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THE ENHANCEMENT OF SKIDDING PRODUCTIVITY RESULTING FROM CHANGES IN CONSTRUCTION: GRAPPLE SKIDDER VS ROPE SKIDDER

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Abstract: *The development of modern forest operations in Europe has reached an advanced level in the construction of harvesters and forwarders. At the same time, large-size timber and hilly areas are still challenging, especially for timber extraction, therefore a new machine has been developed: the HSM 904-6WD grapple skidder.*
The objective of the study was to compare the productivity of two machines in the same stand conditions. The HSM 904Z-6WD grapple skidder was compared with the RSG 1 rope skidder. The new HSM 904-6WD skidder of a large size – 17.4 tonnes, 6 wheels, a powerful double-drum winch and additional novel crane system for better performance - was built by the project's leading partner, Hohenloher Spezial-Maschinenbau GmbH&Co (HSM). The machine was tested in a 140 year-old beech stand in North Poland and compared with the commonly used RSG 1 rope skidder in the same stand.
For each machine, three 0.25 ha sample plots were established with 3.5 m wide skidroads in the middle of each one, but with a different route for each skidder. Trees were cut by chainsaw operators, and if possible, felled in the direction of the skidroads. In the HSM operation, trees were felled by two cooperating chainsaw operators, whereas in the RSG operation only one chainsaw operator felled trees, which after skidding were crosscut by one person at the crosscutting point.
The results obtained in the study were satisfactory: the average skidding operational productivity, without wood piling, of the HSM skidder was very high: 32.8 $m^3 h^{-1}$ on average and the machine performed a high level of traction and manoeuvrability. Much lower (average) operational productivity, without wood piling, was achieved by the RSG 1 skidder, which reached 14.7 $m^3 h^{-1}$.

1. Introduction

The development of skidders dates back to 1949 (Silversides, 1988). Since that time the development of skidders not only covered the improvement of quality and performance within "development by correction" but conceptual work was also applied and grapple skidders were constructed. High economic competition makes manual work expensive which also reflects on the costs of forest operations (Erler, 2005). Lower costs of forest operations (per cubic meter) are possible if high productivity is achieved, especially with high fixed costs (Mederski, 2006). To lower these costs the introduction of very productive machines such as harvesters and forwarders operated by one person seems to be a good solution (Suwała and Rzadkowski, 2001 a, b). The application of harvesters and forwarders is limited to appropriate stand conditions. They are very useful in coniferous stands on flat areas. In mixed or broadleaved stands, where trees are large, the long wood system is most recommended in which manual felling and skidding of whole trunks is widely used (Bacher-Winterhalter *et al.,* 2006). The effectiveness of skidding is in strong competition with forwarding, which often is more productive (Suwała and Rzadkowski, 2001 a, b). However certain mechanisms make skidding more attractive. Kubiak and Pilarek (1992) found out that making small piles of wood after extraction makes the whole process more productive by 32% in short distance skidding up to 50 m and by 12% within 250 m. Więsik (1999 a, b) in his research shows that an additional person (apart from the operator) employed for trunk-attachment can improve effectiveness but only on short distance skidding. This benefits are not so evident when the distance is longer than 800 m.

Apart from rope skidders, effective in mixed and broadleaved stands, grapple ones lead to better productivity. Gawart (1998) in her research in Canada confirmed that grapple skidding was 2.47 times more productive than rope skidding. Grapple skidders are constructed not only because they are more effective, but they are also very useful in hilly areas and for extracting large size wood from mixed and broadleaved stands. To meet these requirements a new grapple skidder was developed within the ForstInno[1] project: the HSM 904Z 6WD. The purpose of this paper is to find out if the newly constructed grapple skidder is more effective in comparison with the RSG 1 rope skidder. As the operator of a rope skidder has to leave the cabin to attach trunks it is recognised as a more time consuming activity than using a grapple operated from a cabin.
The hypothesis was that the grapple loading system in the new HSM 904Z 6WD skidder would considerably improve productivity when compared with the rope loading system of the RSG 1.

2. Materials and methods

2.1 Study area and forest operations

Research was carried out in March 2007 in Northern Poland, the Regional Directorate of the State Forests Gdańsk, Forest District Wejherowo. Six sample plots were selected in a 140-year-old beech (*Fagus sylvatica* L.) stand 63b, in which final felling after natural regeneration was prescribed. Sample plots were marked as SP 01, SP 02 and SP 03 for the HSM grapple skidder, SP 04, SP 05 and SP 06 for the RSG rope skidder (Table 1).

Table 1. Sample plots characteristics

sample plot	number of trees	tree characteristics								harvested volume (m^3)
		BHD (cm)	max / min	H (m)	max / min	Hc (m)	Max / min	V (m^3)	max / min	
SP 01	35	42	61 / 28	24.1	33.5 / 18.9	11.9	18.4 / 5.0	1.55	5.27 / 0.39	54.12
SP 02	22	45	90 / 27	24.3	32.0 / 15.0	13.8	18.5 / 7.5	2.00	8.44 / 0.53	44.13
SP 03	23	47	63 / 33	23.8	28.0 / 18.0	13.5	21 / 7.5	2.16	5.14 / 0.79	49.64
SP 04	19	42	70 / 20	23.7	33.5 / 13.5	11.8	19.1 / 4.5	1.59	2.91 / 0.77	30.14
SP 05	15	43	55 / 25	23.9	28.0 / 15.0	10.5	15.8 / 5.5	1.49	2.52 / 0.45	22.40
SP 06	19	48	64 / 33	23.8	28.0 / 18.0	10.3	15.0 / 5.0	2.00	4.58 / 1.43	37.99

[1] ForstINNO (COOP-CT-2005-51226981): Development of Ecologically Compatible, Highly Productive Methods of Timber Harvesting for Central European Forestry, financed in the 6^{th} Framework Programme by the European Commission.

There were two systems of timber preparation for both skiddings. For the HSM timber harvesting was carried out within the long wood system: cutting, felling and delimbing was done by two chainsaw operators in the stand area. Two people also carried out crosscutting of logs after skidding next to the transport road. For skidding a newly constructed HSM 904Z 6WD was used, empowered with a 176 kW Iveco engine. The 17.4 tonne machine had 6 wheels with a boogie system at the rear. A 7.2 m long crane with a lift power of 5 tonnes was mounted in the back as well as a double drum Adler HY 16 SR winch with a pulling power of 2 x 16 tonnes. Before felling trees, measurements of the trees were carried out: DBH, height of trees and their crowns were taken with the highly accurate, computer-based Haglöf Digitech Professional caliper and Vertex III for height measuring (Table 1).

In the analysed forest operation, the skidder drove on marked, 3.5 m wide, parallel skid roads at 40 m intervals. On three SP 0.25 ha, trees were cut and felled into the direction of the skid roads. Before skidding the trees were delimbed and the tops of the trees were cut at a min. 7 cm over bark diameter. When skidding was carried out, single logs were pulled towards the skid roads and a load of usually a few logs was formed before the second stage of skidding. Forming the load was carried out using two methods: on SP 01 sometimes a winch was used to pull remote logs, afterwards a grapple was used to collect the prepared load. On SP 02 and 03 no winch was used and a grapple only to prepare load and haul it 200 – 300 m to the crosscutting point.

For RSG skidding, timber harvesting was carried out within the short wood system: cutting, felling and delimbing was done by one chainsaw operator. Two people also carried out further crosscutting of logs (pulp wood) after skidding next to the transport road. In the RSG operation the short wood system was applied due to ecological requirements: the protection of natural regeneration. Rope skidding of long wood would have considerably damaged the young trees.

For skidding, the RSG 1 built in 1997 was used, empowered with a 59 kW engine. The machine weighing 7.2 tonnes, had 4 wheels without a boogie system and a hydraulic, 7.2 bar winch DLW-ZM7/230. In the analysed forest operation, the skidder drove on an unmarked, 3.5 m wide, irregular, "S" shape skid road going between gaps of natural regeneration. In three sample plots, SP 04, 05 and 06, 0.25 ha each, trees were cut and felled into the direction of the skid road. Before skidding the trees were delimbed and the tops of the trees were cut at a min. 7 cm over bark diameter, the trunks were cut into halves or into three pieces if necessary. When skidding was carried out, logs were pulled towards the skid roads and a load was formed before the second stage of skidding. Afterwards, the whole amount was grabbed and hauled 300 – 400 m to the crosscutting point.

2.2 Time study and productivity

During tree cutting, log preparation, skidding and crosscutting, the timing was measured (at all stages of the whole operation) using a stop-watch. Each stage of logging was differentiated according to the schedule of work time classification (Mederski, 2006). Finally, the data obtained concerning operational time (T_{02}) of skidding and piling was used in the analysis of operational time of forest operation productivity (P_{02p}), understood as:

$$P_{02p} = \frac{Q}{T_1 + T_{2p}} \quad (1)$$

where Q is the volume of extracted wood (m^3), T_1 is effective time (loading, unloading) and T_2 is additional time (driving) including time of piling.

Additionally, more calculations were done concerning skidding cycles: 1) number of logs per extraction, 2) number of cubic meters per extraction, 3) loading time per cubic meter and 4) productivity of cycle, understood as:

$$P_{02c} = \frac{Q}{T_1 + T_2} \quad (2)$$

where T_1 is effective time (loading, unloading) and T_2 is additional time (driving, without piling).

Shorter, cut logs in RSG skidding were considered as single logs, because time of loading was measured individually for each piece.
Statistical analyses such as Student's t-tests were provided for 3) loading time per cubic meter and 4) productivity of cycle.

3 Results

The best productivity (without time of log piling) was achieved in the HSM operation: 32.76 $m^3 h^{-1}$, which was more than twice better than the productivity in the RSG operation: 14.66 $m^3 h^{-1}$ (Table 2).

Table 2. Productivity results for analysed operations

		P_{02p}	P_{02c}
		$m^3 h^{-1}$	
HSM	SP 01	23.4	36.3
	SP 02	19.8	32.7
	SP 03	19.8	29.3
	mean	21.0	32.8
RSG	SP 04	8.7	19.0
	SP 05	9.5	14.2
	SP 06	7.1	10.8
	mean	8.4	14.7

In the analysed sample plots of the HSM it varied from 29.32 to 36.28 $m^3 h^{-1}$. In the RSG operation the differences were bigger: from 10.80 up to 19.01 $m^3 h^{-1}$. The time of log piling influenced productivity considerably and made productivity lower by 36%, to 21.0 $m^3 h^{-1}$. In the RSG skidding piling made productivity lower by 43%, to 8.4 $m^3 h^{-1}$ (Table 2). The difference in productivities were statistically different (Table 3).

Table 3. Student's t-test of single productivities obtained in single cycles of extraction

mean	mean	t	df	p	N	N	std dev.	std dev.	F	p	F(1.df)	df	p
HSM	RSG				HSM	RSG	HSM	RSG	variance	variance		Levene	
32.77	14.73	5.79423	50	0.000	26	26	14.653	6.688	4.801021	0.000208	11.2591	50	0.0015

A higher number of logs were on average delivered by the RSG skidder. The difference was not very big, 0.5 of a log on average (Table 4). However, the RSG logs were shorter and smaller due to crosscutting before extracting. This is clearly seen in cubic metres skidded in one extraction. The HSM skidder took on average 62% more volume (5.71 m^3) than the RSG skidder (3.52 m^3) per delivery (Table 4).

Table 4. Characteristics of single extraction cycles

	mean	min	max	mean	s.dev.	min	max	mean	s.dev.	min	max	mean	s.dev.
HSM		SP 01				SP 02				SP 03			
nr of logs per extraction	3.2	2.0	6.0	3.5	1.4	2.0	4.0	2.8	0.7	3.0	4.0	3.3	0.5
m^3 per extraction	5.71	3.28	9.19	5.41	1.78	2.72	10.09	5.52	2.23	4.03	10.90	6.21	2.30
loading time, h $(m^3)^{-1}$	0.032	0.011	0.233	0.074	0.076	0.002	0.018	0.009	0.006	0.003	0.022	0.014	0.006
productivity, m^3 h^{-1}	32.76	16.19	73.85	36.28	17.18	11.40	45.14	32.70	11.64	17.26	61.01	29.32	14.86
RSG		SP 04				SP 05				SP 06			
nr of logs per extraction	3.7	1.0	5.0	2.8	1.2	3.0	6.0	4.3	1.0	3.0	5.0	4.1	0.7
m^3 per extraction	3.52	1.58	4.18	3.01	0.90	2.91	4.69	3.73	0.74	1.42	5.82	3.80	1.33
loading time, h $(m^3)^{-1}$	0.030	0.005	0.042	0.019	0.011	0.019	0.042	0.029	0.009	0.015	0.114	0.042	0.029
productivity, m^3 h^{-1}	14.66	8.36	33.63	19.01	7.60	11.00	24.05	14.15	4.89	3.34	16.37	10.80	3.93

The average loading time per cubic metre was slightly shorter (7%) in the RSG skidding: 0.030 h $(m^3)^{-1}$, while in the HSM skidding it was 0.032 h $(m^3)^{-1}$. The differences were not statistically different. However, comparing the results from SP 02-03 and 05-06, the loading time of the HSM (0.011 h $(m^3)^{-1}$) was 68% lower than that of the RSG loading (0.035 h $(m^3)^{-1}$).

4 Discussion

The analysed comparison of the new HSM grapple skidder with the RSG rope skidder showed the better productivity of the new constructional solution. The better productivity of the HSM, however, generated another question: does the loading system, with the grapple, considerably improve productivity? The studied time of loading showed that there is no difference, at least no statistical difference, although occasionally a winch was used for remote logs on SP 01 which made the loading time much longer. Taking into consideration the loading time on SP 02 – 03 and comparing it with the loading time on SP 05 – 06 it was significantly lower (68%) on average in the HSM skidding. This difference suggests the need to pursue further studies on loading time with respect to the pure time of grapple working versus time of winch in operation. Additionally, in the RSG operation, a skidroad was made while driving in the stand with two priorities: 1) to omit natural regeneration and 2) to get as close as possible to the prepared logs.

Taking into account the skidding distance, the longer it was, the lower the productivity was (SP 03 and 06 were the most remote). However, in the RSG operation, these differences were bigger. Such a difference can be explained by the smaller engine power and slower skidding of the RSG while moving to (and from) the crosscutting point.

The obtained productivity of the HSM operation: 32.76 m^3 h^{-1} seems to be very good when compared with any rope skidders. For example 11.6 m^3 h^{-1} achieved by the Timberjack 240C in a mountainous fir stand, skidding very large trees up to 3.9 m^3 (Sabo and Prošinsky, 2005). Using a rope skidder Ecotrac 120V, productivity can reach 6 m^3 h^{-1} (Horvat *et al.,* 2007), or using LKT-81 Turbo: 7.15 m^3 h^{-1} in the mountains in an 82-year-old fir stand (Porter and Strawa, 2006). The presented results of rope skidders show that only the Timberjack 240C was more productive in the mountain conditions, where larger logs than presented in this paper study were extracted.

Gawart (1998) presented in her research the very high productivity of a grapple skidder in Canada, reaching 52.6 m^3 h^{-1} and 21,3 m^3 h^{-1} for a rope skidder. The grapple skidder was different, however, in construction (the grapple on a short crane moving vertically up and down); in addition the timber logs were already prepared in piles by a processor, just ready for skidding.

As a rule, skidder productivity depends on various factors, skidding distance and terrain conditions (mountainous or flat terrain), playing a major role. Generally, the HSM 904Z 6WD skidder is designed for large timber extraction. Due to its very good traction potential it is also good for skidding on slopes.

5 Conclusions

In the presented study the HSM grapple skidder achieved more than twice better productivity than the RSG rope skidder. This was achieved due to a more powerful engine which enabled faster driving with the load as well as without the load back to the sample plots.

There were no statistical differences observed in loading time per cubic metre between both skidders. However, when comparing only two selected sample plots of both operations, the average time of loading is significantly different in favour of the HSM skidder.

In favour of the HSM skidder is also the size of a single load: 5.71 m^3, which was 62% bigger than the RSG single load: 3.52 m^3. There were two factors influencing this: the logs were loaded by the HSM as whole trunks and the machine power was bigger, allowing the HSM to load more. The HSM skidder was also more efficient in wood piling, which lowered productivity by 36%, while in the RSG skidding it was lowered by 43%. This difference can also be explained by the fact that the HSM engine was more powerful.

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