Ergonomic characterization of wood harvesting systems in Russia

Anton Sokolov
Forest Engineering Faculty
Petrozavodsk State University
A. Nevsky av. 58, 185030, Petrozavodsk, Russia
a_sokolov@psu.karelia.ru

Yuri Gerasimov*
Joensuu Unit
Finnish Forest Research Institute
Yliopistokatu 6, 80101, Joensuu, Finland
yuri.gerasimov@metla.fi

Abstract:
A comparison of 14 wood harvesting systems was assessed from an ergonomic performance. Altogether, over 150 different parameters of 36 units of equipment that impact ergonomics and work conditions were measured directly at workplaces in the actual working conditions. Then the results were 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 workload on operators. In many respects, the ergonomic standard is now good, except for cable skidders. Visibility and work postures were considered the most critical features influencing the operator's performance. 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 harvesting done with cable skidders showed the worst results in terms of ergonomics.

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

1 Introduction

The efficiency and functionality of a particular wood harvesting system depend on a number of characteristics. The economic benefits can be evaluated by such indicators as labour productivity and costs. Environmental indicators can include soil damage (rut depth or degree of soil compaction), damage to undergrowth or remaining trees, etc. The wood quality indicators are determined by evaluating the quality of timber in accordance with the quality specifications in the customer contracts, as well as with other quality requirements. Certainly, wood safety and ergonomics cannot be ignored when comparing different technologies. Wood harvesting has been associated with high accident risk due to the low level of mechanization especially with a lethal outcome; the latter has been estimated at 1.4 deaths per 1 million m^3 cut in Russia (Gerasimov and Karjalainen 2008). Recently, special attention has been paid to comfortable and safe working conditions in felling operations. This will make harvesting work more attractive to youth and employment in a harvesting company more desired. Ergonomic indicators describing the work severity (noise and vibration levels, visibility, etc.) can be used to evaluate the safety and comfort of the work.

2 Material and Methods

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 local conditions. To evaluate the efficiency of the harvesting methods currently used in Russia, the authors performed a comprehensive field study (measurements) and a personal survey (interviews) in the Republic of Karelia (Fig. 1). Karelia 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 oversea machinery (Syunev at al. 2009).

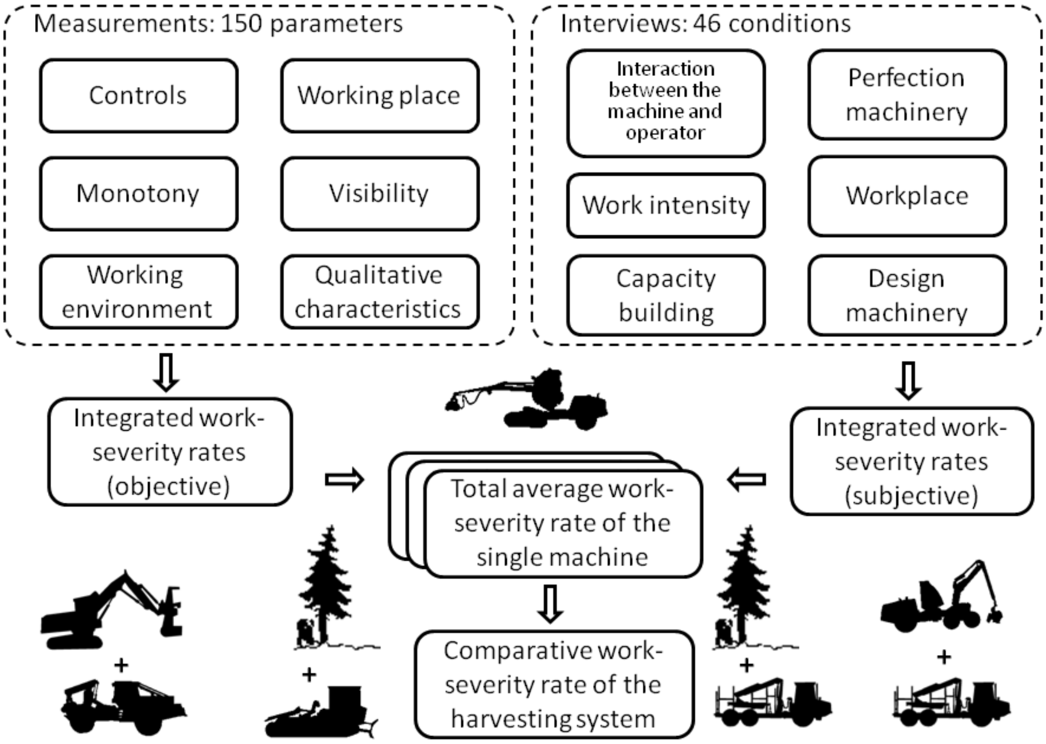

Figure 1: Outline of the study

2.1 Field study

A standardized method was used for the field data measuring and processing. Various parameters that impact ergonomics and work conditions were measured directly at workplaces in the actual working conditions, for example comfort of the cabin layout and seat, location of controls, operator's body position, etc.; noise and vibration in the cabins and on chainsaw handles; and the force needed to operate machine controls, etc. Altogether, more than 150 different parameters were measured for 27 machines and 9 chainsaws (Table 1).

The measured parameters were grouped depending on which factor of the working conditions they were used to evaluate (Gerasimov et al. 2008). Group "Controls", total of 34 parameters: location and course of controls; force required to operate controls; hand-operated controls; foot-operated controls (pedals); controls in general. Group "Workplace", total of 38 parameters: body position of operator; seat; cabin and seat position in the cabin; workplace in general. Group "Monotony": repetitiveness of the work; complexity of the work; monotony in general. Group "Visibility", total of 29 parameters: visibility angles; visibility in the working direction; visibility in the moving direction; cleanliness of the windshield; visibility in general. Group "Working environment", total of 21 parameters: noise; vibration; working environment in general. Group "Safety", total of 32 parameters: cabin access; parameters other than cabin access; safety in general. The results were then compared with the effective norms and standards, and on the basis of the degree of compliance with the stipulated values parameters were assessed (scale 0-1). An integrated indicator was determined for each group of parameters, the level of which enables the evaluation of the comfort of the seat or controls in general, vibration, etc. These indicators were further integrated into one parameter – the so-called work-severity rate (Gerasimov and Sokolov 2009). This permits the direct comparison of working conditions at different workplaces. A higher integral severity rate stands for harder working conditions. Depending on this value, the working conditions were categorized as comfortable, relatively uncomfortable, extreme or super-extreme (Table 2).

Table 1: Number of measured machines and interviewed operators by models

Type	**Model**	**Number of machines**	**Number of interviews**
Wheel harvester	John Deere 1070D	2	1
Wheel harvester	John Deere 1270D	2	8
Wheel harvester	Valmet 901.3	1	1
Wheel harvester	Valmet 911.3	1	1
Track harvester	Volvo EC210BLC	1	1
Wheel forwarder	John Deere/Timberjack 1010	3	1
Wheel forwarder	Timberjack 1110D	3	1
Wheel forwarder	John Deere 1410D	2	7
Wheel forwarder	Valmet 840.3	1	1
Wheel grapple skidder	Timberjack 460D	3	3
Track grapple skidder	ML-136	1	1
Track cable skidder	TLT-100	2	2
Track cable skidder	TDT-55A	3	9
Feller buncher	Timberjack 850	1	3
Delimbing machine	LP-30B	1	1
Chainsaw	Husqvarna 254XP	8	9
Chainsaw	Husqvarna 262	1	1

Table 2: Classification of the working conditions

Work-severity rate	**Range**
Comfortable working conditions	0 – 3.3
Relatively uncomfortable working conditions	3.4 – 4.5
Extreme working conditions	4.6 – 5.8
Super-extreme working conditions	5.9 – 6.0

2.2 Personnel survey

Measurements enabled the evaluation of some aspects of the working conditions, but not all of them. Some conditions cannot be measured directly, since no reliable measurement methods or appropriate measurement tools are available. For example, it is difficult to measure aesthetic perfection of the machine or its separate elements. On the other hand, workplaces are occupied by people, and each person perceives and evaluates working conditions from his own perspective. Different people prefer different types of work and working conditions. This also influences the person's choice of a profession, and can lead to a substantial difference between an objective survey of working conditions and subjective evaluations obtained from the personnel. Therefore, together with the field measurements, authors performed opinion surveys among the workers (Sokolov 2008). The workers were asked to give their evaluation of their working conditions. Each of the 51 interviewed workers was asked to evaluate 46 working conditions by a 6-score scale (Table 1). Similar to the field measurements, factors were combined into groups. The integrated indicator was derived for each group. A work-severity rate at each of the reviewed workplaces was the result of the interview data.

2.3 Comparison of wood harvesting systems

The main objective of this study was to compare different wood harvesting systems rather than individual work phases. Each system includes its specific types of machines, tools, work operations, etc. It is not difficult to compare two different machines or two different work phases, since it can be done by comparing the work-severity rates. The task gets more complex when there is a need to decide which of the two machine systems is better from the ergonomics and safety viewpoints. It becomes necessary to select a criterion, which would enable the summarization of several work-severity rate values into one aggregated value. The Hodge–Leman (HL) criterion based on the combination of Wald (W) and Laplace (L) criteria was used to resolve this problem (Gerasimov and Khlustov 2001).

According to the Wald's minimax principle, the best machine system is the one where the highest work-severity rate from all the work phases in this system is at the lowest level. In other words, when two machine systems are compared, firstly, work phases with the highest work-severity rate are identified within each system. The machine system where this rate is lower will be considered the best one. If the hardest working conditions in two systems appear to be equal, the second hardest work-severity conditions should be analyzed, and so on. This helps to avoid over-estimation of such machine systems where some work phases have very good working conditions, and some others are very bad. If there is at least one work phase with extreme or super-extreme working conditions in a machine system or a harvesting method, this system or method can never be considered as ergonomically perfect.

In contradistinction to the Wald criterion, the Laplace principle takes into consideration each of the possible consequences of all possible solutions. Thus, their joint consideration in under umbrella of the Hodge–Leman criterion makes it easier to avoid some problems with a subjective decision.

3 Results

The diagrams illustrating the main integrated indicators and the work-severity rate based on measurements of studied models of machines are presented in Figures 2-7. Summarizing Figure 8 shows the total work-severity rates for each of the machines. These values average both the objective, measured factors of the operating environment, and the subjective perception of the workers on these factors. All the three values of the work severity should be taken into account when making a decision to select a certain model of machine.

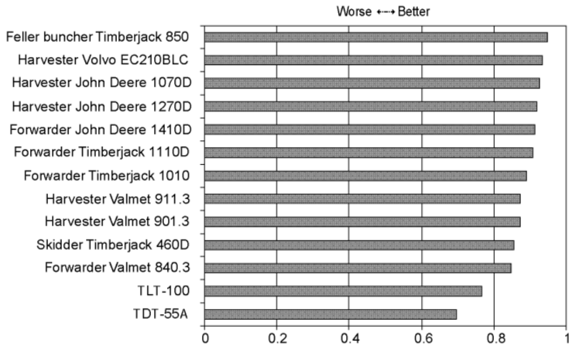

Figure 2: Integrated indicator "Controls"

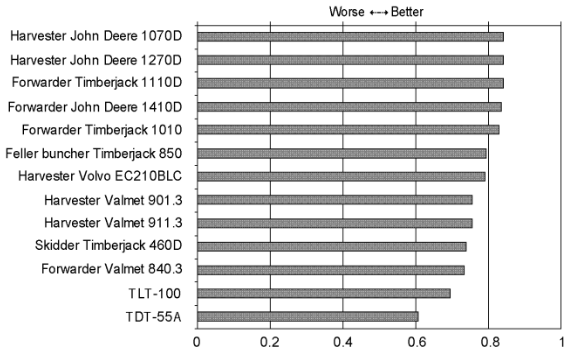

Figure 3: Integrated indicator "Workplace"

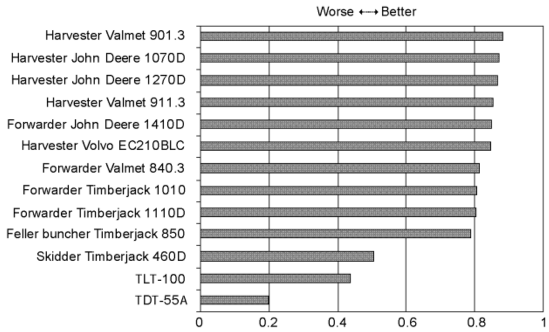

Figure 4: Integrated indicator "Working environment"

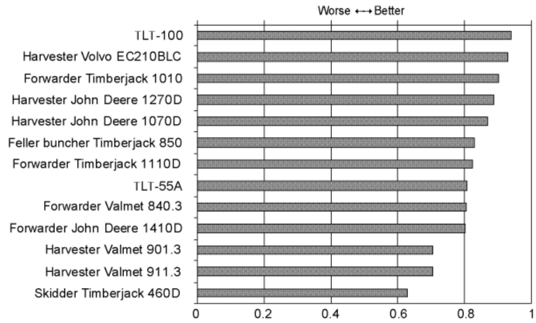

Figure 5: Integrated indicator "Visibility"

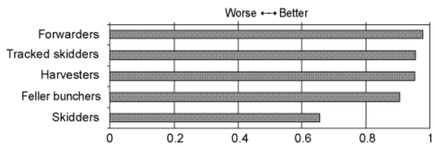

Figure 6: Integrated indicator "Monotony"

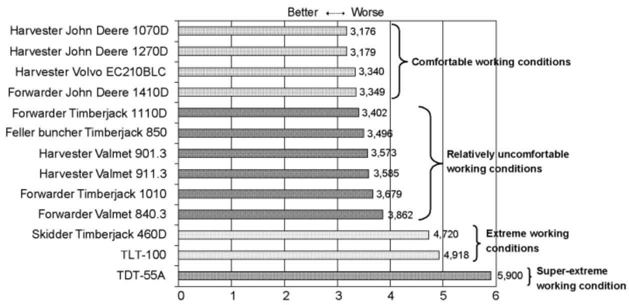

Figure 7: Work-severity rate based on measurements

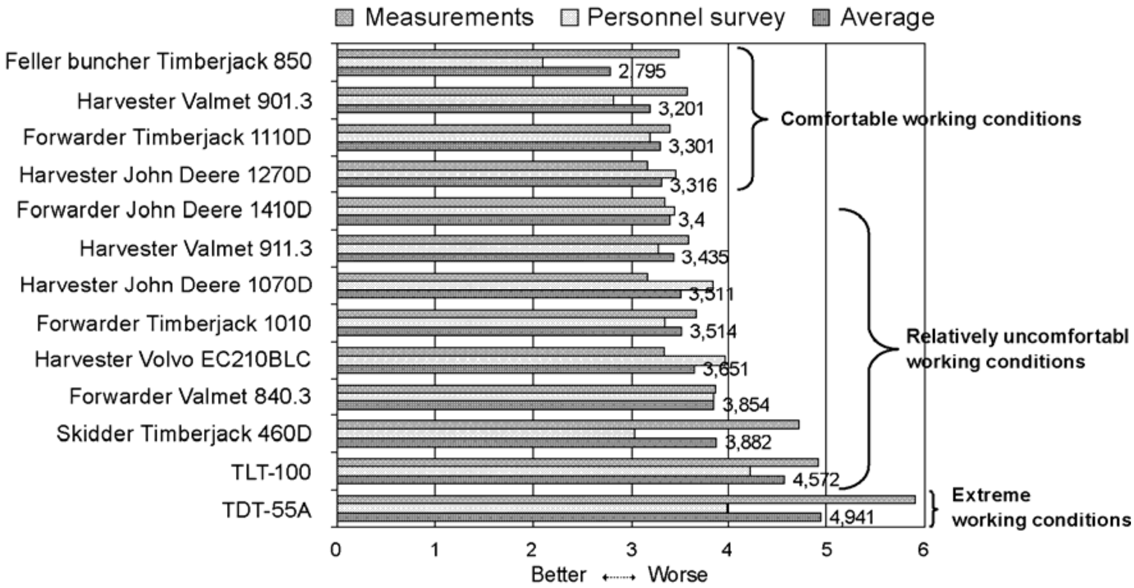

Figure 8: Total work-severity rates

4 Harvesting machines

Five harvester models were studied during the field measurements (Table 1). Figure 8 shows the total average work-severity rate for harvesters based on the measured data and personnel survey data, as well as the average values. Thus, for operators of Valmet 901.3 and John Deere 1270D harvesters, the working conditions can be considered comfortable. For other harvester models, the working conditions can be considered as relatively uncomfortable; however, the difference in the work-severity rate for all the analyzed harvesters was, in fact, insignificant. When reading the figures, it is noteworthy, that the scale of the work-severity rate is opposite to the integrated indicators for measurements and personnel survey, i.e. the higher the rate, the worse are the working conditions.

Only one feller buncher model was analyzed in the course of the study specifically Timberjack 850. This machine proved to be the best by the majority of the evaluation indicators. According to the measurement data, working conditions of the operator for Timberjack 850 feller buncher fell into the category of "relatively uncomfortable", whereas, based on the personnel survey, as well as according to the total work-severity rate, they were in the category "comfortable" (Fig. 8).

4.1 Skidding machines

Four wheel forwarder models were analyzed in the course of the field study (Table 1). The Valmet 840.3 forwarder gained lower scores for "Location and course of controls" and "Pedals". This was mainly explained by the fact that, similar 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. "Body position" and "Seat" indicators were lower because the adjustability of the seat position was at the limits of the recommended range. Visibility in the moving direction was substantially higher in a John Deere 1010 forwarder, because it has a much shorter front (a more compact engine room). Visibility in the operation direction was somewhat lower in a John Deere 1410D forwarder, mainly due to the overall large dimensions of this machine. Thus, the working conditions of the operator were considered as comfortable for the Timberjack 1110D forwarder and for the rest of the models as relatively uncomfortable. Equally to harvesters, the difference in the work-severity rate was not significant (Fig. 8).

Later, two models of Russian-made track cable skidders, the TDT-55A and the TLT-100 manufactured by the Onezhsky Tractor Plant, were analyzed. Thus, the working conditions of the TLT-100 skidder operators can be considered as relatively uncomfortable, while with the TDT-55A skidder, they were extreme (Fig. 8). There was a significant difference in the measurement-based and personnel survey-based integral severity rates of work. The second one appeared to be significantly lower. Based on the measurement data, the TLT-100 working conditions were extreme, and for the TDT-55A they were even super-extreme. Naturally, in such conditions, only operators who do not perceive conditions as super-extreme, thanks to their good adaptation skills, stay in the job. Other operators simply quit the work. This can be seen specifically from the presented results, since for this study, operators having substantial work experience with these machines were interviewed.

Only one model of a wheel grapple skidder was analyzed specifically Timberjack 460D. The main weaknesses of this machine were the following: confined cabin, substantially high noise level, and lack of visibility (visibility in the moving direction does not comply with the recommendations at all, because the forward ground visibility was more than 14 m). As well, high level of repetitiveness should be noted. The operator's working conditions with the Timberjack 460D skidder can be considered as extreme based on the measurement data, as comfortable based on the personnel survey data, and as relatively uncomfortable in general (Fig. 8).

4.2 Harvesting operations performed with chainsaws

Two chainsaw models, Husqvarna 254XP and Husqvarna 262, were analyzed. The latter model was used only during felling, while the former was employed for all the analyzed work phases. Time parameters of the work cycle, as well as noise and vibration parameters were measured (Table 3).

Table 3: Results of ergonomic measurements for different work phases with chainsaw

Work phase	Time, when the chainsaw is running [%]	Time spent in uncom-fortable positions [%]	Weighted average acoustic pressure [dB]	Weighted average vibration acceleration [m/s2]		Average vibration per shift [minutes]	Allowable vibration per shift [minutes]
				Right	Left		
Felling, Husqvarna 254	53	55	83	7.6	10.7	264	197
Felling, Husqvarna 262	53	14	73	4.5	8.1	264	240
Delimbing	66	31	92	10.1	11.9	264	184
Felling – delimbing – bucking	51	27	87	7.9	11.2	253	191
Cross-cutting in piles	27	15	86	4.3	10.7	144	198

The weighted average of the acoustic pressure for all types of work was within the norms, if hearing protectors were used. The allowable continuous vibration can be calculated from the effective vibration acceleration impacting the operator's hands. Having compared the obtained value with the actual measured value (Table 3), it can be concluded that the Russian standard requirements for vibration safety were not met for any operation, except for cross-cutting in piles.

When felling trees with a Husqvarna 254XP chainsaw, the operator had to spend on average 55% of the working time in uncomfortable body positions. This was the highest value in all of the analyzed types of jobs. Uncomfortable positions involved the body tilted forward at great angles; the body weight leaned against half-bent legs, and sometimes turned head and body in order to monitor the tree. Since the Husqvarna 262 chainsaw has handles, similar to the Russian Ural and Druzhba chainsaws, the time spent in uncomfortable positions made only 14% of the total working time. Uncomfortable positions were not as extreme as in the previous case. The weighted average of the acoustic pressure also turned out to be lower, due to the greater distance between the saw and the operator's ears.

Time spent in uncomfortable positions during delimbing was 31%. The uncomfortable position involved the body tilted forward at great angles and the body weight leaned against half-bent legs. In many cases, the operator had to stand on one leg only or on a stem or branches in an unstable position, etc. The weighted average of the acoustic pressure was the highest among all the analyzed operations. This was due to the fact that, compared to other work phases, in delimbing, the chainsaw motor is most frequently running at high rpm levels (66%).

The last type of work, cross-cutting in piles, is used relatively seldom, and it is mainly applied in a combination of tree-length and cut-to-length harvesting when skidding is done in two phases. First, tree-lengths are delivered to the intermediate landing by track skidders. After bucking, the finished assortments are skidded to the upper landing site by forwarders. On one hand, this operation involved long periods of chainsaw idle time (73%), when the feller was measuring the assortments. On the other hand, it was also typical for this operation that the feller did not use the saw at all for significantly long periods of time. Usually, the skidder delivered tree-length bunches to the roadside storage more slowly compared to the time required for cross-cutting. Hence, the period of noise and vibration shortened substantially. Therefore, cross-cutting in piles was the only job among the analyzed work phases where the standard for continuous vibration was met.

All the five indicators which were calculated on the basis of the personnel survey among loggers doing felling, delimbing and cross-cutting stayed within the range of 3 to 4 on a six-score scale. These values further led to the work-severity rate of 3.91, which corresponds to relatively uncomfortable working conditions. On the other hand, based on the measured data, none of the work phases done with chainsaws, except for cross-cutting in piles, complied with the vibration load standards. Taking into account that the work is performed outdoors all year round in various unfavourable weather conditions, the work-severity rate based on measurements equals to 6 and the working conditions were considered as super-extreme. Thus, the total work-severity rate, based on the two above-mentioned values was 4.96 (extreme conditions). This value was used later in comparing different harvesting methods.

4.3 Choker attaching

The results of the personnel survey among the chokersetters, who worked with tracked skidders TDT-55A and TLT-100, are similar to the fellers, except for technical perfection of the machine, which was over 4. This means that chokersetters often considered the machines, as well as the equipment used (cable, choker), as highly imperfect (Fig. 9). Hence, this impacted their subjective evaluation of the work severity. This is why among all the analyzed work phases, this job particularly had the highest work-severity rate value of 5.32, which corresponds to extreme working conditions.

Figure 9: Uncomfortable body positions during operations with a cable skidder

4.4 Wood harvesting systems

Fourteen different wood harvesting systems were compared based on the obtained total average work-severity rate of the single harvesting equipment using the Hodge–Leman (HL) criterion. These systems include:

- four mechanized cut-to-length systems with wheel purpose-build harvesters and forwarders (systems 1, 2, 4, 5) and one system with the excavator harvester and wheel forwarder (system 3);
- one mechanized full-tree system with the track feller buncher and wheel grapple skidder (system 6);
- the motor-manual cut-to-length system with wheel forwarder (system 7);
- two motor-manual traditional full-tree systems with track cable skidders (systems 8-9);
- two motor-manual traditional tree-length systems with track cable skidders (systems 11-12);
- the combination of motor-manual tree-length and cut-to-length systems (system 10);

- two full-tree systems as the combination of the oversea feller buncher and Russian cable skidders (systems 13-14).

The comparative results for studied wood harvesting systems are presented in Table 4.

Table 4: Comparison of wood harvesting systems by working conditions and work place ergonomics

	Wood harvesting system	Total work-severity rates of the single machines					W	L	HL
1	John Deere 1270D → John Deere 1410D	3.32	3.40				3.40	3.36	6.76
2	John Deere 1070D → John Deere 1010	3.51	3.51				3.51	3.51	7.02
3	Volvo EC210BLC → John Deere 1410D	3.65	3.40				3.65	3.53	7.18
4	Valmet 901.3 → Valmet 840.3	3.20	3.85				3.85	3.53	7.38
5	Valmet 911.3 → Valmet 840.3	3.44	3.85				3.85	3.65	7.50
6	Timberjack 850 → Timberjack 460D	2.80	3.88				3.88	3.34	7.22
7	20 fellers → John Deere 1410D	20x 4.96	3.40				4.96	4.89	9.85
8	Feller → chokersetter → TLT-100	4.96	5.32	4.57			5.32	4.95	10.27
9	Feller → chokersetter → TDT-55A	4.96	5.32	4.94			5.32	5.07	10.39
10	Feller → chokersetter → TLT-100 → delimbing/bucking worker → John Deere 1410D	4.96	5.32	4.96	4.57	3.4	5.32	4.64	9.96
11	Feller → 2 delimbers → chokersetter → TLT-100	4.96	2x 4.96	5.32	4.57		5.32	4.95	10.27
12	Feller → 2 delimbers → chokersetter → TDT-55A	4.96	2x 4.96	5.32	4.94		5.32	5.03	10.35
13	Timberjack 850 → 2 chokersetters → 3 TLT-100	2.80	2x 5.32	3x 4.57			5.32	4.53	9.85
14	Timberjack 850 → 2 chokersetters → 3 TDT-55A	2.80	2x 5.32	3x 4.94			5.32	4.71	10.03

5 Discussion

The Timberjack 850 feller buncher provided the best ergonomics of controls (Fig. 2). Altogether, almost all the machines had rather good values of this indicator, however, for Valmet machines and the Timberjack 460D grapple skidder, these values were somewhat lower than for John Deere machines. Russian track cable skidders, especially TDT-55A, demonstrated substantially lower levels of this indicator.

John Deere cut-to-length harvesting machines were the best on the “Workplace” indicator (Fig. 3). For Valmet and Timberjack 460D machines, these values were somewhat lower. The value of the workplace indicator for TLT-100 skidders follows them closely. For TDT-55A this indicator was considerably lower, even compared to TLT-100.

In this study "Working environment" indicator was based on noise and vibration characteristics. As a whole, harvesters had better results (Fig. 4), with forwarders following close behind. The Timberjack 460D skidder and the TLT-100 skidder demonstrated poor results (mainly due to noise). The TDT-55A skidder was inferior regarding this indicator.

"Visibility" was one of the few indicators where Russian machines gained good results (Fig. 5). The TLT-100 skidder even got the best score. However, results were not unambiguous because visibility is impacted by many factors, such as: dimensions of the cabin and whole machine, size of windows, operator's eye position with regard to windows, etc. The Timberjack 460D skidder had the lowest values in visibility due to its very long engine room limiting visibility in front of the machine.

Harvesters, forwarders and tracked skidders showed good results in the "Monotony" indicator (Fig. 6). Feller buncher' values were slightly lower, and wheel 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.

The integral ergonomic performance of the machines was evaluated by comparing their work-severity rate calculated using all of the above-mentioned elements of integrated indicators (Fig. 7). The latest John Deere and Volvo machines held the leading position with comfortable conditions. For other machines used in cut-to-length harvesting, 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 "extreme" working condition category. The working conditions of the TDT-55A skidder turned out to be totally unacceptable with regard to the present requirements.

The total work-severity rate was obtained for each of the machines (Fig. 8). This value includes both the objective, measured factors of the operating environment and the subjective perception of the workers on these factors. All the three values of the work severity should be taken into account when making a decision to select a certain model of machine.

According to comparative results (Table 4), fully mechanized cut-to-length harvesting performed with the "harvester + forwarder" technology (harvesting system 1-5) and full-tree harvesting with the "feller buncher + wheeled grapple skidder" (harvesting system 6) appeared to be the one that provides the best working conditions (HL=6.76-7.50). The motor-manual cut-to-length harvesting with "chainsaw + forwarder" (harvesting system 7) and the combination of oversea feller bunchers and Russian cable skidders (harvesting systems 13-14) were in second place (HL=9.85-10.03) providing uncomfortable working conditions. The traditional Russian tree-length technology that employs chainsaw and cable skidders and its various modifications (harvesting systems 8–12) had the worst results in terms of ergonomics, work severity and occupational safety (HL=9.96-10.39). Thus, when a motor-manual 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.

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