Original scientific paper – *Izvorni znanstveni rad*

Ergonomic Characterization of Harvesting Work in Karelia

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Abstract – Nacrtak

A comparison of the ergonomic performance of 13 harvesting machine models was assessed from an ergonomic viewpoint. The main objective of the study was to compare ergonomic performance to harvesting machine operators' work and propose viable solutions to improve the work environment. The principal assessed ergonomic requirements were operators' workspace, operators' seats, visibility, work postures, whole-body vibration and noise in the cab, all as related to the tasks involved in typical harvesting cycles. Altogether, more than 120 different parameters that impact ergonomics and work conditions were measured directly at workplaces in the actual working conditions. The results were then compared to the effective norms and the degree of compliance with the stipulated values was determined. The obtained estimates for the degree of compliance were integrated. This permits a direct comparison of the work-load on operators with a single integrated indicator (severity). In many respects the ergonomic standard is now good, except for skidders. Visibility and work postures were considered to be the most critical features influencing the operator's performance. Even in highly mechanized harvesting work, problems still exist despite extensive development of cabs. The best working conditions in terms of harvesting systems were provided by »harvester + forwarder« in cut-to-length harvesting and »feller buncher + grapple skidder« in full-tree harvesting. The traditional Russian tree-length harvesting done with cable skidders showed the worst results in terms of ergonomics. When a partially mechanized harvesting system is employed, use of cable skidders should be as limited as possible, because, as a whole, they do not comply with the present ergonomic requirements.

Keywords: wood harvesting, ergonomics, harvester, forwarder, skidder, feller buncher

1. Introduction – *Uvod*

The ergonomic design of harvesting machines has been the subject of continuous study. Ergonomic guidelines have been developed and successfully introduced to the manufacturers of the machines and to the forest industries. Manufacturers have implemented comprehensive ergonomic improvements. Operator workspace, visibility, lighting, operators' seats, mounting and alighting, cab climate, and service of machines have been improved. Noise and vibration levels have been reduced (Hansson 1990, Harstela 1990). A very positive result of the mechanization of harvesting work is the drastic reduction of serious accidents and injuries (Axelsson 1998).

Increasing mechanization is posing new problems, however. Operators of harvesting machinery are being afflicted by overload injuries to the neck, arms, and cervical spine. The main causes of these injuries are probably excessive periods of sitting, excessive work intensity during work in fixed, ergonomically inappropriate positions, and repetitive, short-cycle movement patterns. Advice regarding the ergonomic design of the forest machine and maintenance work is given in the Nordic ergonomic guidelines for forest machines (Frumerie 1999).

In Russia, wood harvesting has been associated with high accident risk due to low level of mechanization especially with a lethal outcome; the latter has been estimated at 1.4 deaths per 1 million m^3 cut (Gerasimov and Karjalainen 2008). Recently, special attention has been paid to safe working conditions in harvesting operations regarding corporate social responsibility. Moreover, comfortable working conditions will make harvesting activities more attractive to youth and employment in a harvesting company more popular (Syunev et al. 2008).

Due to the ergonomic feasibility of harvesting operations being a critical element for the development of wood harvesting in Russia, the main objective of the study was to compare ergonomic performance to harvesting machine operators' work and propose viable solutions to improve the work environment.

2. Materials and methods – *Materijali i metode*

Hence, there is a need for a comprehensive approach towards the evaluation of ergonomic performance of harvesting operations and selection of the most appropriate technology for Russian conditions. To evaluate the efficiency of the harvesting methods currently used in Russia, the authors performed comprehensive field studies. The Republic of Karelia in north-west Russia was selected as a study region because its territory is very representative in terms of the wide range of used harvesting machinery and the fact that nearly all employed harvesting technologies in different natural conditions are typical for north-west Russia. The study was performed in 2007–2009 and involved 15 harvesting companies which provide approximately 40% of the total harvest in Karelia. The selected companies perform harvesting operations across the whole territory of the Republic of Karelia in different natural and production conditions, and apply all the mentioned technologies using both Russian and foreign machinery.

A common approach was used for field data collection and processing. Different parameters that impact ergonomics and work conditions were measured directly at workplaces in the actual working conditions. The results were then compared with the effective norms and standards and the degree of compliance with the stipulated values was determined. The obtained estimates for the degree of compliance for all the measured parameters were integrated into one indicator – to so-called integral work severity rate. This permits a direct comparison of working conditions at different workplaces. A higher severity rate stands for harder working conditions. Depending on this value, the working conditions were categorized as comfortable, relatively comfortable, relatively uncomfortable or uncomfortable.

2.1 Collection and processing of field data *Prikupljanje i obrada podataka*

Field research was carried out at 23 harvesting sites, the locations of which are shown in Fig. 1. Twenty-five harvesting machines of 13 models (harvesters, forwarders, feller buncher, cable and grapple skidders) were studied during the field measurements (Table 1).

A time study of the working cycle was made by means of direct timekeeping using video recording. The total time during which the operator's body was in an uncomfortable work posture, and the number of working position changes, were averaged. It was necessary to find out the time required for each operation, because some factors determine working conditions change from one operation to another. For example, a harvester operator is exposed to the highest vibration load when the machine is moving, while moving and delimbing/cross-cutting cause the highest noise load. This had to be taken into account when calculating the work-load on operators.

Altogether, more than 120 ergonomic parameters listed in the effective Russian and Swedish ergonomic standards and norms were measured in the course of the study, including:

⇒ Geometrical characteristics such as comfort of the cab layout and seat, location of controls and the operator's body position were measured using a drawing scale, a measuring tape and a goniometer. Three measurements per parameter were averaged.

⇒ Forces on hand and foot-operated controls were measured using a laboratory dynamometer. Five measurements per parameter were averaged.

Table 1 Studied harvesting machines
Tablica 1. *Istraživani šumski strojevi*

Technology *Metoda izradbe*	Type of machine *Vrsta stroja*	Model *Model*	Number *Broj*
Cut-to-length *Sortimentna*	Harvester	John Deere 1070D	2
	Harvester	John Deere 1270D	2
	Harvester	Volvo EC210BLC	1
	Harvester	Valmet 901.3	1
	Harvester	Valmet 911.3	1
	Forwarder	Timberjack 1010D	3
	Forwarder	John Deere 1110D	3
	Forwarder	John Deere 1410D	2
	Forwarder	Valmet 840.3	1
Full-tree *Stablovna*	Feller buncher	Timberjack 850	1
	Skidder, grapple	Timberjack 460D	3
Tree-length and full-tree *Deblovna i stablovna*	Skidder, cable	TDT-55A	3
	Skidder, cable	TLT-100A	2

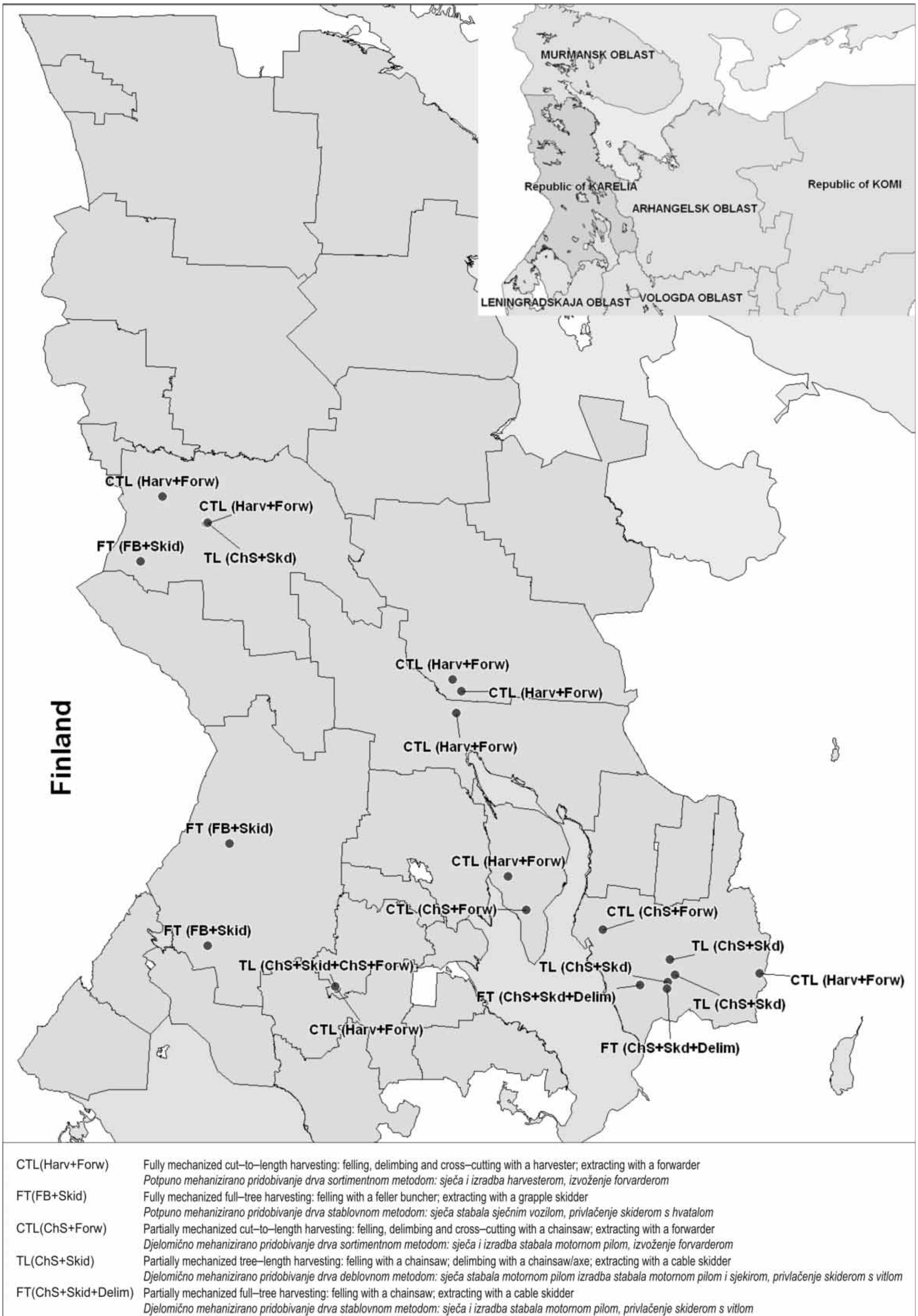

Fig. 1 Study area

Slika 1. *Područje istraživanja*

- ⇒ Parameters of noise and whole-body vibration were measured separately on all operations of the working cycle using a vibrometer and a noise meter. 20 measurements per operation within the working cycle, and the weighting according to the operation's share in the working cycle time, were averaged.
- ⇒ The degree of windshield cleaning was defined using photo images.

The average share of work time during which the operator has to be in an uncomfortable work posture is another important factor that affects the overall comfort of operating the machine.

After averaging of the repeated measurements the weighting of the measurements in different conditions is given by Eq. (1).

$$x' = \frac{\sum_{i=1}^{n} x_i t_i}{nT} \tag{1}$$

where:

n	number of different conditions
x_i	parameter value in the i_{th} condition
t_i	operational time in the i_{th} condition
T	total time of the working cycle

The working cycle was analyzed according to Frumkin et al. (1999) and was defined by the coefficients of work repetitiveness and complexity.

The standardized coefficient of work repetitiveness is defined by Eq. :

$$p_{st} = \frac{1}{N} \sum_{i=1}^{n} \frac{m_i^2}{M_i} \tag{2}$$

where:

n	number of continuous groups of elementary operations in the working cycle
m_i	number of elementary operations in the i_{th} group
M_i	total number of elementary operations and logical conditions in the i_{th} group

The standardized coefficient of work complexity is defined by Eq. :

$$p_{\log} = \frac{1}{N} \sum_{i=1}^{q} \frac{r_i^2}{R_i} \tag{3}$$

where:

q	number of continuous groups of logical conditions in the working cycle
r_i	number of logical conditions in the i_{th} group
R_i	total number of elementary operations and logical conditions in the i_{th} group

The assignment of control activities to the hands is defined by Eq. :

$$Z = \sum_{i=1}^{N} \left(\left(T_i - 2\sum_{j=1}^{T_i} U_j \right) \frac{W_i}{T_i} \right) \tag{4}$$

where:

N	number of algorithms
T_i	number of addresses to controls in the i_{th} algorithm
j	step number of algorithms
$U_j = \begin{cases} 0 - \text{if action by right hand;} \\ 1 - \text{if action by left hand;} \end{cases}$	
W_i	frequency coefficient of the i_{th} algorithm

2.2. Compliance with the effective standards and guidelines – *Sukladnost s postojećim normama i smjernicama*

The compliance of ergonomic characteristics with the effective standards and norms is defined according to Frumkin et al. (1999) by Eq. .

$$V = 1 - 0.69 \cdot \left(\frac{\left| x - 0.5 \cdot (x_{\max} + x_{\min}) \right|}{0.5 \cdot (x_{\max} + x_{\min})} \right)^4 \tag{5a}$$

if standards determine the possible interval of requirement

$$V = 1 - 0.69 \cdot \left(\frac{x}{x_{\max}} \right)^4 \tag{5b}$$

if standards determine the maximum possible value of requirement

$$V = 1 - 0.69 \cdot \left(\frac{x_{\min}}{x} \right)^4 \tag{5c}$$

if standards determine the minimum possible value of requirement

where:

V	degree of compliance of the requirement
x	measured value of the requirement
$x_{\min}$ and $x_{\max}$	minimum and maximum possible value of the requirement according to the standards and norms

Each degree can be valued from 0 to 1. The higher the value, the better compliance with the effective standards and norms.

The following sources of ergonomic standards and guidelines are taken into account:

- ⇒ State standards of the Russian Federation (GOST R 51863–2002, GOST 12.2.102–89, GOST 12.1.012–90, GOST 12.1.003–83, GOST 12.2.120–88),

Table 2 The results of a time study
Tablica 2. *Rezultati studija vremena*

Type of machine *Vrsta stroja*	Recording time *Snimljeno vrijeme* (PSH_0)	Travel loaded *Vožnja s tovarom*	Travel empty *Vožnja bez tovara*	Loading and unloading *Utovar i istovar*	Felling *Sječa*	Processing *Izradba*	Idling *Zauzimanje položaja*	Uncomfortable work postures *Neudobni radni položaj*
	min							
Harvester *Harvester*	50.6	-	2.0	-	8.1	26.8	13.7	4.0
Forwarder *Forvarder*	125.0	20.0	10.0	91.2	-	-	3.8	28.7
Feller buncher *Sječno vozilo*	20.4	-	6.8	-	1.8	11.8	-	0
Skidder, grapple *Skider s hvatalom*	51.6	23.2	20.1	6.2	-	-	2.1	16.0
Skidder, cable *Skider s vitlom*	121.5	34.0	46.2	18.2	-	-	23.1	30.4

⇒ Ergonomic guidelines by VNIITE (1983),

⇒ Ergonomic guidelines by the Swedish National Institute for Working Life, The Forestry Research Institute of Sweden (SkogForsk) and the Swedish University of Agricultural Sciences (Frumerie 1999),

⇒ Ergonomic guidelines by Peskov (2004) and Frumkin et al. (1999).

State standards of the Russian Federation prevail in case of different requirements.

2.3 Categorizing of working conditions *Razvrstavanje radnih uvjeta*

The ergonomic characteristics were grouped as following.

⇒ Location and course of hand and foot-operated controls,

⇒ Force required to operate the controls,

⇒ Work posture of the operator,

⇒ Operator's seat,

⇒ Cab and seat position in the cab,

⇒ Repetitiveness and complexity of the work,

⇒ Visibility of working and moving directions and cleanliness of the windshield,

⇒ Noise,

⇒ Whole-body vibration.

The grading of machine sophistication by the ergonomic group can be done using the integrated indicator shown in Eq.

$$p=\sum_{i=1}^{m} V_i \cdot \alpha_i \tag{6}$$

where:

a_i weight of the i_{th} requirement out of m requirements in the ergonomic group

Each integrated indicator can be valued from 0 to 1. The higher the value, the better the degree of machine sophistication by this factor. Thus, the different machines can be compared using particular ergonomic requirements.

The total grading of machine sophistication by ergonomics can be done using the work severity rate (Frumkin et al. 1999) shown in Eq. .

$$I=7-6p_{\min}+\frac{6p_{\min}-1}{6(n-1)}\left(7(n-1)-6\sum_{i=1}^{n-1} p_i\right) \tag{7}$$

where:

$p_{\min}$ minimum value of the integrated indicator

n number of the integrated indicators

$\sum_{i=1}^{n-1} p_i$ the sum of the integrated indicator values with the exception of the minimum

The work severity rate can be valued from 0 to 6. A higher value means a higher severity of conditions of work. Thus, the different machines can be compared using ergonomic factors.

3. Results – *Rezultati*

3.1 Machines for cut-to-length harvesting method – *Strojevi pri sortimentnoj metodi izradbe*

3.1.1 Harvesters – *Harvesteri*

Observations on the work cycle of the harvesters, video filming and a time study (Table 2) showed the

Fig. 2 Uncomfortable work postures when operating a harvester without a rotating cab

Slika 2. *Neudobni radni polo aji pri upravljanju harvesterom bez okretne kabine*

following distribution of the harvesters' working cycle by the main elements from the ergonomic point of view: processing (delimbing and cross-cutting) – 53%; tree felling – 16%; travel (movement of the machine to a new position) – 4%; idling (orientation when motionless) – 27%.

Regarding uncomfortable work postures, the harvester is a comfortable machine. Valmet and Volvo harvester operators worked almost completely without uncomfortable work postures in typical conditions. This is because these harvester models have a rotating cab and the operator can always observe the operation process looking directly ahead and without having to turn his head in large angles. John Deere harvester cabs were not rotating and, therefore, time spent in uncomfortable work postures was about 8% (Table 2). The uncomfortable position mainly meant that the operator had to turn his head in significantly large angles in order to monitor cross-cutting and delimbing (Fig. 2).

Table 3 shows the main integrated indicators of the working conditions for the surveyed harvester models. The indicators varied between 0 and 1. The higher the indicator was, the better the working conditions were. Valmet harvesters got lower scores in »location and course of controls«. This is mainly because Valmet harvester controls did not comply with three requirements of the Russian norms and standards, namely: the diameter of the control handle falls outside the recommended range (49 mm in comparison with the norm of 20–40 mm); the distance between pedals operated with the same foot

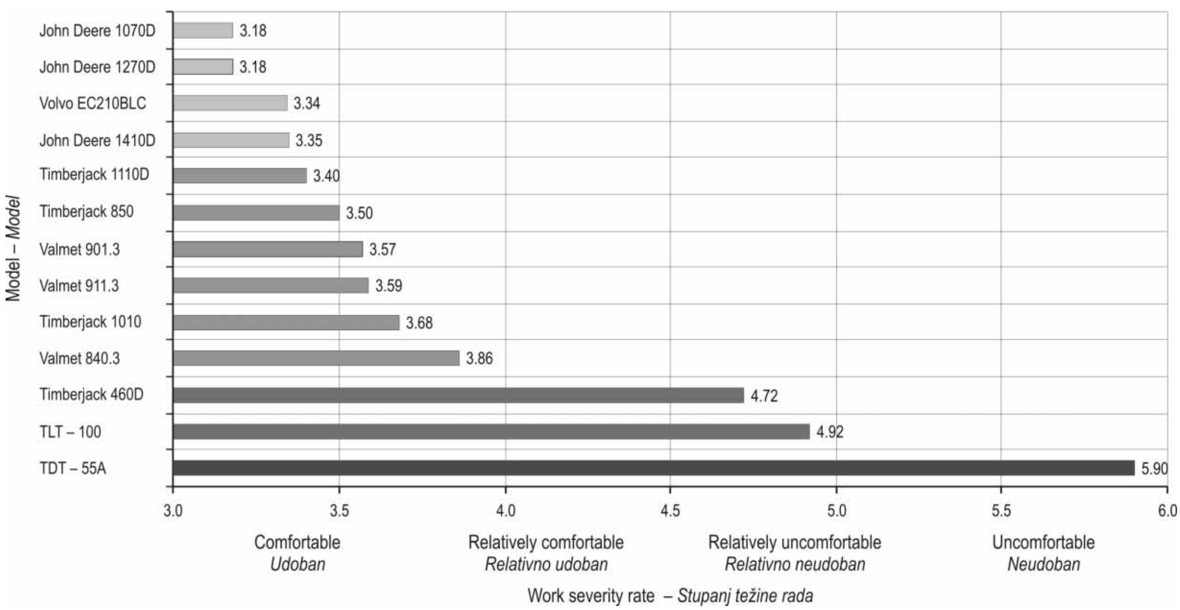

Fig. 3 Work severity rate on ergonomic performance for harvesting machines operator's work

Slika 3. *Stupanj težine rada prema ergonomskim svojstvima za rukovatelja strojeva pri sječi, izradbi i privlačenju drva*

Fig. 4 Uncomfortable work postures of forwarder operator's work

Slika 4. *Nedobni radni položaji pri upravljanju forvarderom*

was too small (40 mm in comparison with the norm of >50 mm); similarly, the pedal stroke distance was too small (50 mm in comparison with the norm of 70–100 mm).

Lower scores in the »work postures« and »operator's seat« indicators for Valmet were caused by the fact that Valmet's cabs were considered relatively more cramped compared with John Deere's cabs. This resulted in noncompliance with the Russian norms set for the longitudinal and vertical seat adjustment range and, consequently, a less comfortable body position (in terms of the angles at the body joints). Volvo's seat had too narrow arm rests and no adjustable seat backrest.

Noise and vibration parameters of the surveyed harvester models did not differ significantly. The »noise« integrated indicator values were close to 0.7, while »vibration« scored close to 1.

Comparatively low visibility angle values for Valmet machines resulted from the fact that the vertical observation angle, which is of particular importance for harvesters, was at the lower limit of the range recommended by the Russian standards. The work severity rates for all analyzed harvesters based on the measured data were estimated at less than 3.4, namely 3.2–3.4. Thus, for operators of harvesters the working conditions can be considered to be »comfortable« (Fig. 3).

3.1.2 Forwarders – *Forvarderi*

A time study (Table 2) showed the following distribution of the forwarder's working cycle by the main work elements from the ergonomic point of view: loading and unloading – 73%; travel loaded (forwarding) – 16%; travel empty – 8%; idling (motionless when orientation) – 3%.

According to the time study, forwarder operators spent a considerable time in uncomfortable work postures: 23% of the total work time on average. Uncomfortable postures involved turning the head and body by large angles during loading and movement of the machine (Fig. 4).

Table 3 shows the main indicators describing working conditions for the analyzed forwarder models. The Valmet 840.3 forwarder gained lower scores for »location and course of controls« and »foot-operated controls (pedals)«. This can mainly be explained by the fact that, similarly to harvesters of the same brand, the distance between the pedals operated with the same foot and the pedal stroke did not comply with the recommended norms. »Work postures« and »operator's seat« indicators were lower because the adjustability of the seat position was at the limits of the recommended range. »Visibility of the moving direction« was substantially higher in a John Deere 1010 forwarder, because it has a much shorter front

Fig. 5 Russian skidders TLT–100

Slika 5. *Skider TLT–100 ruske proizvodnje*

(a more compact engine room). »Visibility of the operation direction« was somewhat lower in a John Deere 1410D forwarder, mainly due to the overall large dimensions of this model.

Thus, working conditions of the operator were considered to be »comfortable« (*I*=3.4) for the Timberjack 1110D fowarder, and »relatively uncomfortable« (the work severity rate *I* being between 3.4 and 4.5) for the rest of the models. Equally to harvesters, the difference in the work severity rate was not significant (Fig. 3).

3.2 Machines for full-tree and tree-length harvesting methods – *Strojevi pri stablovnoj i deblovnoj metodi izradbe*

3.2.1 Feller buncher – *Sječno vozilo*

Only one feller buncher model was analyzed in the course of the study, namely the Timberjack 850. A time study (Table 2) showed the following distribution of feller bunchers' working cycle by the main work elements from the ergonomic point of view: processing (setting the felling head at the tree and bunching) – 58%; felling – 9%; travel (movement of the machine to a new position) – 33%.

This machine proved to be the best in terms of the majority of the evaluation indicators. Table 3 shows the results of the measurements.

According to the measurement data, the working conditions of the operators of the Timberjack 850 feller buncher fell into the category of »relatively uncomfortable« due to the value of the work severity rate *I* being between 3.4 and 4.5, namely 3.5 (Fig. 3).

3.2.2 Skidders – *Skideri*

Finally, two models of Russian-made tracked skidders – TDT–55A and TLT–100 (Fig. 5) manufactured by Onezhsky Tractor Plant – and one model of a wheeled grapple skidder – Timberjack 460D – were analyzed.

A time study (Table 2) showed the following distribution of a Russian tracked skidder's working cycle by the main work elements from the ergonomic point of view: travel loaded (skidding) – 28%; travel empty – 38%; loading – 15%; idling (motionless when trees hooking) – 19%. The average time during which the operator had to be in uncomfortable work postures was 25% of the total work time. Uncomfortable work postures here were more diverse than in the cases of the other machines (Fig. 6).

A time study (Table 2) showed the following distribution of the Timberjack 460D grapple skidder's operation time by the main work elements from the ergonomic point of view: travel loaded (skidding) – 45%; travel empty – 39%; loading – 12%; idling (motionless when orientation) – 4%. Due to the working methods used with the wheeled grapple skidders and the cab design of the analyzed skidder, the operator had to spend a considerable time in uncomfortable work postures, namely 31% of the work time. A typical uncomfortable work posture occurred when

Fig. 6 Uncomfortable work postures of cable skidder operator's work

Slika 6. *Neudobni radni položaji kopčaša pri radu skidera s vitlom*

Table 3 Main integrated indicators of working conditions for harvesting machine operator's work

Tablica 3. *Osnovni složeni pokazatelji radnih uvjeta za rad rukovatelja strojeva za sječu, izradbu i privlačenje drva*

Ergonomic characteristics *Ergonomske značajke*	John Deere 1070D	John Deere 1270D	Volvo EC210BLC	Valmet 901.3	Valmet 911.3	John Deere 1010	Timberjack 1110D	John Deere 1410D	Valmet 840.3	Timberjack 850	Timberjack 460D	TDT–55A	TLT–100
Location and course of controls *Položaj i smjer upravljačkih komandi*	0.86	0.86	0.87	0.75	0.75	0.89	0.82	0.84	0.70	0.90	0.73	0.68	0.84
Force required to operate controls *Sila potrebna za pokretanje upravljačkih komandi*	1.00	0.98	0.99	1.00	1.00	0.90	1.00	0.99	1.00	1.00	0.98	0.71	0.70
Hand – operated controls *Ručno aktiviranje upravljačkih komandi*	0.89	0.89	0.88	0.81	0.81	0.87	0.86	0.86	0.84	0.84	0.90	0.50	0.55
Foot – operated controls (pedals) *Nožno aktiviranje upravljačkih komandi (pedale)*	0.90	0.89	0.91	0.81	0.81	0.87	0.87	0.89	0.77	0.98	0.72	0.80	0.94
Work postures – *Radni položaji*	0.89	0.89	0.89	0.78	0.78	0.90	0.90	0.89	0.75	0.91	0.89	0.87	0.84
Operator's seat – *Sjedalo rukovatelja*	0.86	0.86	0.73	0.75	0.75	0.88	0.86	0.86	0.77	0.70	0.70	0.40	0.55
Cab and seat position – *Kabina i položaj sjedala*	0.74	0.74	0.72	0.71	0.71	0.65	0.71	0.72	0.65	0.75	0.54	0.47	0.66
Noise – *Buka*	0.75	0.74	0.70	0.76	0.71	0.61	0.62	0.70	0.64	0.60	0.33	0.19	0.32
Vibration – *Vibracije*	1.00	1.00	0.99	1.00	1.00	1.00	0.98	0.99	0.98	0.98	0.69	0.21	0.55
Visibility angles – *Kutovi vidljivosti*	0.81	0.81	1.00	0.48	0.48	0.99	0.99	0.97	0.98	0.63	0.99	0.97	0.97
Visibility in the operation direction *Vidljivost u smjeru radnoga prostora*	0.86	0.97	0.99	1.00	1.00	0.95	0.89	0.79	0.85	0.99	0.45	1.00	1.00
Visibility in the moving direction *Vidljivost u smjeru kretanja*	1.00	0.99	1.00	1.00	1.00	0.98	0.46	0.46	0.46	1.00	0.00	0.99	1.00
Cleanliness of the windshield *Čistoća vjetrobranih stakala*	0.90	0.90	0.63	0.69	0.69	0.53	0.71	0.71	0.67	1.00	0.56	0.00	0.70
Repetitiveness – *Učestalost radnih zahvata*	1.00	1.00	1.00	1.00	1.00	0.99	0.99	0.99	0.99	0.81	0.31	1.00	1.00
Complexity of work – *Složenost rada*	0.91	0.91	0.91	0.91	0.91	0.98	0.98	0.98	0.98	1.00	1.00	0.91	0.91

the operator had to turn his head and body in large angles to monitor loading and unloading processes, and also when moving the machine in order to monitor and adjust the grapple and bunch positions.

Results for the skidders are shown in Table 3. For the TLT–100 skidder, most indicators were better than for the TDT–55A skidder. This is because the TLT–100 is a later model equipped with a more comfortable and spacious cab, a more comfortable spring mounted seat, and so on. This is why working environment indicators are two to three times better for the TLT–100 skidder.

The main weaknesses of the Timberjack 460D were the following: confined cabin, substantially high noise level and lack of visibility (visibility of the moving direction does not comply with the recommendations at all, because the forward ground visibility was more than 14 m). Also, a high level of repetitiveness should be noted.

Thus, the working conditions of the TLT–100 skidder operators can be considered as »relatively uncomfortable« (I = 4.9, within 4.6–5.8), while with the TDT–55A skidder they were »uncomfortable« (I=5.9) (Fig. 3). The operators' working conditions with the Timberjack 460D skidder can be considered as »relatively uncomfortable« (I = 4.7).

However, there was a significant difference in the measurement-based and personnel survey-based severity rates of work (Sokolov et al. 2008). Naturally, in such conditions only operators who do not perceive the conditions to be uncomfortable, thanks to their good adaptation skills, stay in the job. Other operators simply quit the work. This can be seen in the presented results, since for this study operators having substantial work experience with these machines were interviewed.

4. Conclusion and discussion – *Zaključci s diskusijom*

The latest models of John Deere and Volvo machines held the leading position regarding »comfortable« conditions (Fig. 3). For other machines used in cut-to-length harvesting, the results were almost similar; each of these machines was assessed as »relatively uncomfortable«. The Valmet 840.3 had somewhat lower results together with the Timberjack 850 feller buncher. These were followed by a significantly worse Timberjack 460D skidder and Russian TLT–100 skidder. They had similar work severity rates and were assigned to the »relatively uncomfortable« working condition category. The working conditions of the TDT–55A skidder turned out to be totally unacceptable with regard to the present requirements.

The Timberjack 850 feller buncher proved to provide the most ergonomic controls. Altogether, almost all the machines had rather good values for this indicator; however, for the Valmet machines and the Timberjack 460D grapple skidder these values were somewhat lower than for the John Deere machines. Russian tracked skidders, especially the TDT–55A, demonstrated substantially lower levels of this integrated indicator.

John Deere cut-to-length harvesting machines were the leaders based on the ergonomic indicators related to the work place: cab entrance, cab interior, operator's seat and controls. For the Valmet and Timberjack 460D machines, these values were somewhat lower. The value of the work place indicators for the TLT–100 skidders follows them closely. For the TDT–55A these indicators were considerably lower, even compared to the TLT–100.

The harvesters, forwarders and tracked skidders showed good results with regard to the repetitiveness and complexity of work indicators. The feller bunchers' values were slightly lower, and the wheeled skidder's even lower. In both cases this was due to the high level of repetitiveness (compared to the standards); in other words, the job was very monotonous.

Visibility was one of the few indicators where Russian machines gained good results. The TLT–100 skidder even got the best score. However, the results were not unambiguous because visibility is affected by many factors, such as: dimensions of the cab and the whole machine, size of the windows, the operator's eye position with regard to windows, and so on. The Timberjack 460D skidder had the lowest values in visibility due to its very long engine room, limiting visibility in front of the machine.

The harvesters achieved better results regarding the noise and vibration characteristics, with forwarders following close behind. The Timberjack 460D skidder and TLT–100 skidder demonstrated poor results (mainly due to noise). The TDT–55A skidder was inferior regarding this indicator.

A summary of the evaluation of the machines by ergonomic parameters revealed that the best working conditions in terms of ergonomics and occupational safety were provided by the »harvester + forwarder« system in cut-to-length harvesting. Within this combination, the John Deere machine system showed the best results, while the Volvo and Valmet machine systems had lower ergonomic indicators. The »harvester + forwarder« technology was closely followed by the »feller buncher + grapple skidder« in fully mechanized full-tree harvesting, the difference not being significant. The traditional Russian tree-length harvesting done with cable skidders showed the worst results in terms of ergonomics, work severity and occupational safety. When a partially mechanized harvesting system is used, use of the TDT–55A skidder should be as limited as possible, because, as a whole, they do not comply with present ergonomics requirements (the »relatively uncomfortable« working conditions score).

Acknowledgements – *Zahvala*

This work has been carried out in the project »Wood harvesting and logistics in Russia – Focus on research and business opportunities«, funded by the Finnish Funding Agency for Technology and Innovation (TEKES).

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Sažetak

Ergonomsko označivanje radova na pridobivanju drva u Kareliji

Svrha je rada usporedba ergonomskih svojstava strojeva pri različitim metodoma pridobivanja drva te njihov utjecaj na rukovatelje strojeva radi poboljšanja uvjeta rada. Rukovatelji šumskih strojeva često ozljeđuju vrat, ruke i zatiljne kralješke vjerojatno zbog pretjeranoga sjedenja, ergonomski neodgovarajućega položaja i čestih istih pokreta dijelova tijela u kratkom vremenu. Za ergonomsku procjenu šumskih strojeva i metoda pridobivanja drva autori su obavili sveobuhvatno terensko istraživanje u Republici Kareliji (sjeverozapadni dio Rusije) na 23 različita radilišta (slika 1). Istraživanje je obavljeno na 25 strojeva među kojima su: harvesteri, forvarderi, sječna vozila te skideri s vitlom i hvatalom (tablica 1). Različiti parametri koji utječu na ergonomiju i radne uvjete mjereni su neposredno i u trenutačnim radnim uvjetima.

Studij vremena radnoga ciklusa obavljen je neposrednim snimanjem vremena videokamerom. Rezultati studija vremena za pojedine vrste šumskih strojeva prikazani su u tablici 2.

Više od 120 različitih parametara koji se nalaze u važećim normama Rusije i Švedske mjereno je neposredno na mjestu rada i pri trenutačnim uvjetima rada. Najvažniji su mjereni parametri: geometrijske značajke kao što su udobnost kabine i sjedala, položaj upravljačkih komandi i položaj tijela radnika, sile na ručnim i nožnim upravljačkim komandama, vibracije na cijelom tijelu vozača, buka u kabini i vidljivost iz kabine. Prosječni udio vremena rada tijekom kojega je radnik u neprikladnom radnom položaju također je važan čimbenik koji utječe na ukupnu udobnost upravljanja strojem. Preglednost i radni položaji tijela radnika uzeti su u obzir kao presudni čimbenici koji utječu na radni učinak radnika. Uzimana je prosječna vrijednost ukupnoga vremena tijekom kojega je radnikovo tijelo bilo u nepovoljnom radnom položaju te broj promjena radnoga položaja. Čak i kod visoko mehaniziranoga rada problemi uvijek postoje usprkos naprednomu razvoju kabina.

Izmjerene vrijednosti ergonomskih svojstava uspoređene su s važećim normama te je iz navednoga odnosa izražen složeni pokazatelj radnih uvjeta za rad rukovatelja stroja (izraz 6). Pokazatelj može poprimiti vrijednosti od 0 do 1. Veća vrijednost pokazatelja ukazuje na bolje uvjete rada (tablica 3).

Ukupno vrednovanje ergonomskih svojstava pojedinoga stroja izraženo je stupnjem težine rada, koji se izračunava prema izrazu 7 te može poprimiti vrijednosti od 0 do 6. Veća vrijednost ukazuje na teže uvjete rada sa strojem (slika 3).

Opisanim pokazateljima moguće je usporediti radne uvjete na različitim radilištima i pri primjeni različitih šumskih strojeva.

Najbolji uvjeti rada s obzirom na sustav pridobivanja drva jest kombinacija harvestera i forvardera u sortimentnoj metodi te sječno vozilo i skider s hvatalom u stablovnoj metodi. Tradicionalno pridobivanje drva deblovnom metodom uz pomoć skidera s vitlom pokazalo je najgore rezultate što se tiče ergonomskih svojstava. Kada se koristi djelomično mehanizirani sustav pridobivanja drva, korištenje skidera s vitlom trebalo bi se što više ograničiti jer ne udovoljava trenutačnim ergonomskim zahtjevima.

Ključne riječi: pridobivanje drva, ergonomija, harvester, forvarder, skider, sječno vozilo

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Received (*Primljeno*): April 13, 2009
Accepted (*Prihvaćeno*): November 11, 2009005