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TESTING AND IMPLEMENTATION OF TECHNOLOGIES INTO LOGGING DURING A JOINT USE OF SKIDDER, HARVESTER AND FORWARDER IN BULGARIA

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Abstract

In Eastern Stara planina Mountain, during a 3-year period with some intermittences due to repair works, the following technological schemes have been studied and implemented during practical work: 1) felling of trees using a chain saw, haulage of whole trees by a skidder, felling, delimbing, bucking, cut-to-length (CTL) of full trees by a harvester and assortments transportation by a forwarder; 2) felling and a primary processing of trees by chain saws, haulage of assortments by a skidder and transportation by a forwarder, and 3) felling and primary processing of trees by a harvester and forwarder of assortments. The application of the respective technological scheme depends on the available forest-exploitation conditions. The following machines have been used for the purpose: TK 40 Bolgar and Universal-651 skidders, John Deere 1270D harvester and John Deere 1110D forwarder. The machines John Deere 1270D and John Deere 1110D have been bought second hand (as used machines). The studies have been conducted in Black pine plantations (*Pinus nigra* Arn.) and Scots pine ones (*Pinus silvestris* L.), growing on terrains of a hilly and up to a mountain character. The conditions are as it could be expected after fires, windfalls, snowbreaks, and calamities but appropriate for works which are to be performed by the studied machines. The forestry targets include a clearance of the above mentioned areas, i.e. the clear cuttings. Productivities from 26 up to 68 m3/day have been achieved being its lower limit related to a technology where a chain saw is used while the upper one is related to a completely mechanized technology.As for the harvester and the forwarder, their productivities differ one from another, taking into consideration that the size of the trees exerts greater influence on the work performed by the harvester. Multi-operational machines operators‘ professionalism and experience are significantly important for the implementation of the works and both professionalism and experience are gained by knowledge obtained in the course of a specialized training.

Key words: cutting area, productivity, time study, wood harvesting, work-cycle elements.

Introduction

When harvesters are used, the working time is 71 % of the total shift time (Glöde 1999). The greatest share is taken up by the working hours of 74.8 %, followed by the hours for maintenance of 9.2 %, and the time required for repairing: 5.9 % of the shift time (Dvorak 2010a,b).

On the basis of the available data (Väätäinen et al. 2007), the average productivity of the single-grip harvesters at the stems average volume of 0.3 m^3 is of 18 m^3 PMH approximately, in clear cuttings. The

productivity of the harvester depends upon many factors, as forest stands composition, forest area, character of the surface, relief, operator‘s motivation and habits, character of the tree crown, planned works, trees' size, number of the assortment species, quantities of the trees in the cutting area, undergrowth density and structural characteristics of the machines (Richardson 1989, Makkonen 1991, Jiroušek et al. 2007, Suchomel et al. 2010).

The productivity obtained in assortment harvesting is of 16.9 m^3/productive machine hour (PMH) by Timberjack 1270 harvester and 14.3 m^3/PMH by Timberjack 1010 forwarder, at the average stem volume of 0.32 m^3 (Gingras 1994), while, according to Gerasimov et al. (2012), with harvester John Deere 1270D, the harvesting operations in forest stands composed of spruce (48 % on average), pine (19 %), birch (22 %), and aspen (11 %), with an average stem volume 0.31 m u.b. of cut-to-length stems by a harvester, are from 4.3 to 14.9 m u.b./(PMH) and 16.0–49.5 m u.b./stem processing machine hour (SMH). The operation of tree processing (0.05–2.00 m^3/stem) varies from 62 to 171 s (0.02–0.24 h/m^3).

According to Goltsev et al. (2012), the distribution of the harvester work-cycle elements is, as following: 55 % tree processing time, 16 % tree felling time, 4 % for the harvester moving in the stand and 27 % for idle running, while the forwarder work-cycle includes: 73 % for loading time, 16 % for wood transportation, 8 % for movement of the unloaded machine and 3 % for idle running.

At the moment, the manpower, i.e. the operators, which work performance depends upon training and experience, is being taking more and more for a key factor contributing to a high productivity achievement (Dvořák 2010).

The harvester productivity is closely related to the stem volume and the forest stand composition (Richardson 1989, Makkonen 1991, Bulley 1999, Gellerstedt et al. 1999). The time consumption for felling and processing with Valmet Snake is a function of the tree volume and the silvicultural treatment strategy. The locomotion time depends upon the number of trees felled per harvester stop, soil bearing capacity and terrain slope (Stampfer and Steinmüller 2001).

The productivity of the forwarders is highly correlated to the payload volume and the average distance of the haulage, i.e. there is productivity increasing when the payload increases and decreasing with distance increasing (Valenta and Neruda 2004, Bergkvist 2009, Zimbalatti and Proto 2010).

Significant differences exist among the operators and the levels of their training. Regardless of that, if there are good operators, good cares should be taken for them, as such operators can be considered the most precious assets (Purfürst 2007).

In fact the effect exerted by the harvester operator on the productivity of the entire system has been neglected for a long time (Purfürst and Erler 2011). For that reason, 10–15 % of the differences in the operator's performance are due to the differences in machinery, 20–30 % are explained by a more effective control exerted by the management bodies and 50–55 % result from a better planning and decisions making (Väätäinen et al. 2004).

Besides the above, the general factors, as labour conditions, working time, as well as operators‘ motivation, significantly differ in different countries (Liden 2005). And yet, the differences in achievement of better productivity are still great, even among the experienced operators (Purfürst 2010).

Preplanning and pre-execution shall be obligatorily conducted. And, especially, the harvester drivers' skills are of a particular importance. It is a fact that good operators only feel sure in the cabin. Any ineffective and dangerous operation shall be avoided. The technical capabilities of the devices are really considered as risk factors for the good operator. From our viewpoint, many weeks are needed to find a proper rhythm of work. Over 1000 hours of work are required, as a minimum, to get a command of that machine.

The purpose of this study is on the basis of new logging technologies, developed by us in Bulgaria, the achieved levels of productivity to be shown, for their use in practice when multi-operational forest machines are purchased, and to be implemented into the work performed by these machines.

Material and Methods

This paper reflects three-year studies (with intervals necessary for the repairing) of the first harvester and forwarder machines, and for the time being, the only ones in Bulgaria, used in logging: John Deere 1270D and John Deere 1110D, respectively, both of them second hand purchased (Fig. 1).

The study has been performed in Black pine plantations (*Pinus nigra* Arn.) and Scots pine ones (*Pinus sylvestris* L.), growing on terrains of a hilly and up to a mountain character. The stands are after fires and calamities but appropriate for operations performed by the above mentioned machines under observation. The forestry objectives include release of the areas for new afforestation by clear cuttings.

The data collection has been separated according to the machine type and each machine has been examined in its proper production environment. In addition, some independent variables have been also collected as related to the above said machines. These variables have included the trees diameter at breast height, the slope and the terrain characteristics. Working time measurement has been taken by chronometer and the measurement of the forwarding distance by a measuring tape.

The harvester cycle includes: moving in cutting area; searching of a tree; harvester head starting; cleaning under tree; inclusion tree, advancing down, cut-

a b

Fig. 1. John Deere 1270D harvester (a) and John Deere 1110D forwarder (b) in working process.

ting tree; summing up the tree to place splitters and advancing the assortments, delimbing, bucking, etc. (max. 4 assortments).

The forwarding includes: travelling empty; moving in cutting area for loading; stacking of the assortments in the cutting area; loading; travelling loaded; unloading and stacking of the assortments in store. The forwarding distances are from 800 to 1000 m.

It has been found in the course of the works that the operator should be familiar with forestry. But it is obvious that great differences exist in productivity among different operators. A skilled and experienced operator is a good observer on the entire system, being able to a prompt and reliable sensory-motor reaction.

The specific requirements of the survey are based on the understanding that an effective operative management requires clear objectives, enough information and a realistic idea of what the process itself means. In this study, we represent the situation as it is in Bulgaria, regarding the utilization of the contemporaneous multi-operational machines. Of course, in comparison with their use in the world practice, as well as with the traditional technologies for forests use, mainly based on the process of forest exploitation, i.e. using motor chain saws and tractors provided with winches. The economics of using the harvester technology depends also upon the forwarder work. The usage factor of the forwarder is compared in complex with the harvester. In our case, while the forwarder is working, the harvester shall be expecting for ready material, because of its frequent repairs. Maybe it is aim oriented to have a ready one and then to forward the material. As in Bulgaria work only these two machines we had to apply this technology.

The data collected during the study have been subjected to a regression analysis to develop regression models relating elemental time to some independent variable. Estimates of total cycle time for harvester and forwarder were then computed for a range of independent.

Results and Discussion

Table 1 illustrates the taxation characteristics of the stands in the cutting areas (Site A and Site B) where the concrete studies have been performed.

Table 1. Main characteristics of the harvested stands.

Parameter	Value	
	Site A	Site B
Resources, m^3/ha	432	407
Cutting area, ha	2,2	3,9
Average terrain slope, %	40	30
Altitude, m	600	650
SFB composition	*Pn* 10	*Ps* 7*, Pn 3*
DBH, cm	34	26
H, m	19	21
Harvesting method	Combination between CTL	Combination between CTL
Sylvicultural system	Clear cuttings (after fires)	Clear cuttings (after windthrow)

Note: CTL – cut to length.

Table 2 shows the first results achieved from the work performed using John Deere 1270D harvester and John Deere 1110D forwarder. What makes an impression is the scarce productivity of both machines. It is relatively low and highly variable: mainly due to machinery technical state and poorly qualified operators. The difference in productivity between the operators abroad and in Bulgaria is significant, due to our operators' insufficient experience, especially with the harvester. That difference consists of a bad positioning of the machine by the Bulgarian operator in the course of works and of his operations performed at low speeds of its working bodies.

The trees shape and size have a direct effect on time for processing related to the effective time in machine hours, and, especially, with the increase of the stems average size. The productivity of the machines could be raised by increasing the time for stems processing instead of improving the methods of work, i.e. if, for example, it is possible to arrive at more than 0.7, the productivity will raise over 100 m^3/day.

Besides the above, the observations show that while the harvester was used, the time, required for the processing of one tree with volume of 0.218–0.307 m^3/tree, was varying from 115 to 182 s and decreasing by reducing the number of obtained assortments: that is to say, by reducing the size of the trees. The highest share was noted of the bucking and the felling time, as well as of the time for the harvester moving in the cutting area, as of 50 %, 13 % and 13 %, respectively. Using the forwarder, the time was varying from 80 to 117 min/cycle, and the highest share fell to the time of unloading, the times of transportation to and moving in the cutting area: of 33 %, 12 %, 28 % and 13 %, respectively (Fig. 2).

It has been ascertained that no common rule exists for a statistically significant correlation of the single operating costs and time consumption. Such correlation was noted, to a certain extent, in bucking operations when the trees' diameter was taken into consideration, during the work with the harvester, and in trans-

Table 2. Share of operative times for harvester John Deere 1270D and forwarder John Deere 1110D.

John Deere 1270D Harvester		John Deere 1110D Forwarder	
Operation	**Time, s**	**Operation**	**Time, min**
Moving in cutting area	17–24	Travelling empty	8–12
Searching a tree	5–10	Moving in cutting area for loading	10–15
Harvester head starting	5–10	Stacking of the assortments in the cutting area	12–17
Cleaning under tree	7–12	Loading	27–38
Inclusion tree, advancing down, cutting tree	16–24	Travelling loaded	12–16
Summing up the tree to place splitters	8–10	Unloading	11–13
Advancing the 1st assortment, delimbing, bucking, etc. (max. 4 assortments)	57–92	Stacking of the assortments in store	0–6
Total	115–182		80–117

Note: Assortments with diameter in cm: logs at the thin end – 30 cm (15 %) и 18–29 cm (40 %), for beams – 16–18 cm (10 %) and for cellulose.

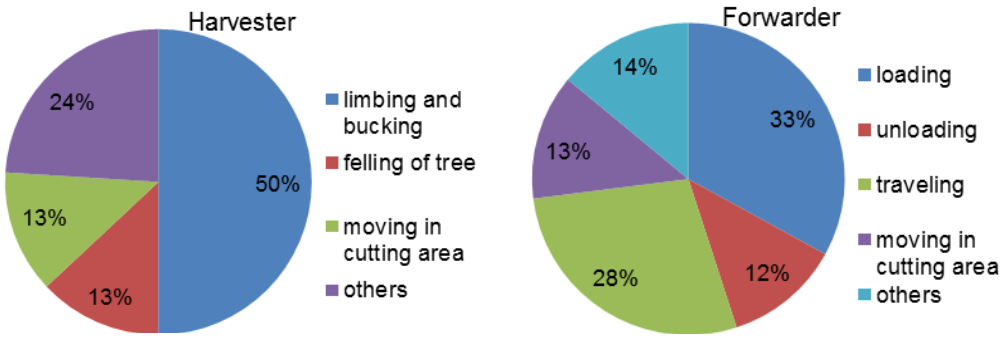

Fig. 2. Distribution of time for machine work.

portation, depending upon the forwarding distance, when the forwarder was used but its degree of significance was low. It is due to high variations in the precision of the operations performed by the operators and that is why it was impossible to find out other substantial relations in the examined processes. For this reason, after noting a sufficient experience gained by the operators, the observations went on subsequently.

That is why, about six months later, experimental studies have been conducted on the technologies as follow below:

1) The felling of trees using a chain saw, haulage of whole trees by a skidder, felling, delimbing, bucking, cut-to-length of full trees by John Deere 1270D harvester and assortments transportation by John Deere 1110D forwarder: 33–55 m³/day. The skidder TK 40 Bolgar provided with a winch was used for haulage of full trees cut within the steeper sections of the cutting area. That had also a positive aspect as created a possibility to wood assimilation from the inaccessible part of the cutting area.

2) The felling and the primary processing of trees by a chain saw, haulage of the assortments by a skidder and their forwarding by John Deere 1110D: 26–34 m³/day. The assortments were hauled by Universal-651 skidder where its winch only was used for their drawing out. What really makes an impression is a comparatively higher productivity obtained by applying that kind of 4) technology which is known in Bulgaria as appropriate for skidding by Universal-651 and forwarding away by Bulgarian assortment tractor MSI 100 (28 m³/day). The reason for that is the higher pass ability of John Deere 1110D forwarder which is able to access to the assortments in the cutting area without causing any negative effect on the undergrowth. There should also be pointed out the purpose to follow, as less as possible, the same wheel-track, to contributed the lack of undergrowth.

3) The felling and the primary processing of trees by John Deere 1270D harvester and the forwarding of the assortments by John Deere 1110D forwarder: 46–68 m³/day. As distinct from the first technology, the harvester worked on comparatively even terrain.

The technology (4) which had been used more than 25 years before was given immediately after the technology (2) being the former similar to the latter one, yet, it could not find its application due to some imperfections of MSI 100 assortment tractor.

The results achieved by using the above mentioned technologies are shown on Fig. 3.

It is obvious that the highest productivity has been obtained by the application of the third technology. In comparison with the results indicated in Table 2, it can be clearly seen that thanks to the gained experience, it is quite possible to get a significant raise of productivity. It is realized by exerting the maximum loading of the machines and the maximum pressure on the work performed by the operators thus tending to improve it. When the harvester and the forwarder are used, the logging shall be considered as a production chain which first stage effects on the next one.

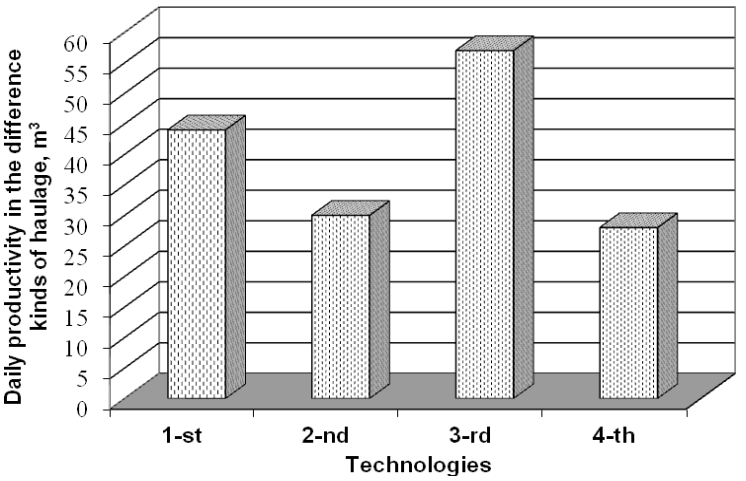

Fig. 3. Productivity of the examined technologies applicable to logging in Bulgaria.

The simultaneous running of both processes is important, so that, by making the machines work uninterruptedly, to achieve a raise of their productivity. It is preferable, along with taking into consideration the characteristics of stand, other factors to be taken as well, as the upper soil layer, the relief and such a road network which could enable an easy access of the forwarder. Hence, to optimize the daily loading of the forwarder, the harvester operator can optimize its productivity.

The obtained results shall be used for an effective introduction of machines as the above indicated ones in Bulgaria, taking into account the concrete conditions for that. Any potential user of harvester and forwarder gets a possibility to make his own cost estimates in different conditions and to assess the competitiveness of alternative variants. Especially, in such companies which have been still applying conventional technologies to haulage by tractors and where the cheap manpower is a hindrance to investments for specialized forest machines.

The professionalism and the experience which are gained by the multi-operational machine operators after obtaining knowledge through a specialized training are of a significant importance for the implementation of the assigned tasks. Thus, well trained operators of forest machines will be able to provide higher productivity: 2–3 times greater compared to that which could be reached by the operators working now, whose training is usually conducted inside the enterprise.

There are few differences in the direct operating costs of various machinery systems and for that reason many companies tend to transfer their activities entirely to mechanized technologies. In perspective, it will offer a reduction of operating costs, a raise of productivity and subsequently, an improvement in the financial state of the enterprises.

Regardless of some certain achievements in using of the only harvester and

forwarder, it is interesting to make some comparisons with the operating costs sustained by other countries where there are already traditions in using harvesters and forwarders. For example the time for moving of the harvester consists of 3–6 % in other countries (Mäkelä 1986; Kärhä et al. 2006; Väätäinen et al. 2007, 2008; Bergkvist 2009), while it is over 13 % in Bulgaria. The idle time due to reasons of technical, technological and other character is up to 15 %, while in Bulgaria, the time for repairing and maintenance of the harvester is 31 % of the working hours (comprised the idle time for repair in 2013, divided within the examined period). The operating time consists of 63 % of the total working one. A little better are the results about the forwarder where that time is 72 % approximately. As for the machine utilization extent, the results show 61 % for the harvester and 74 % for the forwarder in Bulgaria, while in other significantly experienced countries the indices are over 85–90 %. It depends, to the highest extent, upon the machinery condition and the operators‘ experience. The full costs, the overall expenses for the repair of the machines, the harvester and the forwarded comprised, are of 7 eur/m^3 (64 eur/h) and 6 eur/m^3 (44 eur/h), respectively. As a whole, the indices are worse, compared to those ones indicated in the publications. The main reasons for such results are the machines' state and the poorly qualified operators, particularly, operators working with a harvester.

The process of assessment of the impact on the environment in the forest proves that any machine, to a different extent, contaminate the soil, especially when the operations are performed on sandy and humid soils. Such damages occur to a greater extent when the forwarder is used and to a lower when operations are done by harvester. However, the use the above mentioned machines causes less damages than works by tractors and trucks which are being actually used in Bulgaria. Higher is the impact by the harvester on the undergrowth and the under forest. In that case, the subjective factor has influence as well. The observations conducted on the ergonomics indices give a reason to establish that the best working conditions in logging, as regards to ergonomics and safety, are when mechanized cutting, processing and transportation by multi-operational machines are used.

Conclusions

Three kinds of technologies have been elaborated taking into account the forest felling conditions, growing on terrains of a hilly and up to a mountain character and the mechanized means available, as well as the possibilities for the exploitation of multi-operational machines. The productivity obtained from the implementation of the technology into the felling trees with a chain saw, the full trees skidding by tractor TK 40 Bolgar, the delimbing, the bucking, the cut-to-length of full trees by John Deere 1270 harvester and forwarding of the assortments by John Deere 1110 forwarder was 33–55 m^3/day. The productivity obtained from the implementation of the technology in the felling and the primary processing of trees by a chain saw, the skidding tractor of the assortments by a Universal-651 skidder and their forwarding was 26–34 m^3/day. The productivity obtained from the implementation of the technology into the felling and the primary processing of trees by a harvester and the forwarding of the assortments was 46–68 m^3/day. The above mentioned studies have been conducted

at an average stem volume of from 0.218 to 0.307 m³ and a haulage distance from 800 to 1000 m.

The productivity is comparatively low and highly variable, mainly due to the poor condition of the harvester and the forwarder and low qualified operators. There is a possibility for raising the productivity and it could be achieved by increasing of tree size, applying a maximum loading on the machines and improving the work of the operators. A number of cases could be adduced when a harvester operator prefers to access closer to the trees instead of having recourse to the maximum range of the manipulator. That way of operating leads to a loss in productivity, due to the frequent moving of the machine. It also reflects on operations performed by the forwarder.

The highest share of the total working hours is that of the operational time – 57.8 % followed by the time for maintenance – 18.0 % and for repairing: 24.2 % of the shift time. The distribution of the harvester working cycle by elements is as following: 50 % – time for trees processing, 13 % – for trees felling, 13 % – for moving in the stand and 24 % – for the remaining time, while the distribution of the forwarder working cycle is: 33 % for the time of loading, 12 % – for unloading, 28 % – for travelling, 13 % – for moving in the cutting area and 14 % – for the remaining time.

In problematic stands, such as calamity ones, the inexperienced operators lose much time to make the right decision for trees processing, especially in the beginning and at the end of the work. The multistage, reiterative and frequent use of the equipment for the same operation is considered a disadvantage.

It has been understood that for the effective functioning of the system harvester – forwarder in Bulgaria, a reserve of 2–3 days for wood material supply between the two phases of cutting and primary processing and transportation shall be taken into account. More time is not necessary because there is also a risk of jamming that may occur and cause major operational delays.

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