.00)	9	0.00	255.00	110.48 (101.50)
Time consumption for cable releasing (Tcr)	26	55.00	680.00	199.95 (180.00)	23	80.00	967.00	267.96 (240.50)
Time consumption for logs' hooking (Tlh)	16	23.00	307.00	132.54 (123.00)	12	39.00	299.00	134.76 (130.00)
Time consumption for mechanical winching (Tmw)	41	89.00	827.00	315.34 (279.00)	43	145.00	1290.00	503.98 (509.00)
Time consumption for logs' unhooking (Tlu)	7	0.00	464.00	56.00 (40.00)	12	0.00	294.00	118.02 (106.00)
On-trail skidding	100	807.00	2800.00	2079.93 (2167.00)	100	574.00	4175.00	2308.74 (2351.50)
Time consumption for empty travel (Tet)	49	263.00	1515.00	1031.93 (1083.00)	47	147.00	1806.00	1077.57 (1178.00)
Time consumption for load attachment (Tla)	8	28.00	655.00	157.59 (114.00)	9	14.00	460.00	204.43 (195.00)
Time consumption for load rising (Tlr)	1	7.00	34.00	14.80 (13.00)	1	0.00	35.00	15.13 (13.00)
Time consumption for loaded travel (Tlt)	39	134.00	1408.00	814.27 (827.00)	40	212.00	2114.00	932.67 (893.50)
Time consumption for load detachment (Tld)	3	23.00	241.00	61.15 (57.00)	3	16.00	198.00	78.93 (73.50)

Table 4 Delay-free time consumption shares on groups of work elements (operations) for TAF 690 OP and TAF 657 winch skidders

Operation (group of work elements)	Share in total delay-free time consumption	
	TAF 690 OP	TAF 657
Time consumption for a delay-free skidding cycle	100	100
Time consumption for winching (Tlw)	26	33
Time consumption for on-trail skidding (Tots)	71	64
Time consumption for landing operations (Tlo)	3	3

Following the stepwise backward regression technique, based on AIC, six models were developed for estimating the delay-free time consumption for winching ($WCT_{TAF690OP}$ respectively WCT_{TAF657}), on-trail skidding ($OTSCT_{TAF690OP}$ respectively $OTSCT_{TAF657}$) and overall skidding operations ($SCT_{TAF690OP}$ respectively SCT_{TAF657}). These models (Table 6) may be interpreted and are applicable only for conditions presented in Table 2 as descriptive statistics of the working conditions. In the case of both skidders, the time consumption for winching (Table 6) was mostly affected by the winching distance (*WD*) and number of logs winched within a work cycle (*NWL*). By comparison, in case of on-trail skidding, only the skidding distance (*SD*) became relevant in expressing the time consumption (Table 6) since the skidding slope (*SS*) was either excluded following the multicollinearity test or failed to become relevant during regression analysis, whereas the load volume (*SLV*) failed to become relevant during the backward stepwise regression.

When dealing with the overall skidding operations (excluding landing operations), the obtained models were quite different (Table 6). Thus, in case of TAF 690 OP only the winching and skidding distances (*WD* and *SD*) were found to be relevant predictors, whereas in case of TAF 657 the number of winched logs per load (*NWL*) became an additional relevant predictor.

Skidding productivity

As resulted from the data analysis, a total volume of 515.35 m^3 was skidded during the field observations (the time study was done until all the volume to be harvested was extracted – Table 7). Also, the time study was done on a time span of 148.84 hours, which represented the corresponding time of 8 working days in the case of TAF 690 OP skidder and 9 working days in the case of TAF 657 skidder. However, the mentioned skidders worked in different places within the felling area. In average, the

Table 5 Time consumption shares on main time consumption categories for TAF 690 OP and TAF 657 winch skidders

Time category	Share in total time consumption	
	TAF 690 OP	TAF 657
Total workplace time	100	100
Delay-free time consumption for skidding operations (Tso)	49	57
Time spent for personal delays (Tpd)	30	30
Time spent for operational delays (Tod)	13	10
Time spent for mechanical delays (Tmd)	8	3

Table 6 Time consumption estimation models for winching, on-trail skidding and overall skidding (excluding landing operations) for TAF 690 OP and TAF 657 winch skidders

Skidder /Time estimation model	R^2	N	Constant	Coefficients (*p* -values)			AIC value
				NWP	WD (meters)	SD (meters)	
TAF 690 OP							
Winching WCTTAF690OP (seconds)	0.565	41	-264.39	91.16 (<0.000)	29.52 (<0.000)	-	196.898
On-trail skidding OTSCTTAF690OP (seconds)	0.570	41	978.82	-	-	1.123 (<0.000)	209.506
Overall skidding SCTTAF690OP (seconds)	0.481	41	1264.14	-	25.45 (0.004)	1.119 (<0.000)	221.332
TAF 657							
Winching WCTTAF657 (seconds)	0.444	46	-200.60	119.56 (<0.000)	21.46 (<0.000)	-	230.242
On-trail skidding OTSCT TAF657 (seconds)	0.742	46	733.91	-	-	1.808 (<0.000)	243.578
Overall skidding SCT TAF657 (seconds)	0.685	46	176.97	155.73 (<0.000)	27.37 (0.008)	1.806 (<0.000)	257.657

Table 7 Gross and net productions for TAF 690 OP and TAF 657 skidders in the studied conditions (including landing operations)

Parameter	TAF 690 OP	TAF 675	Overall
Total skidded volume V (m^3)	267.28	247.57	515.35
Total delay-free time TTdf (h)	34.77	44.13	78.90
Total working time, including delays TT (h)	71.49	77.35	148.84
Average skidded volume per load (m^3)	6.52	5.38	5.92
Net production rate Pnet ($m^3 h^{-1}$)	7.70	5.61	6.53
Gross production rate Pgross ($m^3 h^{-1}$)	3.75	3.20	3.46

number of skidding work cycles done per day was of 5.125 in case of TAF 690 OP and 5.111 in case of TAF 657.

Discussion

Along with the increased skidding distances, the overall work conditions required important amounts of time for performing certain work tasks. In the case of winching operations, assuring the skidder's stability took one percent of the delay-free time (both skidders), which was considerably smaller by comparison with other reported results (Behjou et al. 2008, Behjou 2010, Ghaffarian et al. 2013). This could be explained by smaller skidding distances in the mentioned studies, compared with our study which automatically leads to time consumption redistribution on categories. However, this was also true when comparing the effective average consumed time, which took 7-11 seconds in this study, less than results reported in quite similar slope conditions by Behjou et al. (2008) and Behjou (2010)(16 seconds). This work component was required (in the vast majority of work cycles) in order to assure the safety conditions for winching, which was reported only by few studies (Behjou et al. 2008, Behjou 2010, Ghaffarian et al. 2013). Differences between the results of this study and those reported by other studies may be the consequence of local conditions and work patterns of the operators. In this study, winch preparation for operation took, in average, about the same time for both skidders and it was not reported until now as a separate work element. Hooking the logs accounted for an important share, due to the difficult terrain conditions and to the direct use of cable in performing this task (no chokers were available). However, the use of chokers in such operations may reduce substantially the time consumption since shares of 8% (about 1.4 minutes) for choker settings and 4% (about 0.7 minutes) for choker opening were reported for even greater trees (Ghaffarian et al. 2013). Generally, the time consumed for this work element was considerably greater than that reported by most of the other studies, accounting for about 133-135 seconds by comparison with about 17 seconds reported by Behjou et al. (2008) and Behjou (2010), about 82 seconds reported by Ghaffarian et al. (2013), 70-100 seconds reported by Mousavi (2012), but comparable with results reported by Özturk (2010a)(132 seconds). These important differences were the result of harder local working conditions and operational patterns. Hook-up technical procedures are not clearly described for each study done so far. However, in the present study, many logs required double-winding procedures when hooking up. This procedure was also applied (in most of cases) when the loads were attached to skidder.

Despite the fact that the average winching distance was slightly smaller in the case of TAF 690 OP skidder by comparison with TAF 657, the mean consumed time for cable releasing and pulling was in fact greater. Considering that the cable releasing was done manually, this could be the result of the slightly increased mean winching slope in the case of TAF 657 skidder, as well as of the differences related to cable pulling direction (uphill-downhill). In what concerns the average winching distance, by comparison with other studies done in similar conditions (Behjou et al. 2008, Ghaffarian et al. 2013), both, the shares in total delay-free time as well as the mean effective time consumption for mechanical winching were considerably higher in this study as a result of more difficult conditions which forced the inclusion of unavoidable delays for this work element. The unavoidable delays referred mostly to the logs unblocking when it became necessary.

Significant differences were found also in the case of logs' unhooking between the two studied skidders which might be, along with slightly different working conditions, the consequence of different situations regarding the number of logs which formed a load. For instance, this work element was done more frequently in case of TAF 657 than in case of TAF 690 OP. In the case of on-trail skidding, the time consumptions distributions for each studied work element were almost even for the two studied skidders.

Empty travel and loaded travel speeds differed from situation to situation in the results reported until now. Speeds for empty travel starting with 4.15 km h^{-1} (Behjou et al. 2008) and ending with 8.10 km h^{-1} (Spinelli & Magagnotti 2013) were reported for certain working conditions and used machines. Also, for the loaded travel were reported speeds between 1.33 km h^{-1} (Zečić et al. 2005) and 7.3 km h^{-1} (Spinelli & Magagnotti 2013). However, according to different working conditions the empty travel speed may be higher or lower than the loaded travel speed, as reported until now. For this study conditions, empty travel took more time than the loaded travel resulting in average speeds of 2.90 km h^{-1} in case of TAF 657 and 3.42 km h^{-1} in case of TAF 690 OP. By comparison, the loaded travel was done at speeds of 3.36 km h^{-1} and 3.60 km h^{-1} in case of TAF 657 and TAF 690 OP respectively. Being done uphill, the empty travel was more difficult to be realized during the field observations due to the reduced adherence of skidders, which was generated by increased slope of skid trails on some limited portions as well as by increased soil moisture during operations. Compared with other studies (Behjou et al. 2008, Spinelli & Magagnotti 2012, Ghaffarian et al. 2013) the empty travel and the loaded travel speeds were considerably lower, and, associated with increased skidding distances they generated increased time consumptions during these work elements.

Also, landing operations accounted for smaller shares in the effective time consumption (Table 4) - 3% by comparison with 14.6% (Sabo & Poršinsky 2005) despite the fact that, similar to other studies, these operations consisted in moving and piling. This difference might be explained mostly as time consumption redistribution on categories because of the increased skidding distances in this study. Thus, when comparing the obtained average effective time for landing operations with that reported by Behjou et al. (2008), significant differences were identified (almost two times greater in this study).

The winching operation accounted for 26-33% of the effective time, while, the on-trail skidding accounted for 64-71%. The share of effective winching time is comparable with that reported by other authors (Horvat et al. 2007, Sabo & Poršinsky 2005), but again, it can be interpreted only as a simple coincidence. More than half of the time was consumed by delays in case of TAF 690 OP team, situation which was slightly improved in the second case (43%). Personal delays presented the same shares in both cases (30% of the total work time), and most of them were the consequence of meal breaks and other inexcusable delays. If compared with other studies (Sabo & Poršinsky 2005, Zečić et al. 2005, Horvat et al. 2007, Behjou et al. 2008, Behjou 2010, Ghaffarian et al. 2013), in general, the delay time share was greater.

In the overall time management context, the effect is even worse in conditions of reduced accessibility, where the long skidding distances generate important shares of time consumption for on-trail skidding, thus masking the delays effect in the total time distribution by comparison with shorter skidding distances. However, in the case of up-hill skidding Zečić et al. (2005) reported greater shares for delays than those obtained in this study, even for shorter skidding distances (<250 m).

In what concerns the time consumption estimation models, not all the assumptions were proved following the regression analysis. For example, in some cases, slope was excluded from the very beginning because of the multicollinearity tests. Other variables were excluded following the stepwise backward regression procedures and application of AIC in model choosing. The only significant differences appeared between the models for estimating the time consumption for overall skidding operations, where, in case of TAF 657, the number of winched logs became relevant, fact demonstrated also by Mousavi (2012) in a study carried out on Timberjack skidders. In this study, the relevance of *NWL* variable may be related with the procedures used in log unhooking, which occurred more frequently in the case of TAF 657 team, leading to twice more time required during this work element. Operating distances (*WD* and *SD*) were the most relevant variables for the developed time consumption estimation models, fact which complies with all the studies done so far (Kluender et al. 1997, Kluender et al. 1998, Wang et al. 2004, Sabo & Poršinsky 2005, Zečić et al. 2005, Horvat et al. 2007, Behjou et al. 2008, Naghdi & Mohammadi 2009, Behjou 2010, Özturk 2010a,b, Spinelli & Magagnotti 2012, Mousavi 2012, Ghaffarian et al. 2013). The main difference when comparing the results of this study with those reported by other scientists (Wang et al. 2004, Naghdi & Mohammadi 2009, Behjou 2010), consists in the exclusion of the skidded load volume variable (*SLV*) which failed to become relevant in the studied conditions, maybe due to relative uniform payloads from one cycle to another. Also, the winching slope as well as the on-trail skidding slope (*WS* and *SS* respectively) were excluded, in some cases, following the multicollinearity tests, despite the fact that some studies found that these predictors were relevant in the developed models (Behjou et al. 2008, Behjou 2010, Mousavi 2012, Ghaffarian et al. 2013).

As expected, the gross and net productions were smaller when compared with results reported by other studies (Sabo & Poršinsky 2005, Horvat et al. 2007, Behjou et al. 2008, Naghdi & Mohammadi 2009, Behjou 2010, Özturk 2010b, Mousavi 2012, Ghaffarian et al. 2013). For both skidders, this was strongly correlated with the working conditions (intervention type, general terrain conditions and mean skidding distance). However, the improved work conditions (mostly in terms of winching distance, travelling speed and engine performance, reduced time for load attachment) in the case of TAF 690 OP skidder, yielded a net production rate of 7.7 $m^3 h^{-1}$ which was 1.37 greater than in the case of TAF 657 (5.61 $m^3 h^{-1}$), situation which was somehow attenuated when the gross production rates were considered, due to a better management of the effective work time in the second case. At the felling area level (no matter which skidder was used), the gross production rate was of 3.20 $m^3 h^{-1}$ while the net production rate was of 5.61 $m^3 h^{-1}$. These rates are comparable with those reported by Spinelli & Magagnotti (2012) for quite similar conditions regarding the skidding distance (4.7 $m^3 h^{-1}$ for an average skidding distance of 1119 m).

Conclusions

In our study, we found significant differences regarding the performance of skidding operations in windthrow salvage cuttings when compared with those reported for regular ones (e.g. selective cuttings, clear cuttings). Increased time consumptions on work elements where the results of generally harder working conditions generated by scattered timber distribution over the harvesting area and the operational patterns of teams which served the studied skidders. Consequently, the performances of studied skidders (net production rates) were generally poorer than those reported by other studies, fact which can be correlated mostly with the increased skidding distance and difficulties during winching. Noticeably were the reduced travelling speeds for empty and loaded skidding turns when comparing with other results. Along with an important share of personal, mechanical and organizational delays, this fact contributed to a greater extent to the reduced productive efficiency (gross production rates). The results presented by this paper may be useful in production organization when dealing with similar work conditions. Considering the important share of personal delays in the total workplace time, a way to improve the productive efficiency in this kind of operations would be a better management of the work time. As the time consumed for on-trail skidding depended, in this study, on the skidding distance only, for similar conditions, the time needed for this phase may be estimated using the skidding distance.

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