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Investigation of the Applicability of Multi-Operational Logging Machines in Hardwood Stands

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Abstract – As a result of new developments in technology, harvesters may no longer be confined to softwood forests only. Several studies carried out in black locust, Turkey oak and beech stands have justified the use of these machines in hardwood stands. Evaluating the results of the cost and time analyses we concluded that harvesters are more efficient in several cases compared to traditional felling with chainsaws.

harvester / logging / performance / operating cost / working day structure

Kivonat – Többműveletes fakitermelő gépek alkalmazhatóságának vizsgálata magyarországi lombos állományokban. A gépfejlesztéseknek köszönhetően a harveszterek, ma már nem csak kizárólag a fenyvesekben alkalmazhatóak hatékonyan. Számos terepi méréssel sikerült Magyarországon (akác, cser, bükk állományokban) is igazolni a „gépcsodák" létjogosultságát. Az idő- és költségelemzések során kapott eredmények tudatában biztonsággal állíthatjuk, hogy a lombos állományokban is alkalmazhatóak harveszterek, sok esetben hatékonyabb munkavégzés valósítható meg, mint a hagyományos motorfűrészes fakitermelés során.

harveszter / fakitermelés / teljesítmény / üzemóraköltség / munkaidőszerkezet

1 INTRODUCTION: LOGGING WITH HARVESTERS IN HARDWOOD STANDS

Highly mechanized tree utilization, applying the harvester-forwarder combination has very rapidly become common and almost exclusive in developed West Europe (primarily in Scandinavia) and in North America where the logging of vast areas of softwood stands is common. As a result of the excellent performance and spread of these softwood harvesters, research and development began to focus on the adaptation of these machines in hardwood forests.

The operations of a harvester are identical for both hardwood and softwood stands apart from a few steps. There are no significant differences in the workflow in spite of the fact that the growth character of the trees and the structure of the forests are markedly different.

The most fundamental difference between harvesting hardwood and softwood stands is in the separation of the thick branches from the trunk which is no longer done with the pivotable gripping arms which also function as arc knives. Using the manipulator arm, the machine operator places the felling head onto the branch to be cut off. As the operator fixes the head,

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the limb is removed using the hydraulic chain saw equipment. After this the debranching, assorting and cross-cutting of the limbs can be carried out and the further processing of the log can be continued (Kryzanowski 2004, MacDonald – Clow 2012) (*Figure 1*).

Already in the 1970s the use of multi-purpose and multi-operational logging machines was regarded as one of the most important possibilities for increasing productivity in logging. Besides the need to increase productivity foresters recommended buying these machines in response to the increasing shortage of labour (Szepesi 1967, Csontos 1977, Horváth 2003). However, in Hungary the use of multi-purpose machines has not spead to the expected extent and rate, for the following reasons:

- As the machines were obtained from various vendors, it turned out to be extremely difficult to achieve optimal coordination of this equipment when they were assembled into machine lines
- In the earlier economic and organisational environment a 4-5-fold cost increase appeared compared to traditional logging with chain saws.

2 ANALYSIS AND EVALUATION OF THE WORK WITH HARVESTERS

Nowadays multi-operational logging machines work in both hardwood and softwood stands (*Figues 2-5*). Depending on conditions of terrain, some of this equipment is primarily used in hardwood stands, while other types are almost exclusively used in softwood forests. Based on the foreign results in efficiency and productivity of harvesters, there is no doubt that these machines should be the first choice for domestic softwood forests too. However, their use in domestic hardwood stands raises many questions. In the past few years multi-operational logging machines have already been used for logging domestic forests (in black locust, alder, hybrid poplar, Turkey oak, hornbeam-oak, beech, hornbeam-Scots pine, spruce, Scots pine and black pine stands). Clearcutting, thinning, preparatory cutting and sanitary cutting were all done with these machines.

Figure 1. Harvester logging of a Turkey oak stand

In order to analyze and evaluate the structure of the work day and performance of the harvesters, field surveys were done with continuous time measurement. Besides recording the duration of individual actions, the total volume of the timber processed in each cycle and the distances of changeovers were also recorded. During the survey, the following types of actions were distinguished:

- Grabbing the tree (*GT*): equals the time required for the machine operator to place the harvester head onto the base of the tree, using the manipulator arm.
- Felling and processing the log (*F*): involves the time for felling, preassembly, debranching of the log as well as the conversion into assortments and piling by assortments.
- Changeover (*C*): is the duration of machine displacement.
- Felling only (*FO*): time spent on logging very thin or poor quality (e.g. completely rotten) logs, which do not yield valuable assortments.
- Arranging branch material (*B*): transfer and rearrangement of branches obstructing the path of logging.
- Arranging timber (*T*): transfer and arrangement of timber stacks obstructing the path of logging.
- Rest period (*R*): time for meeting personal needs.
- Troubleshooting (*TH*): time for fixing technical defects in the machinery.
- Waiting (*W*): other time losses (e.g. phone calls)

Figure 2. Valmet 911.3 harvester, Szentgál

Figure 3. Ponsse HS16 Ergo harvester, Balinka

Figure 4. Timberjack 1270B harvester, Horvátzsidány

Figure 5. Ponsse Buffalo Dual harwarder, Kecskemét

2.1 Clearcutting in a black locust stand using Valmet 911.3 and Silvatec 896 TH-H harvesters

A field survey was made in a black locust stand, group-mixed with 25% black pine, with a total area of 23.6 hectares. 4.3 hectares of the stand with pure black locust forest were clearcut. The average age was 42 years, average stem height was 17 m, average diameter at breast height measured 20 cm. With a canopy closure of 96%, there was an average of 640 stems/hectare, with a standing volume of 148 m^3/hectare. This row-planted seedling stand was classified into yield class IV. The shrub layer was moderate (30–70%) but even. The logging and processing of the trees was done with the Valmet 911.3 and Silvatec 896 TH-H harvesters. During clearcutting, the machines all worked in 15 m wide tracts, moving periodically (logging changeover). The distance of changeovers ranged between 2-10 m, depending on the location of the trees within the tracts. The branches of the shrub layer, (which had been previously cut with chain saw), and the tree branches were continuously moved to the right side of the tract by the machine operator. The branchwood was collected at the right side of the skidding trail (located in the middle of the tract) while different groups of roundwood assortments were collected at the left side. Two types of assortments were produced: firewood and pole wood. Pole wood was converted from the logs with a length of 3 m and a top diameter of 15–25 cm. The rest of the roundwood was sorted for fire wood, also with a length of 3 m. The forwarding of the timber was done with a Valmet 860.3 machine.

The field survey and data recording of the Valmet harvester lasted 698.47 minutes (2 days). During the period of the measurement (*Figure 6*) 41.3% of the operating time was spent on felling trees, 3.9% was for changeovers, and around 22.9% of the time was spent arranging the branch material. Altogether 37 m^3 timber was harvested. The shift performance and performance per hour was determined on the basis of the work day structure and the volume of logged timber. Using the country specific machine utilization factor ($P = 60\%$ for Hungary) expected performances were calculated (*Table 1*). The productive time (P) of the harvester during the investigation was 80.1%.

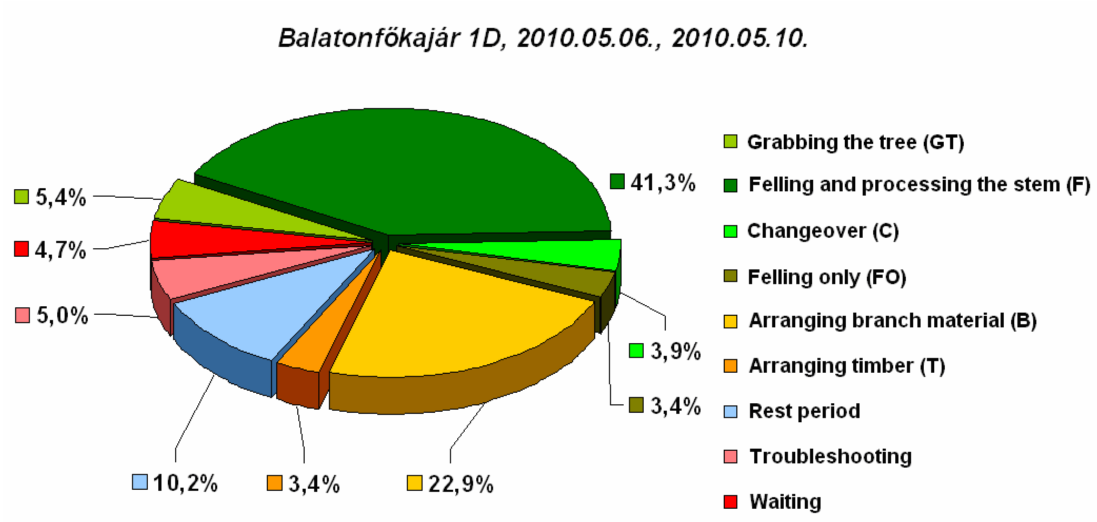

Figure 6. Operating time structure of the Valmet 911.3 harvester

Table 1. Performance of the Valmet 911.3 harvester

Performance		m^3/h	m^3/shift
Logging	(*GT+F+C*)	6.3	50.3
Logging + site clearing	(*GT+F+FO+C+B+T*)	4.0	31.7
During the whole measurement time	(*S*)	**3.2**	**25.4**
Expected performance (P=60%)			
Logging	(*GT+F+C*)	3.8	30.2
Logging + site clearing	(*GT+F+FO+C+B+T*)	**2.4**	**19.0**

The field survey and data recording of the Silvatec harvester took 263.87 minutes, and 12.4 m^3 of timber was harvested. During the period of the measurement 43.0% of the operating time was spent on tree felling and processing, and 29.5% was used for arranging the branch material (*Figure 7*). The achieved and expected performance data are summarized in *Table 2.*

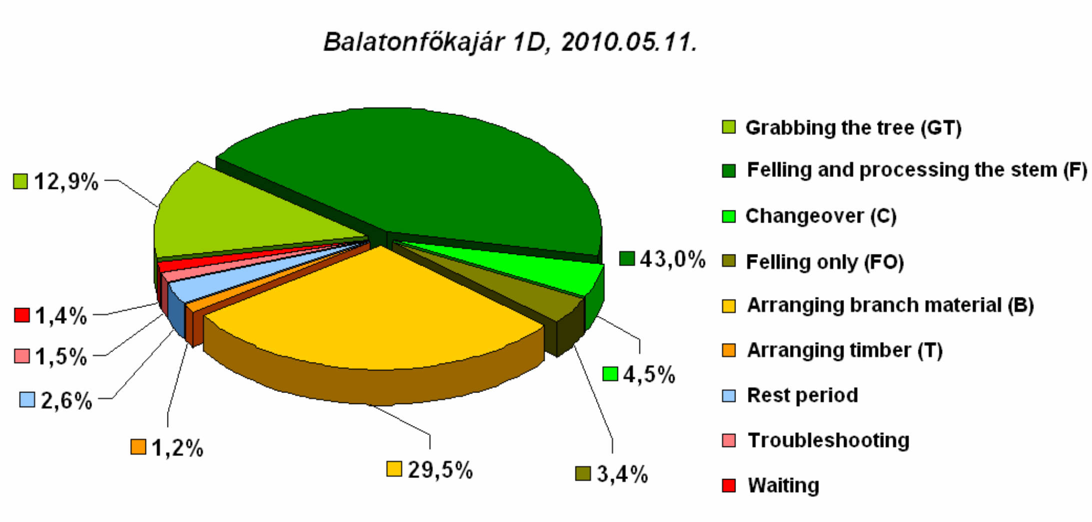

Figure 7. Working time structure of the Silvatec 896 TH-H harvester

The low performance of the machines (3.2 m^3/h and 2.8 m^3/h) can be primarily attributed to the weak yield class of the stand and to the fact that the heads of the harvesters had sizes at the lower application limit of the economical range. Moreover, efficient work was also hindered by the fact that machine operators were not sufficiently experienced.

Table 2. Performance of the Silvatec 896 TH-H harvester

Performance		m^3/h	m^3/shift
Logging	(*GT+F+C*)	4.7	37.3
Logging + site clearing	(*GT+F+FO+C+B+T*)	3.0	23.9
During the whole measurement time	(*S*)	**2.8**	**22.6**
Expected performance (P=60%)			
Logging	(*GT+F+C*)	2.8	22.4
Logging + site clearing	(*GT+F+FO+C+B+T*)	**1.8**	**14.3**

2.2 Thinning in a mixed hornbeam – Turkey oak – beech stand using the Ponsse HS16 Ergo harvester

The increment thinning in a 72-year-old, 14.7 hectare total area of hornbeam – Turkey oak – beech mixed stand was done using a Ponsse HS16 Ergo multi-operational logging machine. According to the data of the management plan, the average diameter of the stand was 21 m, and average diameter at breast height was 26 cm. Before the thinning, workers of the forest management unit had marked the trees intended for cutting with paint. The machine operator converted the logs into assortments as follows: from a top diameter of 25 cm, 3 m logs, from a top diameter of 15 cm, 2.5 m industrial firewood, and 4 m household firewood. The timber was forwarded using a Timberjack 1110 forwarder. The cross-cutting of the 4 m household firewood assortment into 1 m chunks was done at the landing site using chain saws.

During the study (nearly 4 hours) 48.4 m^3 timber were produced. About 60.0% of the working time was spent on grabbing, felling and debranching, conversion into assortments, cross-cutting, and stacking (*Figure 8*). This type of harvesting involves a relatively high frequency of changeovers. During the experiments, 91 changeovers were made, with an average distance of 13 m. The time loss of over 20% (46.3 minutes) could be attributed to the malfunctioning of a sensor in the cutting unit of the harvester head.

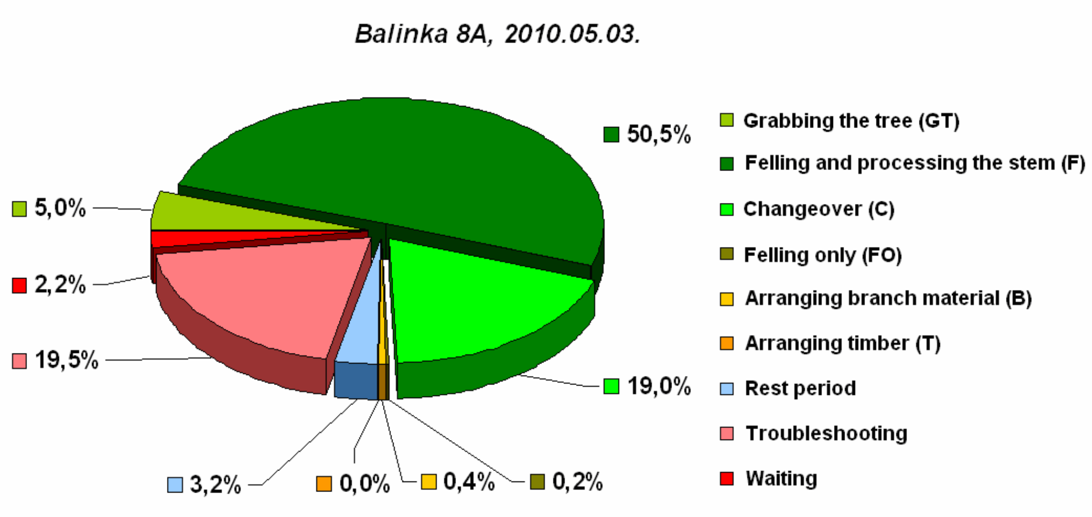

Figure 8. Working time structure of thinning operation

Despite the relatively high proportion of time losses, 75.2% of the total working period was productive. The performance per hour calculated for the whole time was 12.3 m^3/h (*Table 3*). The performance of the shift during the productive periods exceeded 130 m^3/shift. Under similar conditions, the expected performance of the machines was calculated at 9.8 m^3/h.

Table 3. Measured and expected performance values

Performance		m^3/h	m^3/shift
Logging	(*GT+F+C*)	16.5	132.0
Logging + site clearing	(*GT+F+FO+C+B+T*)	16.4	130.9
During the whole measurement time	(*S*)	**12.3**	**98.4**
Expected performance (P=60%)			
Logging	(*GT+F+C*)	9.9	79.2
Logging + site clearing	(*GT+F+FO+C+B+T*)	**9.8**	**78.5**

2.3 Selective regeneration cutting in a Turkey oak and beech stand using the Valmet 911.3 harvester

The whole of the 8.5 hectare Turkey oak – beech stand was subject to the selective regeneration cutting. The average age of the stems was 77 years, average tree height was 19 m and the average diameter at breast height was 27 cm. With a canopy closure of 70%, there was an average of 410 stems/hectare, with a standing volume of 231 m^3/hectare. During the logging the rubber-tyred Valmet 911.3 harvester had to cope with a shrub layer of over 70% and with the large amount of Turkey oak regrowth. The machine discontinuously moved forward in a 15-20 m wide tract, while forming a winding skidding trail in front of itself driving around remaining trees. The stacking of the 3-meter-long assortments was done beside the machine, the branch material, thin twigs and the limbs of the crown (diameter under 5 cm) were collected at the right and left sides of the skidding trail. The shrubs, which were a hindrance to the logging process and had been previously cut by chain saws, were collected by the machine operator to the near side of the skidding trail using the manipulator arm of the harvester. The roundwood assortment was forwarded with a Valmet 860.3 machine. In order to protect the tender tree regrowth and to ensure undisturbed development, both harvester and forwarder machines moved along the skidding trails and the branch material as well as the previously chain-sawed shrubs were both collected next to the these pathways.

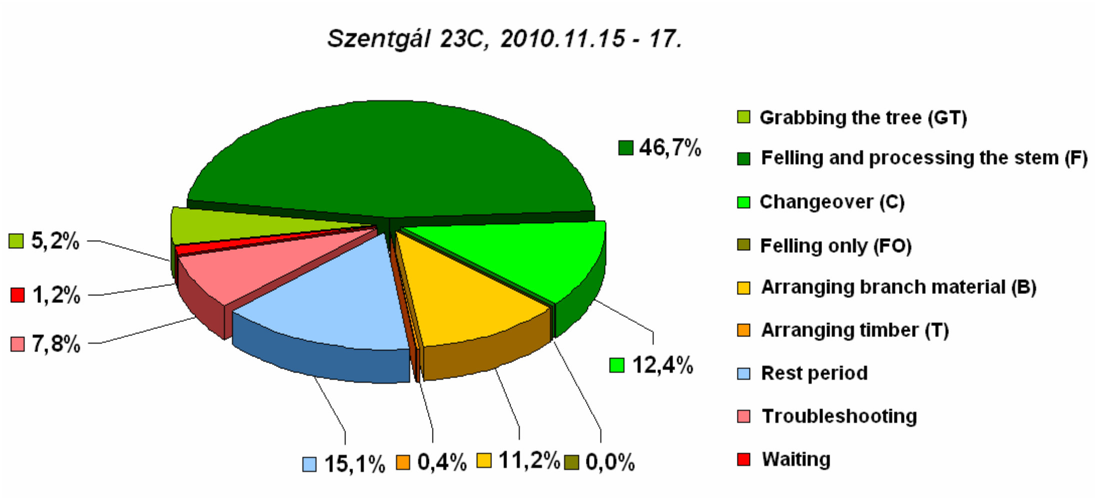

Figure 9. Work time structure of regeneration cutting

The field survey and data collection were done in 3 days (1130 minutes). The percentage of the actions during the working time is depicted in *Figure 9*. 75.9% of the overall working hours were productive. The proportion of troubleshooting, waiting and rest periods is quite low.

The volumes of harvested and processed timber (196.1 m^3) and the duration of the single actions were considered to estimate performance values. The hourly performance of the Valmet 911.3 multi-operational logging machine (related on the whole measurement time) was 10.4 m^3/h. The expected shift performance – under similar circumstances and stand conditions – was calculated as 65.6 m^3/shift (*Table 4*). The average changeover distance was 10 m, and the average time needed for changeovers 0.35 min.

Table 4. Measured and expected performance values in the preparatory cutting

Performance		m^3/h	m^3/shift
Logging	(*GT+F+C*)	16.2	129.2
Logging + site clearing	(*GT+F+FO+C+B+T*)	13.7	109.4
During the whole measurement time	(*S*)	**10.4**	**83.0**
Expected performance (P=60%)			
Logging	(*GT+F+C*)	9.7	77.5
Logging + site clearing	(*GT+F+FO+C+B+T*)	**8.2**	**65.6**

The performance data indicate that harvesters can be used efficiently for logging Turkey oak stands, despite their strong branch system and the great number of warped and twisted logs. Optimal workflow and proper machine design led to minimum site disturbance and damage to the remaining stand and regrowth caused by the machine-assisted logging.

3.4 Sanitary cutting in a beech stand struck by windthrow using a Valmet 911.3 harvester

Investigations were carried out in a 60-year-old storm damaged stand. The tree species were beech, common ash, hornbeam and Turkey oak with an average height of 12–14 m, and with an average diameter at breast height of 13–17 cm. Storm damage affected primarily trees with large crowns and large diameters ($d_{1,3}$: 25–40 cm). Windthrow hit the trees in groups, uprooting them as a result of heavy and intense spring rain. In most cases, trees fell onto each other or got stuck on remaining standing trees. Following the rules applied to the exploitation of storm-damaged stands, the logging of the thrown trees was carried out moving from the outside inwards and from the top downwards. In some cases the special position of the trees required an alternate processing to commence at the crown and moving towards the stump of the tree. The 3 m long assortments were forwarded with the Valmet 860.3 machine.

Data recording of the field survey took place in Szentgál 63B forest subcompartment for 312 minutes. Most of the working time was used for felling and processing, changeovers and arranging the branch material (*Figure 10*).

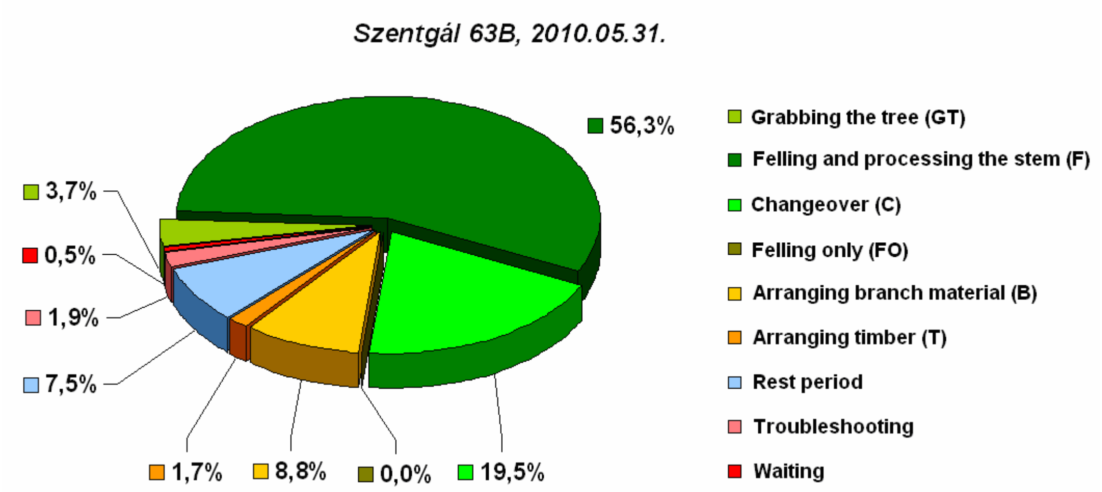

Figure 10. Working time structure of sanitary cutting in a storm-damaged stand

Changeovers were done in two different ways. One type of changeover was done by moving between the storm-damaged spots (long distance changeovers); the other type of movement (short distance changeovers) was done when timber processing was finished (*Figure 11*). The relatively high scatter of data was due to field conditions, the start time acceleration and the stop time deceleration.

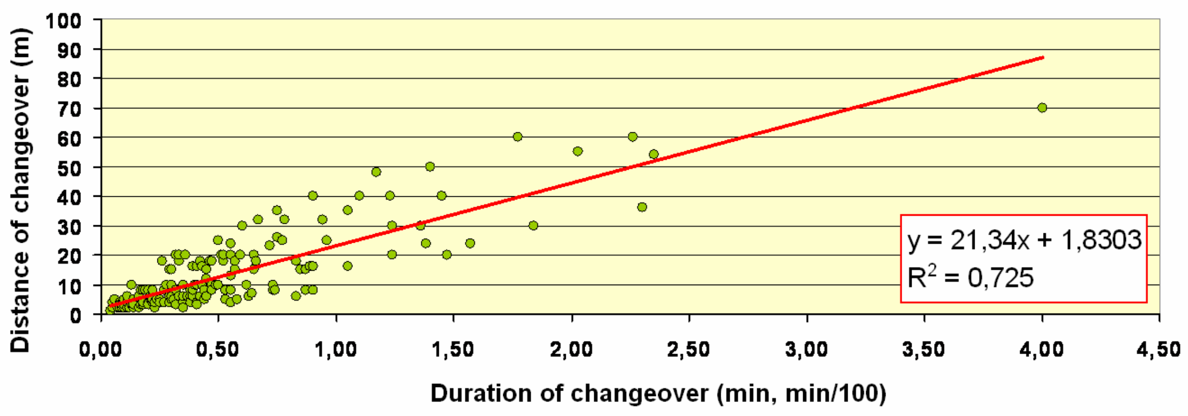

Figure 11. Relation between the distance and the duration of changeovers

Logging storm-damaged stands is always about saving valuable timber. This also involves an above average number of dangerous and risky situations. Following the rules of dangerous logging is recommended for both motor-manual, and mechanized harvesting. Machine operators are safer compared to their colleagues doing the same jobs with a chain saw. Nevertheless careless work can cause dangerous accidents as well as severe and costly technical breakdowns. The effect of additional care required by the special circumstances on performance is negligible (*Table 5*), because the machine operator can manage the processing, moving and cross-cutting of the logs from a safe distance using a crane. The minor decrease in performance can be attributed to the frequent, long distance changeovers.

Table 5. Measured and expected performances

Performance		m^3/h	m^3/shift
Logging	(*GT+F+C*)	10.0	79.8
Logging + site clearing	(*GT+F+FO+C+B+T*)	8.8	70.4
During the whole measurement time	(*S*)	**7.9**	**63.4**
Expected performance (P=60%)			
Logging	(*GT+F+C*)	6.0	42.3
Logging + site clearing	(*GT+F+FO+C+B+T*)	**5.3**	**63.4**

3 ECONOMIC ASPECTS OF THE USE OF HARVESTERS

When considering the utilization of machines with high investment costs, the operating costs and the specific costs of logging are always key factors. The operating costs were estimated using the following formula (the meaning of the characters is shown in *Table 6*):

$$k_B = \frac{A*a}{J*100}*(1+r) + \frac{A*p}{2*J*100} + B_f * b_j + K_E + \frac{u*A_u*(1+\frac{o}{100})*P}{100} \quad (1)$$

Based on this formula the operating costs of a Valmet 911.3 harvester, which logged a black locust stand, have been determined (*Table 6*).

Table 6. Operating costs of a Valmet 911.3 harvester (2010)

Tag			**Valmet 911.3**	**unit**
A	Acquisition cost (w/o VAT)		60	M Ft
n	Machine life (amortization time)		7	yr
J	Operating hours per annum		2 000	h/yr
a	Amortization factor *(100/n)*		14.29	%
r	Reparation proportion		1.20	
p	Rate of interest		5.25	%
u	Fuel consumption		10.00	l/h
A_u	Fuel cost		320	Ft/l
o	Lubricant cost proportion		45	%
P	Utilization (Productive hours / Operating hours)		60	%
e	Other costs / operating costs with wage ratio		0.40	%
B_f	Paid wages		800	Ft/work. h
b_j	Multiplier for wage expenses		1.29	
K_a	Amortization costs	$A/(n*J)=A*a/(J*100)$	4 286	Ft/work. h
K_r	Maintenance and repair costs	$r*K_a$	5 143	Ft/work. h
K_p	Cost of interest	$(A*p)/(2*J*100)$	788	Ft/work. h
F	Operational costs per productive hour	$u*A_u*(1+o/100)$	4 640	Ft/work. h
K_F	Operational costs	$F*P/100$	2 784	Ft/work. h
K_B	Wage cost	B_f*b_j	1 032	Ft/work. h
O_1	Altogether	$K_a+K_r+K_p+K_F+K_B$	14 033	Ft/work. h
K_E	Other costs (tax, storage, insurance)	$O_1*e/100$	56	Ft/work. h
$\mathbf{k_B}$	**Operating costs with wage**	$\mathbf{K_a+K_r+K_p+K_F+K_B+K_E}$	**14 089**	**Ft/work. h**

The specific costs of the investigated loggings are summarized in *Table 7*. According to the data obtained from the surveyed forest management units, the costs of traditional logging (felling with chain saws and using cable skidders) were also evaluated (*Table 8*) for the same forest stands. The calculations demonstrate that the cost of logging with harvesters is between 2,000–3,000 Ft/m^3, forwarding costs 2,500–3,500 Ft/m^3. Thus the total costs of logging using whole process mechanization in the investigated hardwood stands are between 4,500–6,500 Ft/m^3 Although traditional logging is more cost-effective than mechanized logging, work with harvesters is much more productive, and includes site clearing. Felling site harvesting losses can easily be utilized (e.g. with chipping), therefore the cost difference might be even smaller. Another advantage of using the combination of a harvester and a forwarder is less site disturbance which means also less impact on the environment and the ecosystem.

Table 7. Logging with harvesters

Harvester	**Perfor-mance** m³/h	**Operating cost** Ft/h	**Specific cost** Ft/m³
Clearcutting	3.2	14089	4403
Increment thinning	12.3	13031	1059
Regeneration cutting	10.4	14395	1384
Windthrow	7.9	14351	1817
Average of logging with a harvester			2166
Forwarding			2500
Average			**4,666**

Table 8. Traditional logging

Chain saw, cable skidder	**Perfor-mance** m³/h	**Specific cost** Ft/m³	
Clearcutting	2.1	4000	4500
Increment thin.	3.1	3200	3700
Regeneration c.	3.3	2800	3200
Windthrow	2.9	3500	3700
Average			**3,575**

4 SUMMARY

Regarding optimal technological developments, logging done with harvesters can also be introduced to hardwood stands. This however requires higher level professional attention and control.

The 3-year ”forstINNO” project starting in 2006 – in which the Institute of Forest and Environmental Techniques has also participated – primarily targeted the ecologic, economic and technical evaluation of the workflow of a harvester, specially designed for hardwood stands in 9 European countries (ranging from England to Lithuania). Based on the data measured in five countries and according to their own research, it was concluded that with trees averaging 0.07-0.41 m³, the productivity related to productive time ranges between 4.9–16.4 m³/h, also taking into account the different levels of difficulty during working operations and the number of pieces in an assortment (Erler 2007). Based on the operating costs and performance data of a harvester, costs could be calculated, which did not differ significantly from the charges of a small logging business operating at the motor-manual level.

The results of the international project are in accordance with the conclusions of the present study. These findings are also confirmed by the performance data of the harvesters operating in Hungarian hardwood stands, even if some of professionals still look with mistrust at the utilization of multi-operational logging machines in hardwood stands.

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