Statistical analysis of forest machines ergonomic parameters

Anton Sokolov1*, *Alexander* Seliverstov[1], and *Yuri* Sukhanov[1]

[1]Petrozavodsk State University, Institute of Forestry, Mining and Construction Sciences, 185910 Lenin av., 33, Petrozavodsk, Republic of Karelia, Russian Federation

Abstract. The main technology currently used in wood harvesting in Russia is the cut-to-length technology (CTL) based on the use of two machine types: harvesters and forwarders. Powerful and manoeuvrable hydraulic manipulators (cranes) are a main part of the equipment of both the harvester and the forwarder. A statistical analysis of ergonomic parameters of the manipulator control system equipped with partial automation option is described in this article. Two machines were studied in natural field conditions. Differences in the frequency and duration of telescopic extension boom control activations were identified. The distributions of the extension boom use parameters for the crane of the logging machines were defined. It can be used to build various models for the analysis of promising crane design solutions. It is determined that the duration of the rocker switch single press has a log-normal distribution and the period between switch activations has an exponential distribution.

1 Introduction

The main technology currently used in wood harvesting in Russia is the cut-to-length technology (CTL) based on the use of two machine types: harvesters and forwarders. Powerful and manoeuvrable hydraulic manipulators (cranes) are a main part of the equipment of both the harvester and the forwarder. Their use makes it possible to control each of the machines by only one operator. At the same time, the perfection of the crane design, its drive units and control system have a very large impact on the productivity and overall operating efficiency of these machines [1-5]. Therefore, all manufacturers of harvesters and forwarders are constantly working to identify new opportunities to improve the crane-work efficiency and accuracy.

There are three main directions of crane-work improvement. The first is to improve the design of the crane itself in terms of its kinematics, the total number and size of its elements (pillar, booms etc.), and the design and location of hinges, to increase the maximum outreach, manoeuvrability, structural strength and reliability etc. [6-7]. The second direction is related to the improvement of the drive units and, in general, the hydraulic system of machines in order to increase the load capacity, working speed and accuracy [8-9]. The third promising

* Corresponding author: a_sokolov@petrsu.ru

and actively developing direction in recent years is based on the use of automation capabilities to increase the crane performance.

Some approaches that can provide a very high degree of automation of forest cranes, getting closer to the fully automatic operation of industrial robotic manipulators, are being actively developed now. These approaches are based on identifying the most productive recurrent boom-movement patterns and their implementation in automatic mode with minimal control from the operators [10-13]. However, it should be noted that these approaches still exist in the theoretical form, in some cases in the form of laboratory prototypes, and the actual application on serial machines has not yet been achieved [14].

On the other hand, some time ago leading manufacturers introduced interesting additional options for their serial machines that are based on so-called partial automation [15-18]. These options make the operator's work easier in some degree and increase the efficiency and productivity of the machine as a whole. Harvesters and forwarders equipped with these options are already actively used by logging companies, so it is possible to evaluate their impact on various aspects of the crane-work in real conditions.

2 Material and methods

The main controls of the forest crane are two joysticks. Each of the joysticks has an additional two-position rocker switch (Fig. 1). Typically, on all machines, left-right actuation of the left joystick turns the crane pillar and the whole boom system around the vertical axis, back-forth actuation of the left joystick is responsible for turning the second boom relative to the first boom, and the rocker switch on the left joystick extends and retracts the extension boom. Actuation of the right joystick to the left-right turns the machine working element (a grapple or the harvester head) around the vertical axis, back-forth actuation of the right joystick manipulates the first boom, and the rocker switch on the right joystick controls the working element.

Fig. 1. The main controls of the forest crane.

The partial automation (so called "Boom-tip control" (BTC)) changes the standard control logic in such a way that a separate and unidirectional action on a certain control in some cases can lead to simultaneous operation of the various crane drive units to ensure the movement of the working element located at the tip of the extension boom along some predetermined path, usually along a straight line.

This article describes the results of a study of the BTC operation on the example of John Deere machines equipped with Intelligent Boom Control (IBC) [15]. This system changes the control logic as follows. Back-forth actuation of the left joystick initiates such

simultaneous action of the first, second and extension boom drives, which leads to a straight-line movement of the working element back and forth, conditionally parallel to the ground surface. In the same way, back-forth actuation of the right joystick causes the simultaneous action of the drives, which provides straight-line lifting or lowering of the working element, conditionally perpendicular to the ground. The behaviour of the other controls remains unchanged. As a result, control becomes simpler and more intuitive. In addition, there is theoretically no need to use the left rocker switch that controls the extension boom.

Field studies were carried out in the Russian Republic of Karelia (Fig. 2). Two machines equipped with IBC systems were studied: John Deere 1270G harvester (operating weight 20,650 kg; engine power 190 kW; wheel arrangement 6x6; crane CH 710; harvester head H480C) (Fig. 3); and John Deere 1510G forwarder (operating weight 18,230 kg; engine power 164 kW; wheel arrangement 8x8; crane CF 710; grapple FX-26 (LogLift)). Video recording in the cab of the machines was chosen as a method of collecting information about the operator's work cycle. The measurement technique and results are given in the article [19].

Fig. 2. Location of case study.

3 Results

3.1 Harvester

Video recordings lasting 37 minutes 36 sec. for the harvester with the deactivated IBC system and 60 min. 9 sec. for the harvester with the activated IBC system were accepted for analysis after removing the fragments related to the initial and final operations, as well as the time of short-term operational stops [19].

Fig. 3 shows the distribution of moments and duration of the rocker switch activation. In these graphs, the activation time is set along the horizontal axis, and the duration of the observed single pressing is set along the vertical axis. Thus, it is possible to identify the moments of the activation start by the bar position, and the duration of pressing - by the bar

length. For a better comparison procedure, both plots are shown for the first 37 minutes of observations.

The graphs shown in Fig. 4 illustrate the time dynamics of the total duration of rocker switch presses without IBC and with IBC. It clearly demonstrates the positive effect of using IBC.

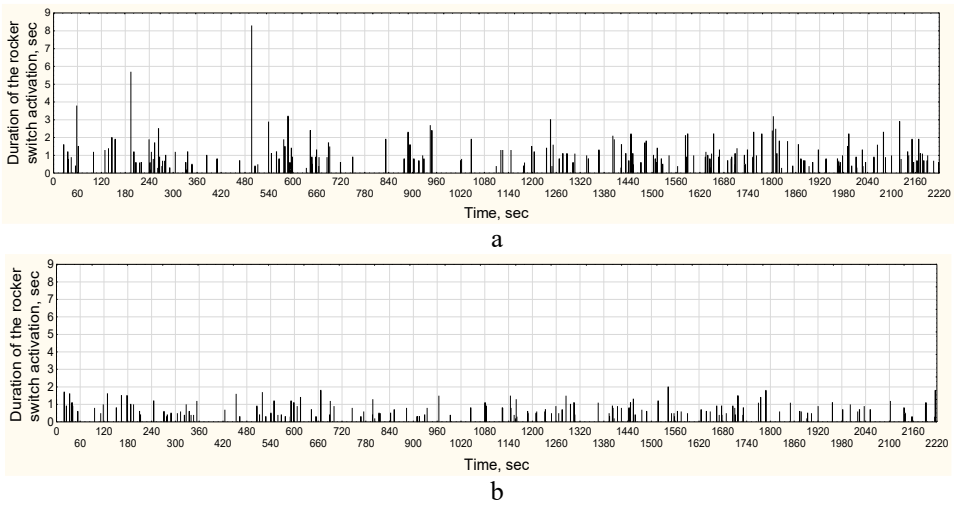

Fig. 3. Distribution of moments and duration of the rocker switch activation: a – harvester without IBC; b – harvester with IBC.

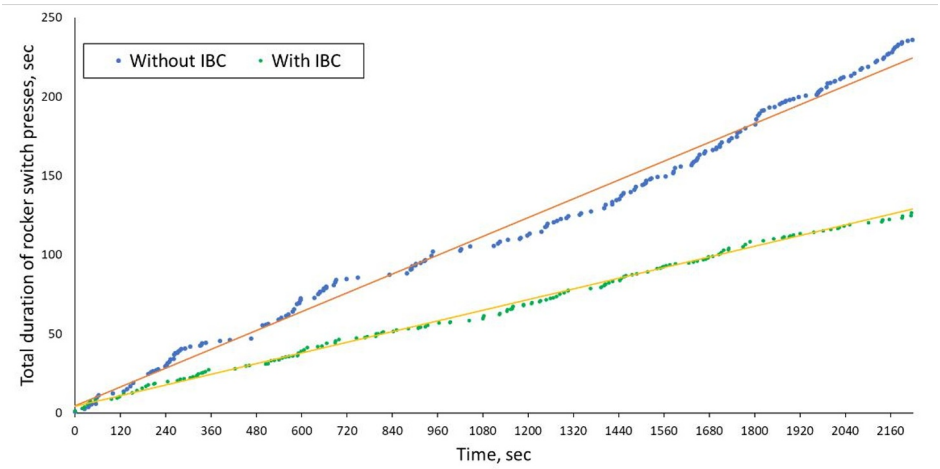

Fig. 4. Dynamics of the total duration of rocker switch presses for harvester.

Statistical analysis showed that the duration of the rocker switch single press has a log-normal distribution with sufficiently high values of the achieved level of significance (p-value) both in the case of the activated and in the case of the deactivated IBC system (Table 1, Fig. 5 a, c). With even greater confidence, we can say that in this experiment the period between switch activations has an exponential distribution (Table 1, Fig. 5 b, d).

Table 1. Statistical analysis for harvester.

	Variable	Distribution	Parameters			χ^2	*p*-value
			$\bar{x}$	σ	λ		
Harvester without IBC	Duration of a single press, sec	Log-normal	1.18	0.897	–	2.06	0.736
	Period between switch activations, sec	Exponential	–	–	0.0897	2.61	0.760
Harvester with IBC	Duration of a single press, sec	Log-normal	0.81	0.461	–	5.08	0.534
	Period between switch activations, sec	Exponential	–	–	0.0679	0.443	0.979

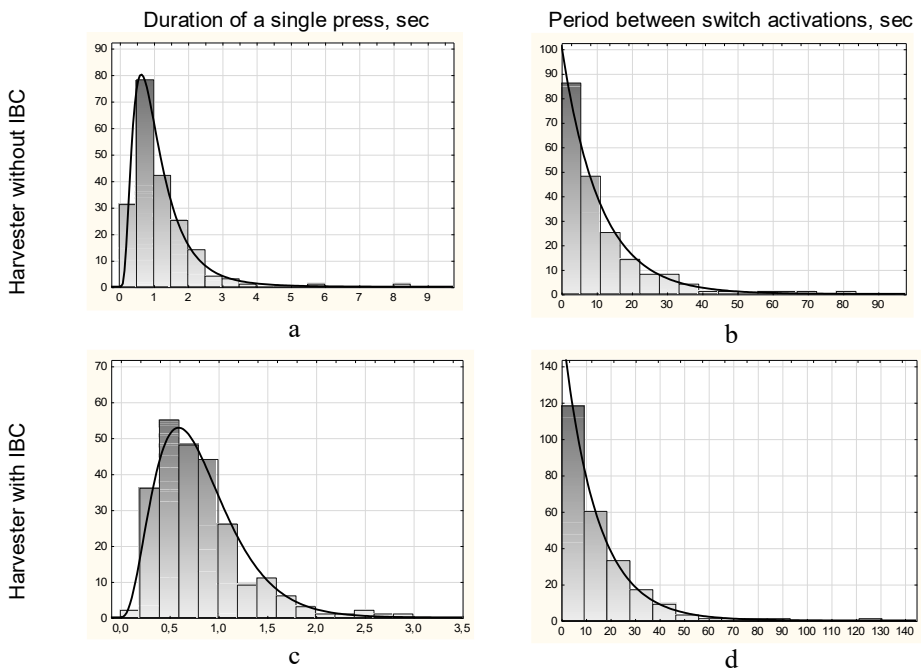

Fig. 5. Distributions of variables for harvester.

3.2 Forwarder

Video recording of the forwarder work was carried out during the cycle, which included three phases: a) collection and loading of assortments at the harvesting site; b) moving with a load; c) unloading [19]. In contrast to the harvester, whose working process is more or less uniform, in the case of the forwarder, the mode of crane use during loading is somewhat different than it is during unloading, and when moving with a load the crane is not used at all. In this regard, data analysis was carried out separately for the loading phase and for the unloading phase.

Fig. 6 shows the distribution of the moments and duration of the rocker switch activation. The first two graphs correspond to the loading phase and are shown for the first 26 minutes

of observations to keep the scales equal for comparison. The second two graphs show the situation at unloading and are given for 12 minutes of operation.

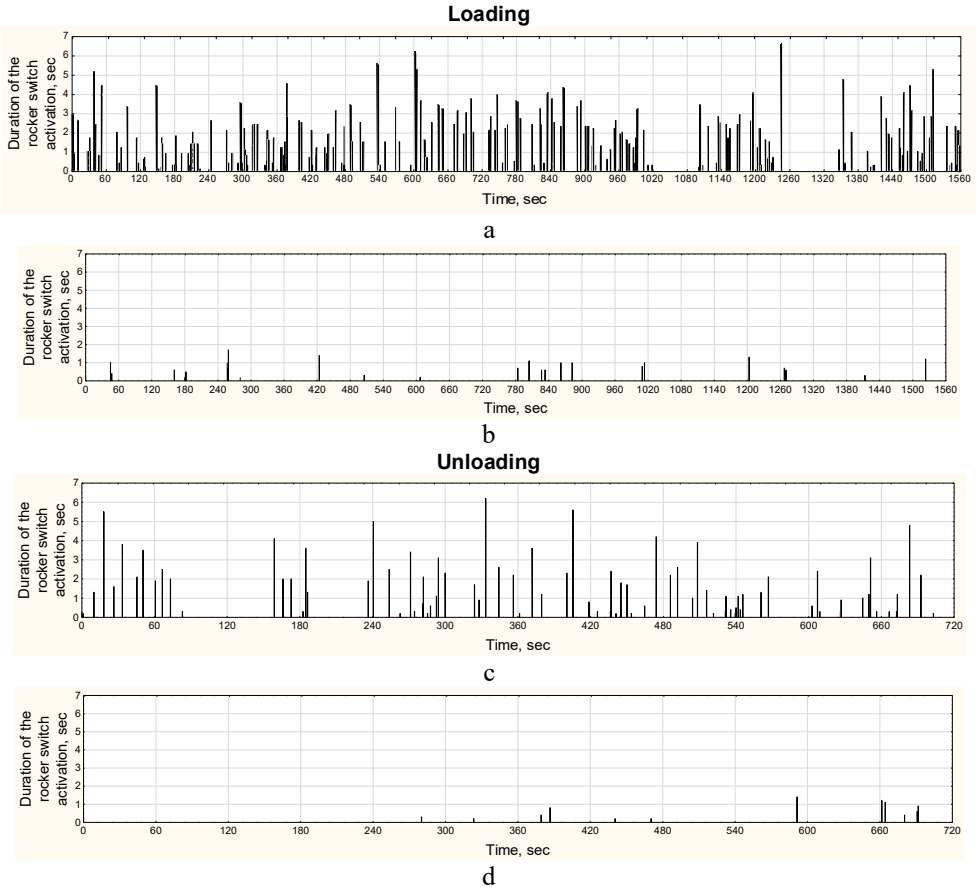

Fig. 6. Distribution of moments and duration of the rocker switch activation: a – forwarder without IBC, loading; b – forwarder with IBC, loading; c – forwarder without IBC, unloading; d – forwarder with IBC, unloading.

The graphs shown in Fig. 7 once again confirm the great (15–20 times) effect of using the IBC system on forwarders.

It was not possible in all cases to determine the distributions for the parameters of using the forwarder boom extension control with a sufficient level of significance (0.05) (Table 2). For example, it was not possible to find the distribution for the duration of a single press of the rocker switch during loading without IBC, although we had a sufficient number of observed values (224). The distribution histogram for this case is shown in Fig. 8 a.

The period between boom extension control switch activations for loading without IBC has an exponential distribution with a sufficiently high value of the achieved level of significance (Table 2, Fig. 8 b). For a forwarder with activated IBC, both this parameter and the duration of a single press of the rocker switch have a log-normal distribution, with the achieved significance levels of 0.252 and 0.495 respectively (Table 2, Fig. 8 c, d).

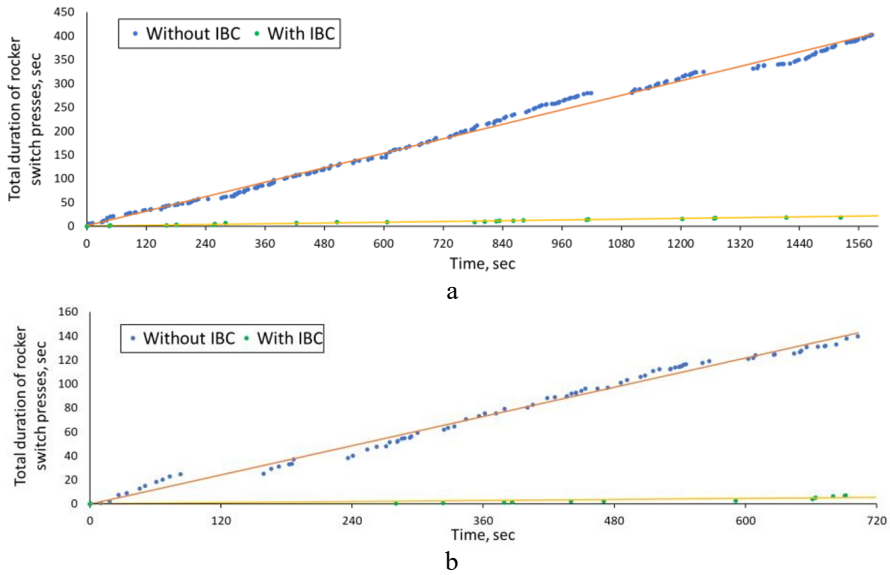

Fig. 7. Dynamics of the total duration of rocker switch presses for forwarder: a – loading; b – unloading.

Table 4. Statistical analysis for forwarder.

		Variable	Distribution	Parameters			χ^2	*p*-value
				$\bar{x}$	σ	λ		
Loading	Forwarder without IBC	Duration of a single press, sec	–	1.72	1.30	–	–	–
		Period between switch activations, sec	Exponential	–	–	0.147	3.41	0.906
	Forwarder with IBC	Duration of a single press, sec	Log-normal	0.91	0.60	–	1.41	0.495
		Period between switch activations, sec	Log-normal	53.09	57.43	–	1.31	0.252
Unloading	Forwarder without IBC	Duration of a single press, sec	Exponential	–	–	0.593	5.16	0.397
		Period between switch activations, sec	Gamma	α = 0.657; β = 12.96			3.19	0.074
	Forwarder with IBC	Duration of a single press, sec	–	0.62	0.42	–	–	–
		Period between switch activations, sec	–	8.52	10.51	–	–	–

For the forwarder without IBC on unloading, the duration of a single press on the rocker switch has an exponential distribution (Table 2, Fig. 8 e), and for the period between switch activations the gamma distribution is most suitable but close to the limit of the specified significance level (p-value = 0.074) (Table 2, Fig. 8 f).
It was not possible to test hypotheses about the distribution of variables for the case of the forwarder with the activated IBC system on unloading due to the very limited number of observations (13 in total).

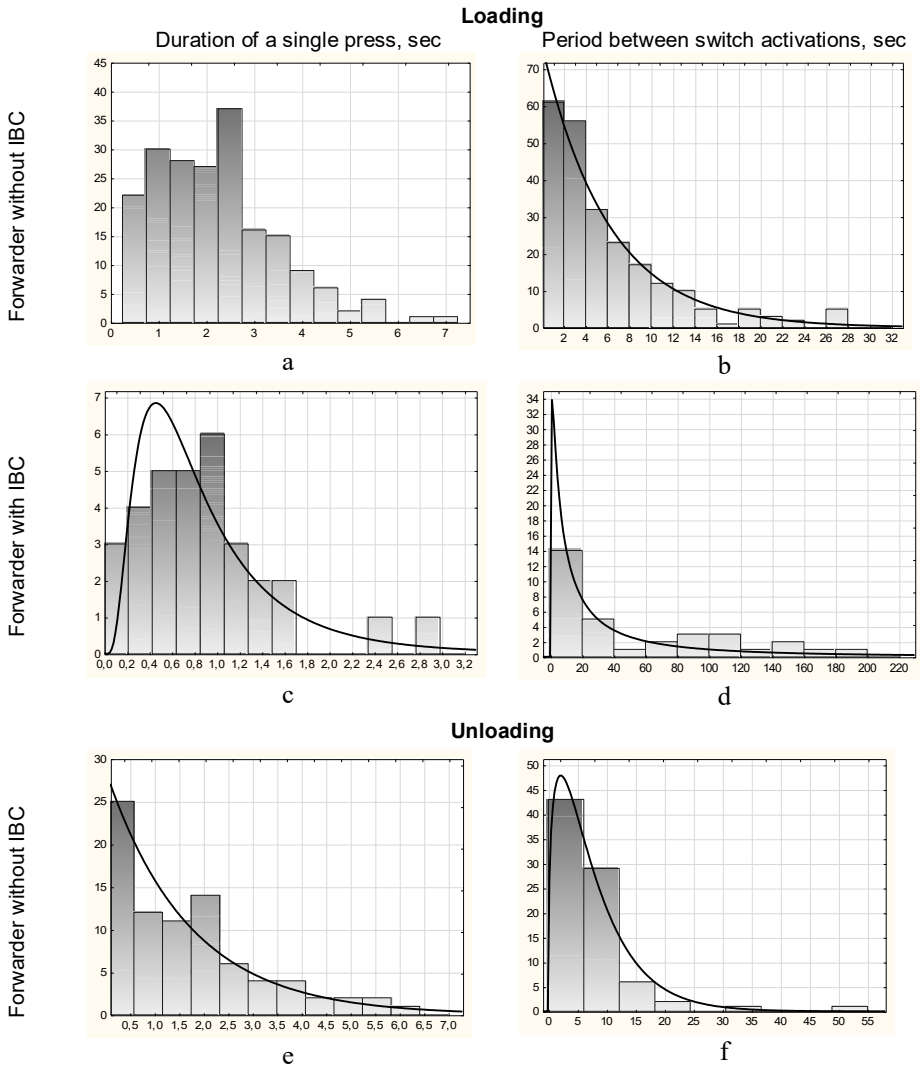

Fig. 8. Distributions of variables for forwarder.

4 Discussion and conclusions

The results of this study clearly show that the use of Intelligent Boom Control (IBC) has a significant impact on the operator work cycle parameters on John Deere harvesters and forwarders.

The distributions of the extension boom use parameters for the crane of the logging machines defined in this study can be used to build various models for the analysis of promising crane design solutions. For the harvester, the distributions are determined with a high level of significance achieved.

In the case of the forwarder, it is preferable to carry out additional observations and measurements to refine the results obtained and supply the missing ones. Within the framework of this study, it was not possible to find the distribution for the duration of a single press on the extension boom rocker switch in the case of the forwarder without the IBC system on loading, despite a rather large number of observations (Fig. 10 a). Presumably, the spatial distribution of various assortments in relation to the trail axis, which is created during the harvester operation, has a great influence in this case (Manner et al., 2013). This leads to the dominance of certain values of the extension boom's required work duration when collecting each type of assortment (one or two types of assortments are usually collected in one run of the forwarder to simplify sorting during unloading).

Not very high levels of significance were achieved in testing the hypotheses about the distribution of the period between switch activations on loading with IBC (log-normal distribution, p-value = 0.252), as well as about the duration and frequency of pressings on unloading without IBC (exponential and gamma distributions with p-value 0.0397 and 0.074 respectively). The unloading cycle is also significantly influenced by factors such as the relative position of piles with different assortment types and current dimensions of piles (height), etc. The influence of these factors can be reduced by collecting data for not one but several unloading cycles.

Additional observations will provide results with higher levels of significance. Analysing the shape of the histograms, it can already be assumed that in the case of a larger sample size, as in the case of the harvester, the lognormal distribution will be obtained for the duration of a single press on the extension boom control and an exponential distribution - for the frequency of its use. Additional field studies are required to confirm this.

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